APPENDIX H

DESIGN BASIS TECHNICAL MEMORANDUMS

Innovative approaches
Practical results
Outstanding service

Lake Ralph Hall – Main Channel North Sulphur River

Stream Restoration Basis of Design Report

Prepared for:

Upper Trinity Regional Water District

Prepared by:

Freese and Nichols, Inc.
4055 International Plaza Suite 200
Fort Worth, TX 76109

July 2019

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. BACKGROUND

This document serves as a basis of design report which outlines the considerations and approaches used in developing the design of the main channel of the North Sulphur River (MC NSR) stream restoration below the proposed Leon Hurse Dam (Dam) near Ladonia, TX. The design objectives of the MC NSR restoration are to:

- Protect the proposed Dam from potential downcutting in the North Sulphur River;
- Restore a stable channel form in the MC NSR below the Dam;
- And provide natural channel restoration and functional/ecological uplift within the MC NSR corridor.

II. DESIGN APPROACH

The design of natural channel stream restoration projects is influenced/informed by, among other things:

- Sediment transport
- Channel forming discharge/flow duration
- Ecological/functional uplift targets
- Hydraulic considerations (velocity, shear stress, unit stream power)
- Constructability
- Cost/benefit of selected measures
- Lateral and vertical constraints
- Regulatory requirements
- Stabilization techniques of channel and floodplain boundaries
- Vegetative influence

The basis of the MC NSR restoration design is the implementation of natural channel design (NCD) methods, which have been successfully used over the past several decades in the restoration of degraded and impaired riparian systems. While a number of natural channel design methods have been developed and are accepted in the natural channel design practice (NRCS, 2007), FNI uses an approach by which a number of design methods are evaluated, and design parameters are selected based on a convergence of the results. Two of the methods include:

- Analog – use of reference natural channel conditions to inform design criteria. In this approach, the relationships of stable natural channel geometry located in the same hydro-physiographic region are used to inform the geometry of the proposed channel.
- Analytical – use of empirically developed formulas that relate channel boundary stability, channel dimension and planform to external forces such as critical shear stress and stream power.

Of particular importance to the design of this project is the awareness of the changes to hydrology and sediment supply, which ultimately govern the stable channel form. The design will take into account the modifications to the system that will occur as a result of the construction of the dam and an overall reduction in sediment supply and flushing events.

III. DESIGN CRITERIA AND ASSUMPTIONS

A. EXISTING PROJECT CONDITIONS

The MC NSR restoration reach is located approximately 3.6 miles northeast of Ladonia, Texas and comprises approximately 7,090 feet of existing channel length of the MC NSR (**Figure 1**). Through this area, the MC NSR was channelized into its current alignment in the early 20th century to provide flood mitigation for surrounding farmlands. The original channelization is reported to have been approximately 16 - 20 feet wide and 10 feet deep. However, this channelization created substantial instability which caused the channel bed and channel banks (incision and widening) to erode along the length of the river, cutting down into the underlying shale bedrock to form its current dimensions of more than 60 feet deep and up to 350 feet wide at the top of bank (see **Figure 2**). The riverbed and banks both continue to erode today. During field visits, it was observed by FNI designers that the channel is attempting to achieve some equilibrium through formation of a stable channel, as indicated by bar formation and sediment deposition (**Figure 2**) however, these formations are discontinuous, embryonic, and routinely flushed away by frequent high flow events within the channel. Lack of floodplain access and relatively smooth boundary condition add to the erosive nature of the system and create a high velocity, high shear stress environment within the channel.

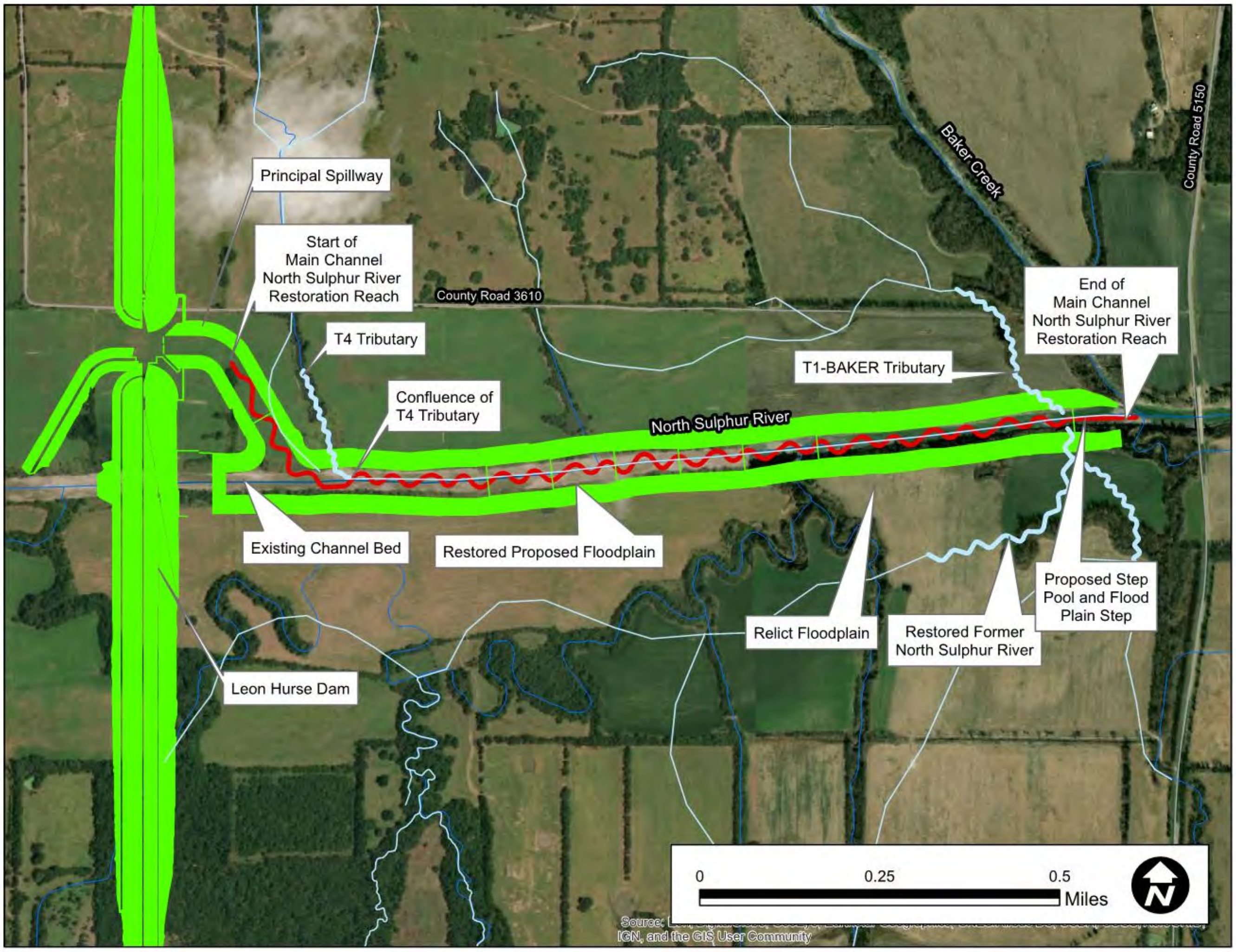


Figure 1. Overview map of the Main Channel of the North Sulphur River, the proposed Leon Hurse Dam location, and the surrounding area.

Figure 2. **Photo of existing conditions of Main Channel of the North Sulphur River as viewed standing on the riverbed (7/25/18). Note the overly wide channel with eroding bed and banks, presence of shallow pools, and embryonic depositional bars with vegetation.**

B. FUTURE CONDITIONS/POST-DAM

Construction of the Leon Hurse Dam will alter the hydrology and sediment supply of the impaired MC NSR system. The main effects of this that are accounted for in the MC NSR restoration design are:

- Change in frequency and magnitude of flow events (flow duration); and
- Reduction in sediment supply (i.e. "sediment starved" system)

Ultimately, the restoration of the MC NSR is expected to provide functional and ecological uplift through, among other things, functioning as an intermittent stream, creating perennial pools, vegetation re-establishment along the widened floodplain corridor, and the restoration of a meandering, stable channel through the restored floodplain. In addition, the significant reduction in flood magnitude from construction of the dam will help with overall ecological recovery within the restoration of the MC NSR.

To help quantify the benefits of the reduction in flood magnitude in the MC NSR, an analysis was conducted of existing and future mean velocities produced in the MC NSR corridor based on existing and proposed channel cross-sections and flood discharges. Normal depth calculations were conducted for the 1-, 10- and 50-year flood frequency events in the channel corridor to determine the associated velocities. The calculations assumed a relatively smooth boundary for existing conditions and a heavy brush condition for restored. The results are shown in **Table 1**.

Table 1. Mean Velocity Comparison Results for the Main Channel of the North Sulphur River for both the Existing Conditions and the Proposed Restored Corridor Conditions

Flood Event	Existing MC NSR Corridor Mean Velocity	Restored MC NSR Corridor* Mean Velocity	Percent Reduction in Mean Velocity
1-year	7 fps	0.5 fps	92%
10-year	9 fps	0.8 fps	91%
50-year	10 fps	2.5 fps	75%

*This includes full width of restored corridor including the bankfull channel and floodplain

Based on these results, the reduction in flood magnitude will provide substantial benefit to the stability of the restored corridor, lowering the mean velocities in the corridor during frequent and large flood events to well below allowable velocities for most channel materials, as published by the US Department of Agriculture-Natural Resource Conservation Service (NRCS) in their National Engineering Handbook: Part 654 (NRCS, 2007) (see **Figure 3**).

Channel material	Mean channel velocity (ft/s)	(m/s)
Fine sand	2.0	0.61
Coarse sand	4.0	1.22
Fine gravel	6.0	1.83
Earth		
Sandy silt	2.0	0.61
Silt clay	3.5	1.07
Clay	6.0	1.83
Grass-lined earth (slopes <5%)		
Bermudagrass		
Sandy silt	6.0	1.83
Silt clay	8.0	2.44
Kentucky bluegrass		
Sandy silt	5.0	1.52
Silt clay	7.0	2.13
Poor rock (usually sedimentary)	10.0	3.05
Soft sandstone	8.0	2.44
Soft shale	3.5	1.07
Good rock (usually igneous or hard metamorphic)	20.0	6.08

Figure 3. Allowable velocities of common channel material published by the US Department of Agriculture-Natural Resource Conservation Service (NRCS, 2007). Note that pre-dam hydrology exceeds allowable velocity for all soils but not all rock types.

C. RESTORATION OVERVIEW

The MC NSR restoration has the following major components, which are depicted in the restoration overview map shown in **Figure 5**:

- Placement of fill on the existing riverbed, from the Dam to Baker Creek, which serves to re-establish a floodplain for the restored channel
- Restoration of a stable (bankfull) channel-form to convey frequent low flows and sediment
- Construction of a floodplain step and step-pool to transition from fill to the downstream channel and provide hydrologic connectivity

Due to the unstable nature of the MC NSR channel bed, a priority objective is to protect the Dam from downcutting in the bed of the river. This objective is proposed to be accomplished by placement of compacted fill, approximately 10 feet deep, over the bed of the current North Sulphur River, while at the same time stabilizing the MC NSR banks by “laying back” the valley walls at a 3.5H:1V slope.

After placement of fill, a new, stable channel for the North Sulphur River will be created through the valley fill using natural channel design and construction methods. The design criterion for this channel is that it has the ability to convey the channel-forming (bankfull) discharge while neither aggrading nor degrading, i.e. to possess a stable-channel form. To provide a stable natural channel design, the following criteria will apply:

- Determination of the channel-forming (bankfull) discharge, which needs to account for hydrologic modifications from the dam, contributing discharges and sediment from the tributaries downstream of the dam, as well as discharge from the principal spillway
- Determination of the potential sediment regime or lack of sediment regime, given that the upstream dam will essentially cut-off most of the sediment delivery from the upstream watershed
- Analysis of reference (analog) design criteria derived from stable reference channels to inform design parameters

An illustrated section view of the proposed MC NSR restoration, showing major design components, is shown in **Figure 4**.

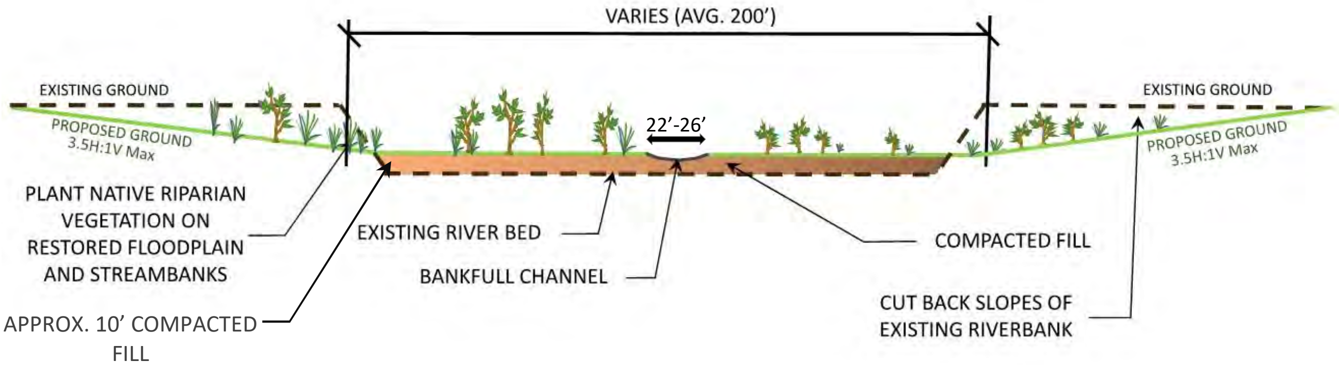


Figure 4. Illustrated section view of the Main Channel of the North Sulphur River restoration corridor. Note the grading of the existing riverbanks to provide fill material placed in riverbed to for new floodplain and stable, bankfull channel.

A downstream transition section, referred to as a "Floodplain Step", will transition the new channel elevation to the existing channel elevation downstream. The purpose of the floodplain step is to provide a grade control that protects the restored floodplain and channel of the MC NSR from any future downcutting in the existing riverbed downstream. However, for ecological consideration and to maintain the hydrologic connectivity between the downstream and restored river reaches of the MC NSR, a step-pool structure, designed to convey low flows, will be built through the floodplain step. These types of structures have been used extensively throughout North America to provide hydrologic connectivity between reaches where there is an abrupt elevation change. In addition, step-pools emulate bedrock nick points found in natural channels.

The restoration of the MC NSR is proposed to occur downstream of the dam for approximately 6,265 ft of the current riverbed length. An additional 870 ft feet of restored floodplain length will be provided by a connection to the proposed principal spillway channel. Thus, the total restored floodplain/valley length will be approximately 7,135 feet. An increase in sinuosity, based on natural reference criteria, will result in a restored channel with an estimated length of approximately 8,506 feet. This will result in a sinuosity of approximately 1.2 for the restored MC NSR. In addition, three tributaries will be connected to the restored channel. One of these tributaries (T4 Tributary) will connect approximately 1,600 feet from the start of the restoration reach, (see Figure 5) while a second (T1-BAKER Tributary) will connect approximately 230 feet from the beginning of the floodplain step structure at the end of the restoration reach. The restored Former North Sulphur River mitigation reach (Former NSR) will also connect to the MC NSR before the floodplain step (**see Figure 5**).

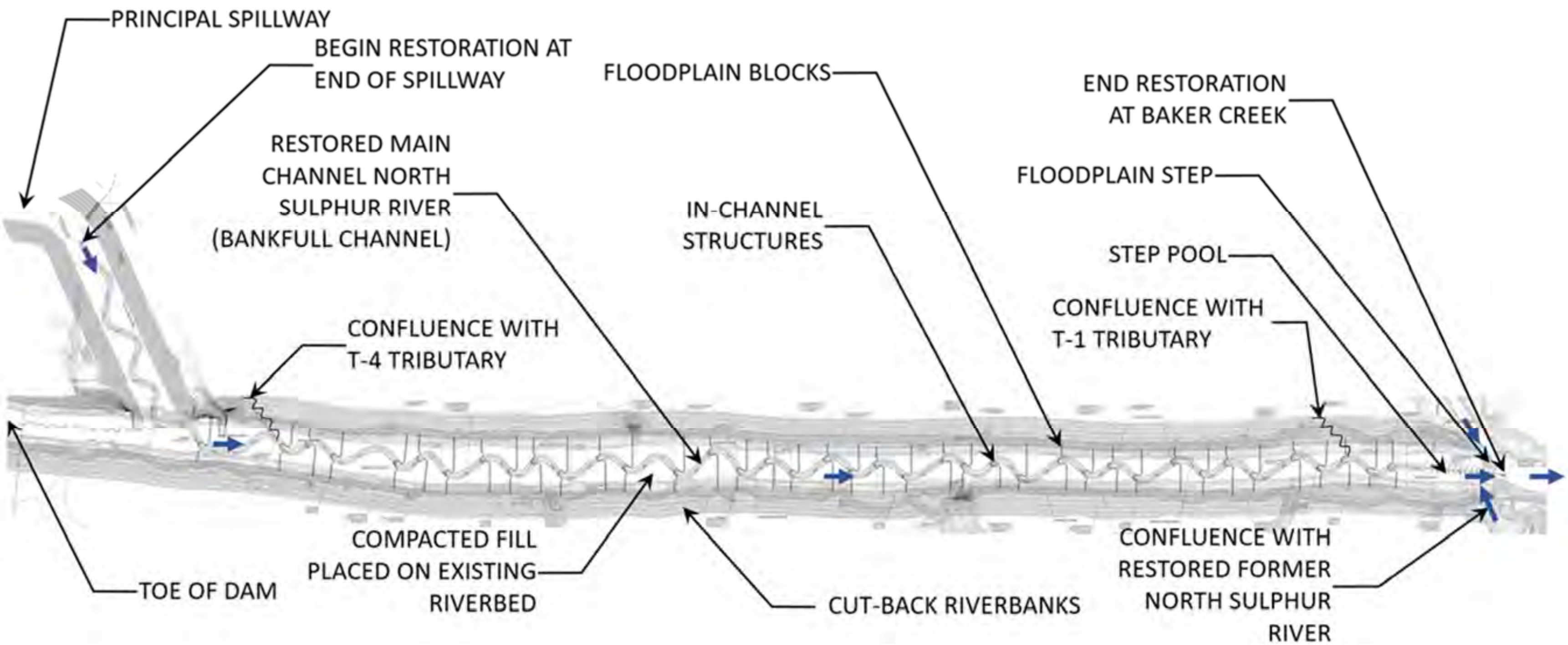


Figure 5. Restoration Overview Map showing plan view of restoration components. The restored MC NSR channel will meander across the riverbed of the existing channel.

D. DESIGN BASIS OF MC NSR RESTORATION COMPONENTS

A discussion of each of the components of the restored MC NSR is included below, along with assumptions and calculations where applicable.

i. Restored Channel Characteristics and Classification

Restoration of the North Sulphur River will be designed as a Priority II stream restoration, meaning there will be construction of a new floodplain at a lower elevation than the historic floodplain of the river (currently at the river top of banks) (Rosgen, 2006). The proposed entrenchment ratio for the restored river will be greater than 15, demonstrating the substantial floodplain connectivity that is being restored and well above the threshold for entrenchment. Restoration of a floodplain is a critical component of stream restoration as it provides an area across which flows can be distributed to dissipate energy during high flow events and provides for greater ecological recovery of riparian flora and fauna.

An important step in natural channel design is to identify the appropriate stable channel type based on design channel analog surveys and analysis of channel evolution. One channel classification system widely used in natural channel design is that developed by Rosgen (2006). Based on design channel analog information collected in the Lake Ralph Hall mitigation zone by Alan Plummer Associates, Inc. (APAI) and Ecosystem Planning and Restoration, LLC (EPR), a Rosgen “C” stream type is most appropriate for this valley and physiographic setting (EPR, 2018) . With this stream type, the proposed channel cross-section will possess a relatively high width/depth ratio (approximately 18 ft/ft). Higher width/depth ratios reduce shear stress and are important in low-sediment supply systems to mimic the natural processes that would mobilize bed material due to “sediment starved” flows.

ii. Effective Discharge Determination/Hydrologic Analysis

A critical component in natural channel design is determining the stable channel-form. As a first step in determining this important design component, as well as the potential hydrologic regime of the restored channel, it was necessary to examine the effect of the proposed dam and principal spillway on the hydrology of the restored MC NSR. FNI completed an analysis of proposed reservoir stage-storage frequency estimates based on the Water-Availability Model (WAM model) created as part of the LRH project (FNI, 2019). This analysis provides an estimate of the frequency and magnitude of discharges from the reservoir into the principal spillway channel, which connects to the upstream end of the MC NSR restoration reach. The discharges expected to occur at different recurrence intervals (the 2-, 5-, 10-, 25-, 50-, and 100-year flow events) were analyzed for two situations: 1) when the reservoir is at conservation pool elevation of 551 feet and 2) based on the annual exceedance probability (AEP) of reservoir peak water surface elevation. In addition, FNI evaluated the estimated frequency and magnitude of discharge from the natural drainage areas of the MC NSR remaining after construction of the Dam (shown in **Figure 6**). These flow contributions into the MC NSR are summarized in **Table 2**.

Table 2. Main Channel North Sulfur Discharge Contribution Analysis. Note that the drainage area below the dam contributes flows into the restored MC NSR, ensuring that that the restored channel will not rely only on spillway discharges for hydrology.

Recurrence Interval (years)	Peak Discharge from Uncontrolled (Natural) Drainage Area at Start of Restoration Reach (cfs)	Peak Discharge into MC NSR from Principal Spillway based on AEP of Reservoir Peak WSE (Realistic) (cfs)	Peak Discharge into MC NSR from Principal Spillway at Conservation Pool (cfs)
1	19	0	78
5	257	0	115
10	374	50	1,971
25	550	75	3,666
50	702	800	4,967
100	869	2,000	6,355

AEP = annual exceedance probability; WSE = water surface elevation; cfs = cubic feet per second

As shown in **Table 2**, if the reservoir is at conservation pool elevation when a flood event occurs in the LRH watershed, the principal spillway will provide flow contributions to the restored MC NSR channel with a magnitude of approximately 78 cfs following a 1-year event. From a realistic perspective, however, the reservoir is expected to be at conservation pool elevation only approximately 15% of the time, the principal spillway is not expected to discharge into the restored MC NSR until roughly a 7-year event. Flow contributions from smaller events are therefore expected to primarily come from the natural contributing drainage area below the Dam. This includes stormwater runoff from the dam embankments and discharge channel side slopes at the very start of the restored MC NSR, a tributary (T4 Tributary) that connects with the restored MC NSR approximately 1,600 feet from the beginning of the restoration reach as well as the downstream area of the dam embankment and valley walls of the proposed floodplain. This generates a total drainage area upstream of the confluence with the restored Former NSR (near the downstream end) and T1-BAKER Tributary of approximately 0.5 square miles (**Figure 6**). Thus, it is expected that the restored MC NSR will have natural contributions of surface water during smaller events, equivalent to other intermittent jurisdictional streams in the region, supplemented by reservoir spills during medium to large events (7-year and above).

From a channel design perspective, the effective discharge or bankfull discharge can be defined as the discharge that does the most work in forming and shaping the channel over time and can be determined from evaluating the magnitude and frequency of sediment transport across a range of flows (Biedenham et al., 2000). Essentially, the flow that moves the most sediment at the greatest frequency is what will shape the channel over time. The Dam will effectively cut off sediment delivered upstream from the North Sulphur River watershed and reservoir overflows are not expected to contribute much if any flow into the channel during smaller events. This means that the effective discharge into the MC NSR will be informed by the sediment loads and the more frequent flows from the hillslope and channel processes of natural, contributing drainage areas downstream of the dam. However, the restored floodplain will still need to accommodate the higher flows expected from reservoir spills, including an estimated 2000 cfs during a 100-year event. Based on this, the proposed restored bankfull channel will be sized based on the bankfull discharge of the drainage area below the dam, while overflows/discharges from the reservoir will be carried in the restored floodplain. This concept mimics how stable channels are able to withstand high flow and high energy events by utilizing the conveyance of flow on the floodplain which has sufficient roughness to reduce velocity and energy. To provide flow and sediment input into the beginning of the restored MC NSR reach, one existing tributary (T4) will be re-aligned to flow into the start of the reach.

iii. Bankfull Discharge Determination

Using only the contributing drainage area from below the Dam as the basis of the bankfull channel design, several regional curves were examined to determine discharge and channel geometry for the design. Regional curves relate the bankfull channel geometry and discharge to the drainage area in watersheds within the same physiographic region. While there is no regional curve providing discharge estimates currently published for the Blackland Prairie Ecoregion, Jones and Jones (2013) performed a correlation analysis between Blackland Prairie streams and Harris County, TX streams, for which there is a published curve relating bankfull discharge to drainage area. This analysis showed that the Harris County Regional Curves are applicable to the Blackland Prairie. The estimated bankfull discharges at each point where a tributary or contributing drainage area ties-in to the MC NSR are shown in **Table 3**. The contributing drainage areas are shown in **Figure 6**.

Table 3. Bankfull Discharge Estimates for MC NSR Restoration Reach

Drainage Area Name	Description	Drainage Area (square mile)	Cumulative Bankfull Discharge at Confluence (cfs)
DA1	Drainage from dam embankment	0.07	10
DA2	T4 Tributary	0.24	29
DA3	Drainage from restored floodplain side slopes	0.15	42
DA4	T1-BAKER Tributary	0.37	66
DA5	Restored Former NSR	3.62	172
Total		**4.45**	

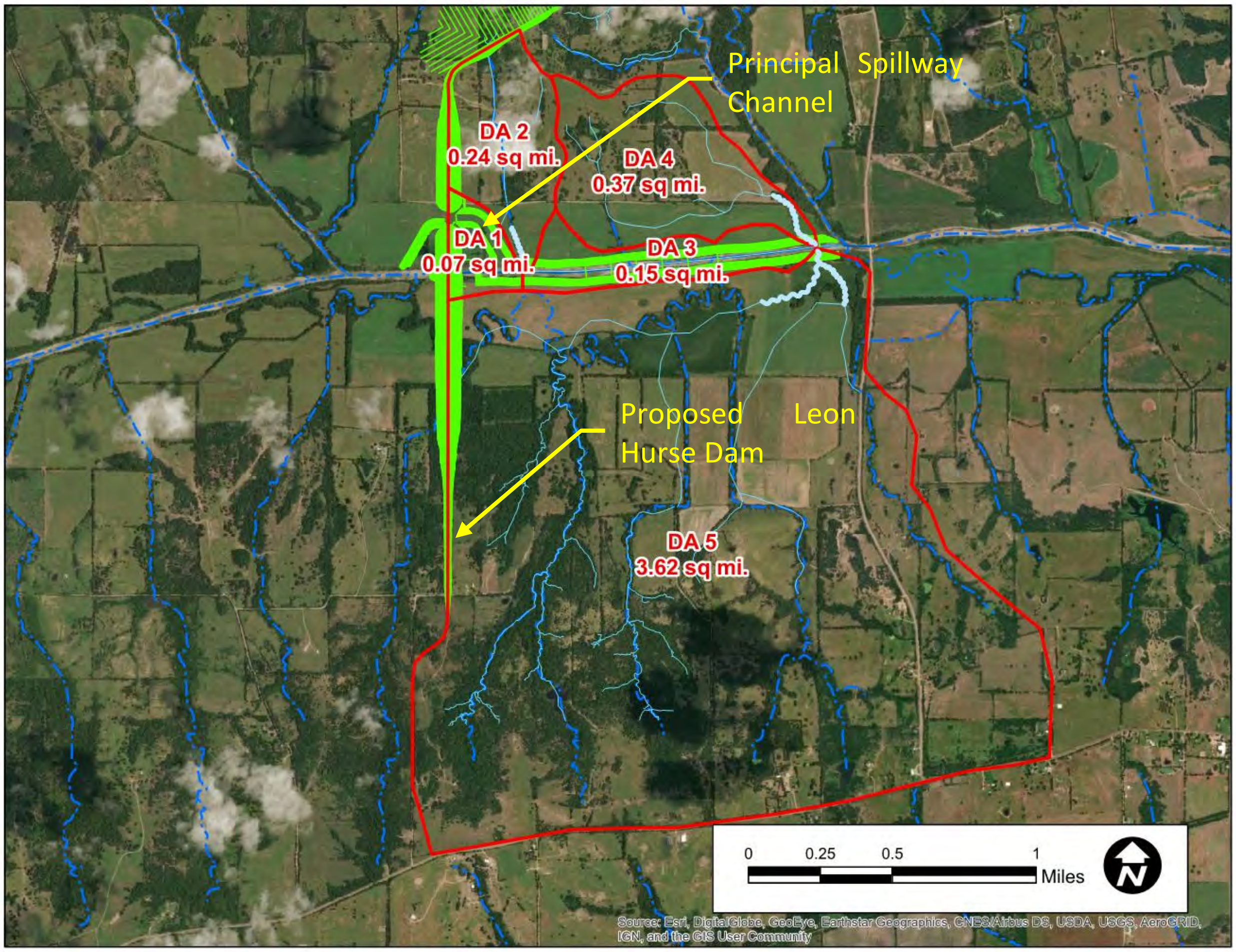


Figure 6. Map of the contributing drainage areas of Main Channel of the North Sulphur River restoration.

iv. Channel Plan, Profile and Dimension

The dimensions of the restored MC NSR are based on estimates of bankfull discharge (see discussion above), target stream type and morphological parameters from the EPR design channel analogs. Sediment transport calculations are currently being completed and will inform the final cross-section design (see discussion below).

The proposed channel will have an average water surface slope/bankfull slope of approximately 0.1% for its length to the downstream Floodplain Step (see discussion below). Analysis of EPR design channel analog information shows that a riffle-pool bed configuration is most appropriate for the restored bedform of the MC NSR. This type of bed configuration will also provide a diversity of in-channel habitat, with relatively deep pools that provide refuge for aquatic organisms. Beginning several hundred feet upstream from the end of restoration at Baker Creek, the bankfull channel will be designed as a step-pool configuration to lower the bed elevation of the MC NSR restored channel to the existing North Sulphur River channel bed elevation downstream and to provide for hydrologic connectivity between the downstream river and restored river reach. In the plans, each step is shown as approximately 10 feet in length with drop heights set at approximately 1 ft.

Using the analog approach of natural channel design (NRCS, 2007), dimensionless ratios for bankfull channel planform, dimension and profile (pool size relative to riffle size, etc.) were derived from stable design channel analogs surveyed by EPR within the project area and used to inform the proposed geometry of the MC NSR restored reach. These reference ratios are not repeated in this report for the sake of brevity but can be found in the technical memorandum from Ecosystem Planning and Restoration titled "Analysis of Stream Mitigation Design Criteria for Lake Ralph Hall Mitigation Area" (EPR, 2018). This provides consistency across the mitigation reaches in terms of reference stream design parameters. However, the application of these parameters is more limited in the MC NSR restoration due to the confined nature of the floodplain, which will be contained entirely within the existing MC NSR and subject to much higher flows from principal spillway discharges. For example, in the design channel analogs studied by EPR with a slope similar to the proposed MC MSR (approximately 0.1%) had much higher sinuosity than that which is proposed for MC NSR. The belt width of the proposed channel, which describes the width of the corridor across which the restored stream meanders, is therefore adjusted downward to meet the confines of the MC NSR channel, resulting in a sinuosity of 1.2 for the restored MC NSR. This pattern mimics the reference systems studied by EPR that were contained within confined valleys.

v. Sediment Transport Considerations and Bed Material

Placement of immobile bed material on the restored bed of the MC NSR is proposed to help maintain vertical stability. It was observed during an initial site visit that the river is currently depositing some cobble and gravel-sized material in depositional areas on the bed (see **Figure 7**). This indicates that there is currently a supply of a variety of bed material sizes delivered from the watershed that deposits and creates a mobile bedload along the river, although most of it appears to be flushed out of the system during the frequent, high flow events. These flushing events do not allow the time for floodplains to form and become consolidated and stabilized with deep rooted vegetation. However, because the Dam will cut-off sediment supply from upstream, this material will no longer be available to replace bedload that is mobilized downstream (i.e. a “sediment starved” condition) and the only sediment contributions will be from smaller tributaries that join the MC NSR. As such, it is necessary to provide some stabilization of the proposed riverbed, particularly the riffles, to resist the excess energy from the low frequency lake discharges that would otherwise be focused on transporting sediments (bedload and suspended) from upstream. This is proposed by using an immobile, cobble-sized bed material placed along the riffles of the channel. The bed material will be sized to be immobile during frequent flood events (1 to 10-year storm event) and will be compacted in a way that will resist higher shear stress during expected high flows (10 to 100-year storm event). The placement of this bed material will also help protect the compacted fill in which the bankfull channel will be formed. In this manner, the design will mimic upper valley, low sediment supply systems that have immobile beds while utilizing the energy reduction of the floodplain to carry high volume flows. Lastly, the material, while designed to be immobile, will mimic the benefits to aquatic organisms provided by the gravel/cobble in the current system by providing interstitial spaces and voids for refugia, and oxygenation of water.

Figure 7. Depositional bar in existing Main Channel of the North Sulphur River showing sand, gravel and cobble deposits. Restoration efforts will incorporate gravel and cobble material into channel bed to provide stability.

Despite the confined nature of the channel, the proposed floodplain will serve to relieve energy in above-bankfull flows as the rate of increasing shear stress slows significantly. Even at the 100-year storm event, which has a significantly reduced discharge in the channel (approximately 2000 cfs) compared with the existing condition, the relatively flat slope of the channel (approximately 0.1% average water surface slope) and increased roughness (from planting with vegetation) will still help to significantly lower the shear stress that can occur in the restored floodplain compared with its current condition.

vi. Downstream Floodplain Step and Step-Pool Cascade to Provide Hydrologic Connectivity

As previously mentioned, to help maintain and protect the proposed approximate 10 feet of fill placed over the existing riverbed, a downstream "Floodplain Step" is proposed to be constructed to allow transition from the filled riverbed elevation to the existing riverbed elevation downstream. A structure is proposed consisting of a sloped face of soil cement at the confluence with Baker Creek, combined with vegetated areas above and upstream of the step (see **Figure 8**). To maintain hydrologic connectivity through the Floodplain Step, the bankfull channel will be constructed as a step-pool structure. Step-pool structures mimic natural, geomorphic features found in steeper streams where channel energy is dissipated through a series of steps that naturally form from boulders, colluvium and other materials. It has been found that these structures provide some of the highest boundary roughness within natural channels (Chin et al., 2009). These structures are widely used in stream restoration practices as a means of transitioning over a steep slope to a lower elevation. They are designed with a height between each step to allow for passage of different species of fish and other aquatic organisms to ascend and descend the stream channel either during low flow or higher flows, depending on the mode of travel by a particular species. A step height of 1 foot is shown on the design drawings as this is this is a widely accepted step height for many hydrologic connectivity applications.

To protect this structure from potential vertical instability of the remaining river channel downstream, a stone-lined stilling basin will be created at the confluence with Baker Creek to help dissipate flows that drop down the step and into the river channel downstream. The restored Former NSR will be connected to the Floodplain Step at the beginning of the step-pool.

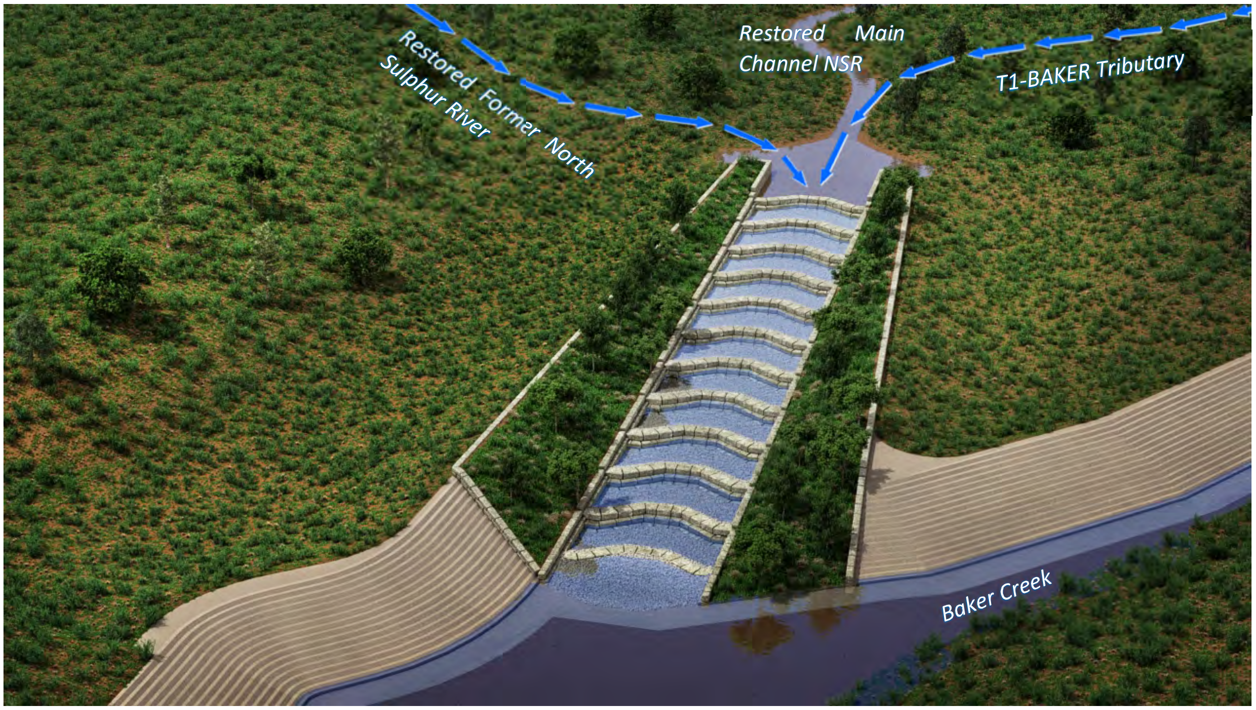


Figure 8. Illustrated rendering of floodplain step components and design.

vii. In-Stream Structures and Floodplain Blocks

In-stream structures are proposed as part of the MC NSR at the end of riffles/head of pool features to help maintain grade, redirect flows away from outside meanders to give time for vegetation to take root, and to help maintain pools to provide habitat and refuge for aquatic organisms. Cross-vanes or vanes are proposed on the meander bends of the restored MC NSR. These structures may be constructed using logs salvaged from on-site clearing operations, or potentially from boulders. Two tributaries (T1-BAKER Tributary and T4 Tributary) and several smaller drainages which join into the MC NSR will have step pools or cascades placed to hold grade, particularly where they transition from a higher bed elevation to the lower, MC NSR elevation.

As an added protection against tendency for scour in the floodplain, floodplain blocks are proposed to extend from the end of cross-vane structures to the proposed floodplain wall. Floodplain blocks consist of a trench dug perpendicular to the channel from the end of a structure across the floodplain and filled with stone. These structures can also be composed of a buried sheet pile wall. These act as a “fail-safe” measure to prevent any scour that might occur in the floodplain from continuing downstream or upstream. These are proposed as an added stability measure for a floodplain that will consist of fill material. The means of stabilizing this fill material will be from vegetation (see discussion below) but the floodplain blocks will add an additional measure of protection from expected higher flood events, particularly in the first several years before vegetation is fully established.

viii. Planting Plan

Planting efforts will focus on two separate zones within the restoration corridor having different hydrologic regimes and will include: streambank vegetation and floodplain community. Along the streambank, vegetation will be subjected to fluctuating stream flows and stresses. The floodplain community on the well-drained portions of floodplain will be subjected to occasional flooding, but because of the well-drained nature of these areas they will be drier much of the year. A descriptive summary of the two planting zones is included below.

Zone 1 – Floodplain Community- Native deciduous trees will be planted in the riparian buffers. A minimum density of bare-root seedlings will be planted to meet the percent coverage detailed in the SWAMPIM metrics. It is anticipated that bare root material will be used – however, containerized plant material may also be incorporated. Actual species used will be based on availability at time of planting.

Zone 2- Streambank Vegetation- To quickly establish dense root mass along the channel bank live stakes will be installed on channel banks. In addition, the channel banks will be lined with coir matting to provide cover and resistance of shear stress until vegetation can be established. Along the tops of the channel banks (riparian area), trees and shrubs will be planted.

E. MAINTENANCE OF INTERMITTENT FLOW WITH PERENNIAL POOLS IN RESTORED MC NSR

An important objective of the restoration of the MC NSR is to provide sufficient hydrology to support and maintain perennial pools and an intermittent flow regime in the channel to provide functional and ecological uplift. To assess this, it is necessary to understand the future hydrologic contributions and losses following construction of Lake Ralph Hall, including both surface water and groundwater. The expected downstream hydrologic conditions, specifically in regard to water retention in pools, following construction of the Dam have already been studied in detail during the water rights permitting process (DiNatale, 2016). Thus, rather than re-create the already substantial efforts in hydrologic modeling by other parties, FNI undertook an investigation of the results of these studies and then compared the proposed conditions of the restored MC NSR to the assumed conditions in the former studies to assess whether the predicted hydrologic conditions would be similar. In addition, groundwater data obtained from piezometers located at the project area were also evaluated as another line of evidence to support maintenance of perennial pools and an intermittent flow regime in the channel. The summary of these investigations is provided below.

i. Previous Studies

DiNatale Water Consultants (DiNatale) was previously contracted as a third party to evaluate the hydrologic models that had been completed for the LRH environmental impact statement in October 2016, which included the following:

1. A Water Availability Model (WAM) developed by the Texas Commission on Environmental Quality, later refined by Upper Trinity, and reviewed by the United States Army Corps of Engineers (USACE),
2. A RiverWare model developed by USACE and later edited by Upper Trinity to include LRH, and
3. A HEC-RAS model developed by USACE.

Relevant to this discussion, DiNatale focused on the use of the RiverWare and WAM models to evaluate the maintenance of water in pools below the Dam. Previous analyses of pool impacts had focused on a monthly time-step. DiNatale theorized that increasing the model resolution to a daily time-step would provide more accurate results. They selected the RiverWare model for this analysis, as opposed to the WAM, as a more conservative predictor of the potential impacts of the Lake Ralph Hall project on the pool volumes downstream of the Dam because it assumes no releases for downstream water-rights (i.e. that water will only come from reservoir spills, rainfall and natural streamflow contribution). DiNatale included daily evaporation and rainfall data from a nearby gage and evaluated the model for the period from 1994 to 2014. They then computed the statistics for the percent of time that a given pool volume (expressed as percent of total volume) would be equaled or exceeded. The results of DiNatale's calculations for the reach from the Dam to Baker Creek are shown in **Table 4**.

Table 4. DiNatale calculations of percent of time pool volume is equaled or exceeded after construction of LRH (Dam to Baker Creek).

Pool Volume	% Time
≥99.9%	8.9%
≥75%	33.6%
≥50%	47.4%
≥25%	60.9%
≥0%	80.3%

As shown, DiNatale's results indicate that some water will remain in the pools for the majority of the year. DiNatale's calculations assumed existing pool volumes in the reach from the Dam to the mouth of Baker Creek based on estimations made by the National Wildlife Federation (NWF). NWF's estimations were based on measurements taken along a representative reach of the channel and then scaled up to the whole reach from the Dam to Baker Creek.

ii. Comparative Analysis

Since the study described above has been vetted by multiple agencies and stakeholders, it forms the most reasonable means of evaluating the potential for functional uplift potential of the proposed design through creation of perennial pools. FNI obtained a copy of the RiverWare spreadsheet developed by DiNatale and revised the input assumptions about total pool volume, pool depth and surface area within the Dam to Baker Creek reach based on the proposed MC NSR restoration design. All other assumptions in DiNatale's model were kept the same. The difference in the results using the restored MC NSR pool geometry, compared with the results from DiNatale (using existing pool geometry as estimated by NWF) are shown in **Table 5**.

Table 5. Comparison of DiNatale results (using existing pool dimensions and volume) of pool retention with FNI results (using restored Main Channel of the North Sulphur River pool geometry).

Pool Volume (% Full)	DiNatale Results % of Time	DiNatale Results Corresponding Pool Depth	FNI Results % of Time	FNI Results Corresponding Pool Depth	% Difference	Impact of Restoration on Pool Retention Time
≥99.9%	8.9%	0.4 ft	14%	4.0 ft	4.6%	Increase
≥75%	33.6%	0.3 ft	38%	3.0 ft	4.2%	Increase
≥50%	47.4%	0.2 ft	61%	2.0 ft	13.1%	Increase
≥25%	60.9%	0.1 ft	71%	1.0 ft	10.3%	Increase
≥5%	-	-	88%	0.2 ft	-	Increase

As shown in the results, the proposed pool geometry of the restored MC NSR results in a greater percent of time that the pools remain filled at a given percentage of their total volume. This is due to the fact that the restoration will produce much deeper pools than what currently exists in the MC NSR (average of 4 feet proposed versus 0.4 feet existing). More importantly, the restored MC NSR will have much more depth of water in the pools for longer periods of time than what currently exists. For example, in the restored channel, 25% of pool volume represents approximately 1' of water depth remaining in pools, meaning that for the majority of the year (71%) there will be at least 1' of water remaining in the pools. This has been reflected in **Table 5** by showing the relative depth of water left at a given percent volume. By restoring deep pools with an average depth of 4 feet, it is expected that 50 percent or even 25 percent of pool volume leaves sufficient depth to act as effective refuge areas for aquatic species. Thus, based on the method of analysis used by DiNatale and incorporating the restored pool parameters, it is believed that the MC NSR will restore more functional pools from the Dam to Baker Creek reach than currently exists, ultimately providing a perennial pool functional uplift. It should also be noted that the RiverWare model analysis assumed no contribution from groundwater inputs, therefore, the actual pool volume will likely be higher as groundwater interaction occurs in the restored channel.

Other design measures that will assist with pool retention include:

- Ensuring adequate compaction of fill in floodplain; the material being used as fill from the side slopes is comprised of a low-permeability clay
- Placing an impermeable layer or barrier behind the proposed Floodplain Step structure (see above) or using the floodplain blocks as a means of retaining groundwater in the restored MC NSR corridor
- Placement of buried, impermeable barriers that function to reduce the risk of alternative flow path formation in the floodplain while retaining groundwater to maintain pool hydrology (impermeable floodplain blocks)

iii. <u>Intermittent Flow Regime</u>

Another functional uplift intent is for the restored MC NSR to possess an intermittent flow regime. That the restored channel will have this classification is supported by the convergence of several hydrological conditions:

- Perennial retention of water in pools (see above for analysis)

- Position of the restored channel below the groundwater table of the surrounding relict floodplain
- Contributions of surface flow from natural drainage areas remaining below the Dam

Groundwater interactions with the restored MC NSR can be inferred from piezometer data and field observations of existing seeps. Piezometers have been installed at the proposed Dam location on the project site to study groundwater levels in the area. Groundwater level readings from the piezometers from August 14, 2018 through January 8, 2019 indicate that the groundwater surface was consistently well-above the elevation of the proposed floodplain and thalweg of the restored MC NSR (**Figure 9**). This was corroborated by field observations of seeps located at the interface between clay soils and the underlying marl (Ozan formation). These observations were made on July 25, 2018 following a 12-day period without rain (Paris 4.5 NNE, 2019), suggesting that these seeps were not temporarily induced by rainfall. An example of one of these seeps is shown in **Figure 10**.

While there is no way to account for an exact contribution of groundwater into the MC NSR given existing data, the position of the restored channel below the groundwater table should help offset evapotranspiration losses in the channel bed, as illustrated by saturated ground around existing seeps (See **Figure 10**). Thus, for this reason, most definitions of intermittent flow regime do not attempt to quantify a required flow rate to achieve this status, as a groundwater surface above the channel implies that there will be groundwater interaction with the channel. Ultimately, the piezometer information provides a line of evidence, augmented by the perennial pool retention, that demonstrates an intermittent regime in the channel.

Figure 9. Piezometer Locations Adjacent to Main Channel of the North Sulphur River for Period 8/14/2018 to 1/8/2019

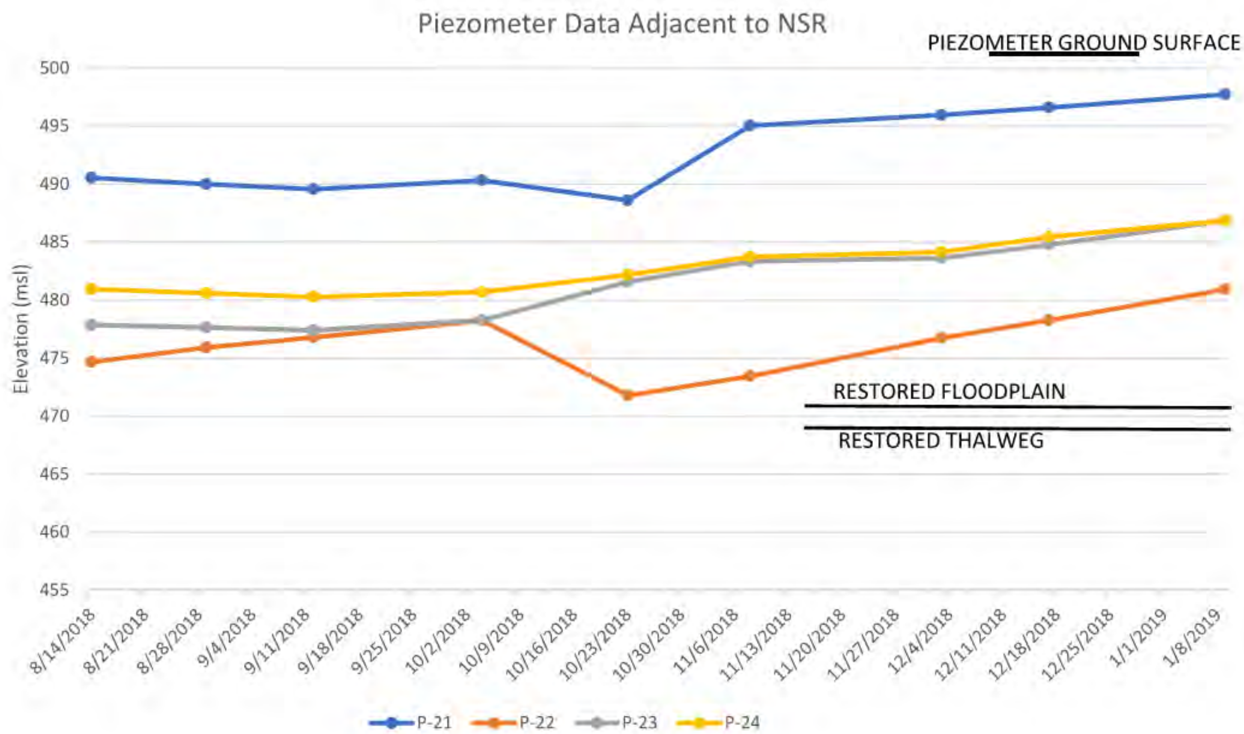


Figure 10. Piezometer Data Adjacent to Main Channel of the North Sulphur River for Period 8/14/2018 to 1/8/2019

Figure 11. Example photo of seep in existing MC NSR. Note the saturated soils.

IV. CONCLUSIONS

The design of the restored MC NSR is ultimately focused on protection of the Dam and providing ecological uplift in the restoration corridor. Fundamentally, the greatest consideration in the design development is accounting for the effects of impoundment of the existing MC NSR on the sediment and hydrologic regime. Analysis of these changes has led to the design and incorporation of specific measures to protect the Dam and to maximize ecological uplift in the channel under future conditions. Natural channel design forms the basis of the restoration, with design elements that mimic both local, stable design channel analogs as well as natural grade-transition features such as step-pools. Based on analysis of stability and functional uplift, it is expected that the objectives of the MC NSR restoration will be met by the proposed design. Ultimately, restoration of the MC NSR will provide substantial benefits to the LRH project, including ensuring protection of the proposed Dam, as well substantial ecological uplift downstream to the mouth of Baker Creek.

V. REFERENCES

The following documents were used to provide the basis for the stream design.

- Biedenham, D; Copeland, R; Thorne, C; Soar, P.; Hey, R.; Watson, C. 2000. *Effective Discharge Calculation: A Practical Guide (US Army Corps of Engineers Technical Report TR-00-15)*. US Army Corps of Engineers, Engineer Research and Development Center. Vicksburg, MS.
- Chin, A., Anderson, S., Collison, A. et al. *Linking Theory and Practice for Restoration of Step-Pool Streams*. Environmental Management. 2009. 43: 645.
- DiNatale Water Consultants (DiNatale). 2016. *Evaluation of Hydrologic Modeling in Support of the Lake Ralph Hall Environmental Impact Statement.*
- Ecosystem Planning and Restoration (EPR). 2018. *Analysis of Stream Mitigation Design Criteria for Lake Ralph Hall Mitigation Area*.
- Freese and Nichols, Inc. (FNI). 2019. *Lake Ralph Hall & Leon Hurse Dam: Hydrologic and Hydraulic Design Report.* February 2019.
- Jones, Steve; Jones, James. 2013. *Applicability of Harris County, Texas Regional Curves to Other Physiographic Regions in East Texas*. Presented at the Southwest Stream Restoration Conference. San Antonio, TX, May 28-30, 2013.
- Natural Resource Conservation Service (NRCS). 2007. *Part 654 — Stream Restoration Design*. USDA, Natural Resources Conservation Service. H.210.NEH.654.
- Paris 4.5 NNE, T. U. (2019). Record of Climatological Observations. Paris, TX: National Oceanic & Atmospheric Administration.
- Rosgen, D.L. 2006. Watershed Assessment of River Stability and Sediment Supply (WARSSS). Wildland Hydrology. Fort Collins, CO.

TECHNICAL MEMORANDUM

To: Loretta Mokry
Tim Noack
Alan Plummer & Associates, Inc.

Copy: Ed Motley, P.E.
CH2M

Larry Patterson, Deputy Executive Director
Upper Trinity Regional Water District

From: Bob Brandes, P.E., Ph.D.

Subject: Preliminary Analysis of North Sulphur River Restored Channel as Perennial Stream

Date: February 24, 2017

STATE OF TEXAS
ROBERT J. BRANDES
39120
REGISTERED PROFESSIONAL ENGINEER
2-24-17

We made a preliminary investigation of whether the restored channel could qualify as a perennial stream based on the standard that none of its pools would ever go dry under natural runoff conditions. While we are still reviewing this analysis and the results, the short answer is that it appears that the restored channel will be perennial. I am providing these results to you now so we can assess whether further analyses are necessary.

The attached document contains pertinent information from this investigation. For evaluating inflows to the restored channel, I applied the Soil Conservation Service "curve number" method to calculate daily runoff from the restored channel's 1,997-acre drainage area (see page 1) using 1940-2016 historical daily rainfall data for the LRH region obtained from the NOAA Climatic Data Center (data from rainfall stations at Honey Grove, Wolfe City, Cooper, Cooper Dam, and Paris in that order were used to develop a single daily rainfall record). The monthly and annual values of rainfall and the corresponding runoff values from this analysis are tabulated on pages 2 and 3 of the attachment. Using the geometric data you provided me for the dimensions of the deep pools, shallow pools and riffle reaches (pages 4 and 5), I constructed a single combined storage-versus-stage data set and a single combined surface area-versus-stage data set, both with data points every one foot of stage (top of page 5). These curves are shown on the plot on page 6, and as indicated, the top level of the combined single storage unit representing the entire length of the restored channel is at 7 feet of stage – above this level, I have assumed that all stored water within the restored channel would be discharged immediately downstream to the North Sulphur River and would not be available to offset evaporation losses. While this is not how the real restored channel will function, i.e., there will overbanking, it nonetheless provides a conservative answer by limiting storage in the restored channel that is available for drawdown due to evaporation during dry periods. I believe that combining all of the pools and riffle reaches into a single water body for representing the geometric characteristics of the entire restored channel is reasonable for

6000 Maurys Trail
Austin, Texas 78730
Email: rjbobbrandes@gmail.com
Phone: 512/461-1477

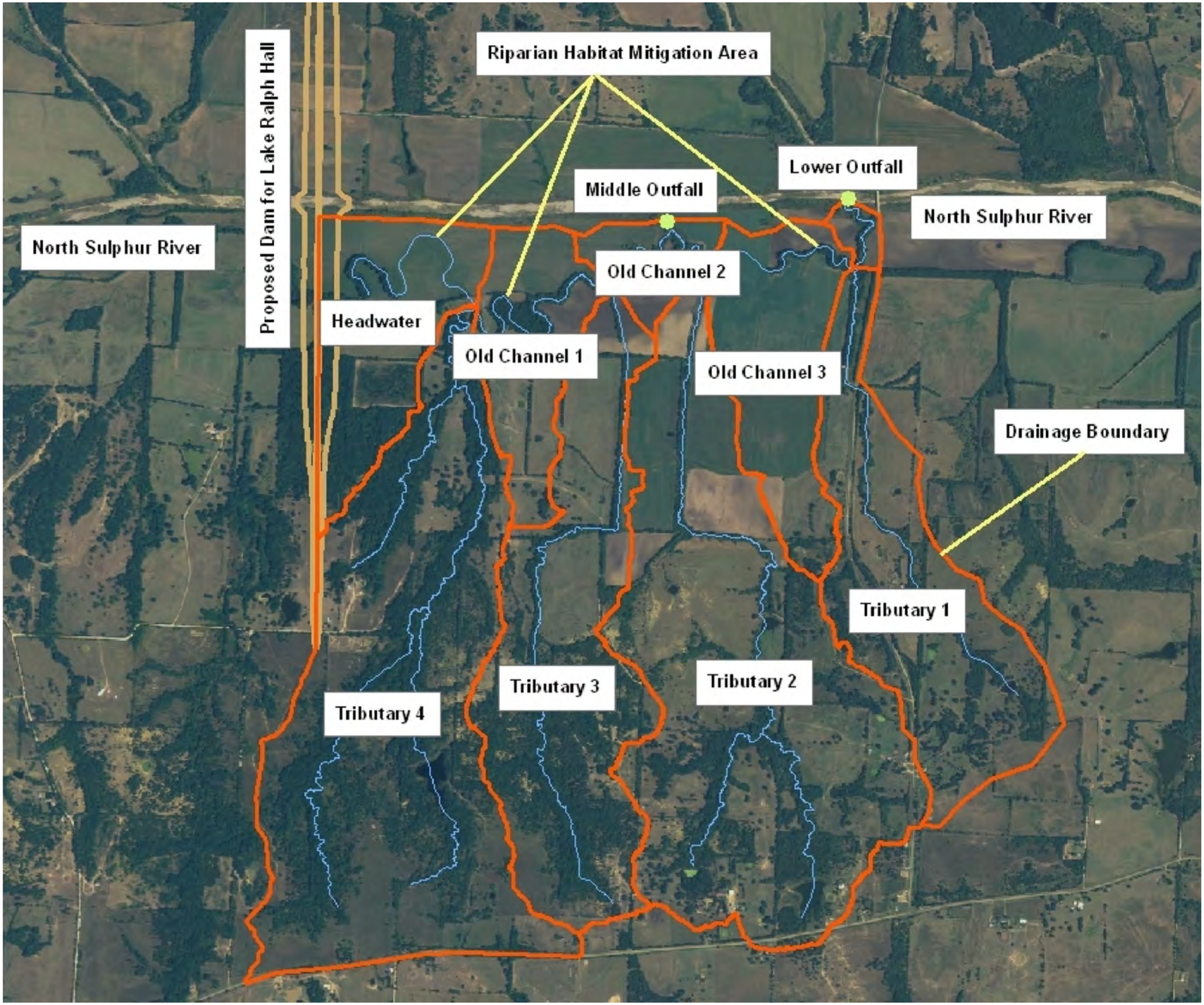
purposes of this analysis because it is likely that inflow would enter the entire length of the restored channel from the four major southern tributaries during runoff events such that all of the pools would respond with generally comparable increases in storage. This allows the entire restored channel to be analyzed as a single water body with regard to rainfall-generated inflows and losses due to evaporation.

The Excel worksheet shown on page 7 of the attachment represents a portion of the hydro-operations model I developed to simulate the time-varying daily storage behavior of the restored channel in response to the 1940-2016 daily inflows as described above and daily evaporation losses. This model performs a mass balance calculation each day of the simulation period to determine the end-of-the day storage in the restored channel by starting with the previous-day's ending storage and adjusting it for the current day's direct rainfall, rainfall-generated inflows from the contributing drainage area, and the calculated evaporation loss. For evaporation, I used 1954-2015 historical monthly lake evaporation data available from the TWDB for the LRH region (average of Quads 411 and 412), extended these data using a regression analysis to estimate annual and monthly lake evaporation values for 1940-1953 and for 2016, and divided each of the 1940-2016 monthly values by 30 to arrive at approximate daily lake evaporation values for use in the model. The resulting simulated monthly and annual values of evaporation loss in acre-feet from the restored channel, taking into account daily changes in surface area with changing storage over time, for the 1940-2016 period are tabulated on page 8. The simulated end-of-month storage in the restored channel for the 1940-2016 period is plotted on the graph on page 9. As shown, the lowest level to which the storage in the restored channel appears to fall is just below four acre-feet in 1956. Referring to the text box on the graph, it is indicated that the lowest storage amount actually occurred on October 10, 1956 at a value of 3.64 acre-feet (these data originate from the hydro-operations model as shown on page 7), thus indicating that the restored channel did not go dry during any day of the 1940-2016 simulation period. With storage at 3.64 acre-feet, the depth in the combined pool of the restored channel is 4.27 feet, which means the depth in the deep pools would be 4.27 feet and the depth in the shallow pools would be 0.27 feet.

After completing the above analysis, it occurred to me that the riffle reaches may not contain a significant amount of flow after a runoff event ceases and the pools have drained down to their respective normal pool levels as controlled by their outlet structures. So I repeated the analysis assuming that no storage would be available in the riffle reaches to offset evaporation losses. This analysis used the same storage-versus-stage and surface area-versus-stage data sets for the restored channel as shown in the table at the top of page 5, except that the values for stage equal to 7 have been reduced to 8.71 acre-feet for storage and 2.27 acres for surface area, reflecting the subtraction of the storage and surface area for the one-foot deep riffle reaches. Results from the model are shown on the plot on page 10 of the simulated end-of-month storage in the restored channel for the 1940-2016 period. As shown, the lowest level to which the storage in the restored channel appears to fall is just above three acre-feet in 1956. Referring to the text box on the graph, it is indicated that the lowest storage amount actually occurred on October 10, 1956 at a value of 2.85 acre-feet, again indicating that the restored channel did not go dry during any day of the 1940-2016 simulation period, even without accounting for any water stored in the riffle reaches. With storage at 2.85 acre-feet, the depth in the deep pools of the restored channel is 3.58 feet, and no water is stored in the shallow pools.

These analyses could be refined by dividing the restored channel into probably five reaches including one for the headwater reach and one below each of the four major southern tributaries for the revised restored channel alignment in order to better represent the distribution of inflows to the channel. Whether it's worth doing or not is questionable; although, maybe doing just the headwater reach could be useful since this reach has a relatively small drainage area (141 acres) and is comparable in length to the others. However, I believe the results presented above are somewhat conservative for a number of reasons. First of all, the simulated storage in the combined pool of the restored channel still has to be reduced by evaporation from its lowest simulated level of 3.64 or 2.85 acre-feet to zero for the channel to go dry, a drop in depth of 4.27 feet or 3.58 feet, respectively. This amount of fall is a lot considering the magnitude of runoff events that occur fairly frequently in this region. Daily rainfall patterns during even extended droughts in this part of East Texas always appear to be characterized by isolated but relatively significant rainfall events such that enough runoff is produced in the model to fill the combined pool of the restored channel – only about two inches of rainfall can produce enough runoff to fill the relatively small storage capacity of the restored channel. I have even artificially eliminated some of these rainfall events during the 1956 and 1957 drought years and still cannot get the restored channel to go dry. Also, I have assumed no overbank storage for the restored channel, while we know flood flows within the restored channel are likely to occur for several days after rainfall events, and it may be several weeks before water stored in the banks of the restored channel return to the channel. These conditions, which I have not considered in my analyses, will tend to offset evaporation losses and prolong storage in the restored channel. Finally, the curve numbers I have used for calculating daily runoff from daily rainfall were derived during our previous flooding modeling back in 2008 based on soil and land use information for the drainage subareas that contribute runoff to the restored channel. Based on these curve numbers, I have compared my computed average unit-area runoff for the entire restored channel drainage area with the measured average unit-area flow for the drainage area above the Cooper streamflow gage on the North Sulphur River for the common period of record of 1950-2015. My value (1.56 acre-feet/day/square mile) is somewhat less than the gage value (1.89 acre-feet/day/square mile), suggesting that my runoff estimates may on the low side. Again, all of these factors would tend to inject some degree of conservatism into my results.

After you have looked at this, we can discuss going forward.


Riparian Habitat Mitigation Area
Proposed Dam for Lake Ralph Hall
Lower Outfall
Middle Outfall
North Sulphur River
North Sulphur River
Old Channel 2
Headwater
Old Channel 1
Old Channel 3
Drainage Boundary
Tributary 1
Tributary 2
Tributary 3
Tributary 4

LAKE RALPH HALL REGIONAL RAINFALL DATA (INCHES)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1940	0.00	3.45	1.11	6.77	8.03	4.01	4.74	1.55	1.32	3.25	6.82	6.70	47.75
1941	0.60	3.57	2.55	7.44	3.96	12.27	6.14	1.68	1.05	8.06	0.92	2.90	51.14
1942	0.80	0.80	2.78	12.40	4.62	5.89	0.00	3.20	8.38	2.98	2.98	3.33	48.16
1943	0.21	1.81	4.78	2.61	3.59	6.59	0.17	0.00	2.65	1.19	1.01	3.13	27.74
1944	2.95	5.60	3.25	2.63	8.22	2.34	2.04	5.02	1.45	1.23	5.80	4.38	44.91
1945	2.60	8.42	7.78	1.87	3.03	8.03	4.12	2.35	8.18	6.30	1.55	0.85	55.08
1946	3.70	3.75	4.83	3.03	8.47	2.23	0.20	5.33	3.00	1.47	12.09	4.58	52.68
1947	1.40	0.50	4.42	5.31	3.43	2.80	1.24	4.91	3.85	1.93	3.53	8.48	41.80
1948	0.70	4.71	2.51	2.56	9.53	3.35	3.75	0.52	0.50	4.16	0.82	2.16	35.27
1949	11.38	5.14	2.75	6.01	2.48	6.27	4.21	5.63	2.47	6.08	0.70	3.31	56.43
1950	9.78	4.65	1.15	3.75	8.80	2.08	11.20	3.81	4.26	0.90	0.00	0.65	51.03
1951	2.81	2.28	0.55	3.25	4.19	12.92	3.17	0.42	4.01	4.87	1.20	0.71	40.38
1952	1.03	1.75	5.20	9.82	5.00	0.65	2.45	0.55	1.47	0.10	6.72	3.22	37.96
1953	1.50	1.02	4.53	8.75	2.43	0.22	6.48	3.72	2.52	2.40	3.75	3.96	41.28
1954	4.15	1.50	0.80	4.72	9.74	3.38	0.25	2.30	6.55	8.28	1.02	1.70	44.39
1955	1.65	1.45	5.25	5.50	3.10	1.45	5.50	4.38	3.70	4.55	0.60	0.82	37.95
1956	2.40	6.06	1.24	3.10	2.65	0.35	0.00	1.50	0.00	2.50	4.39	1.92	26.11
1957	1.90	2.60	7.31	11.91	16.64	6.33	0.25	0.60	6.60	3.87	10.28	2.35	70.64
1958	5.80	1.03	4.98	5.89	5.23	7.50	2.56	1.80	3.40	1.60	1.94	2.68	44.41
1959	0.40	1.55	3.10	1.26	3.60	6.86	8.15	1.70	2.75	4.45	1.30	4.82	39.94
1960	3.60	2.62	1.85	2.15	2.09	7.10	4.00	2.65	4.75	4.45	1.55	7.15	43.96
1961	1.70	2.55	7.10	0.85	2.68	4.82	3.10	2.15	3.65	1.95	4.31	3.85	38.71
1962	3.40	2.30	2.75	4.00	1.75	11.45	5.08	5.05	9.00	5.75	4.50	0.70	55.73
1963	0.80	0.55	1.65	4.60	2.30	1.51	3.45	1.10	0.95	0.05	1.80	1.47	20.23
1964	1.35	2.05	4.48	5.92	5.65	5.05	0.15	3.25	9.22	0.60	5.58	1.10	44.40
1965	2.15	5.85	1.70	1.63	6.20	3.71	0.42	1.30	5.82	1.69	4.95	1.30	36.72
1966	1.03	3.20	1.18	14.55	3.70	1.34	4.35	4.37	3.51	1.00	0.45	2.89	41.57
1967	0.38	1.47	3.74	8.95	8.29	1.30	3.95	1.80	6.88	6.05	1.30	4.13	48.24
1968	2.80	1.70	8.70	6.07	6.15	8.47	5.80	3.00	7.55	2.28	4.95	3.59	61.06
1969	4.30	3.60	5.20	2.70	17.30	3.91	0.00	1.23	4.55	4.81	0.73	5.42	53.75
1970	1.00	4.80	3.77	5.01	2.01	1.30	0.40	2.60	10.20	5.55	2.25	1.05	39.94
1971	1.30	2.25	1.10	0.20	4.35	0.84	4.82	4.17	3.48	10.50	2.75	13.68	49.44
1972	1.01	0.70	1.13	2.02	2.42	2.45	1.48	3.13	2.73	8.41	4.58	2.17	32.23
1973	2.80	2.99	5.60	4.60	2.60	5.75	3.15	1.08	13.39	5.48	3.42	1.11	51.97
1974	3.30	1.39	1.22	5.15	2.37	7.89	1.33	6.13	7.59	5.34	6.05	2.10	49.86
1975	2.63	4.16	3.44	2.69	6.74	7.81	3.65	0.87	0.20	0.06	2.24	1.80	36.29
1976	0.12	0.74	4.15	4.42	4.96	6.76	10.06	2.73	4.34	4.72	2.02	1.48	46.50
1977	3.77	2.66	6.13	3.07	1.38	2.89	0.78	2.70	1.32	0.49	2.39	1.03	28.61
1978	2.57	3.67	3.52	1.41	4.48	2.62	0.53	0.33	2.05	0.04	10.17	2.52	33.91
1979	3.47	3.90	5.34	3.41	6.83	4.54	3.73	2.04	1.40	3.09	1.21	4.10	43.06
1980	2.06	1.76	1.38	1.67	4.19	2.68	0.33	0.20	9.19	4.07	1.42	2.27	31.22
1981	1.35	2.10	4.04	4.26	7.77	7.59	0.95	0.74	0.51	15.84	2.02	0.20	47.37
1982	3.76	2.52	3.16	2.68	19.07	6.62	3.34	2.40	0.55	3.77	5.55	5.17	58.59
1983	1.12	6.63	4.46	1.49	5.55	7.05	3.46	1.87	1.06	4.12	3.38	1.05	41.24
1984	1.37	4.34	6.14	3.41	6.33	1.54	0.61	1.19	3.14	8.35	4.46	5.45	46.33
1985	1.19	3.11	5.02	5.92	5.82	3.39	2.33	0.31	2.72	7.40	5.89	1.27	44.37
1986	0.09	4.89	2.08	3.85	4.71	6.67	3.26	1.59	4.39	2.79	8.35	2.18	44.85
1987	2.06	3.85	2.65	0.13	7.36	3.52	4.45	2.03	8.46	3.93	7.02	5.85	51.31
1988	1.52	2.31	4.66	2.42	1.51	1.04	3.83	0.56	2.69	5.17	4.99	2.92	33.62
1989	2.83	5.09	4.50	0.50	10.29	9.17	6.81	2.32	2.15	1.74	0.80	0.47	46.67
1990	7.53	5.86	6.95	6.02	10.10	3.11	3.84	1.37	2.76	3.10	4.28	3.18	58.10
1991	4.14	4.59	2.63	6.44	3.67	4.33	3.31	5.13	2.45	10.47	2.45	8.51	58.12
1992	3.33	2.24	4.61	2.28	9.22	10.26	6.16	2.80	3.01	0.37	4.86	4.14	53.28
1993	1.98	5.64	4.71	5.09	2.59	3.25	0.00	0.80	3.73	10.95	3.31	4.67	46.72
1994	1.67	2.03	2.63	5.05	8.30	2.63	8.74	1.89	2.38	5.07	6.11	2.67	49.17
1995	4.15	1.28	4.03	5.32	11.31	4.12	2.59	0.69	6.62	0.51	1.42	2.83	44.87
1996	2.44	0.06	2.84	2.82	2.00	9.56	6.29	5.86	2.65	5.57	10.43	1.85	52.37
1997	1.15	8.12	4.26	9.05	3.29	3.64	1.38	3.78	0.60	6.17	2.82	8.84	53.10
1998	6.46	3.51	5.91	2.24	1.61	1.43	2.03	0.80	5.88	5.34	4.13	6.16	45.50
1999	3.32	1.15	3.37	2.11	5.64	2.37	1.90	1.41	3.94	3.25	2.73	5.50	36.69
2000	2.39	2.01	4.00	3.42	5.84	9.17	0.21	0.00	2.26	5.22	10.86	6.20	51.58
2001	3.06	11.41	4.37	2.78	5.12	3.17	0.42	6.73	4.49	5.00	1.90	7.55	56.00
2002	5.77	1.29	10.30	4.36	3.33	1.62	4.87	4.47	2.45	9.50	1.14	4.88	53.98
2003	0.00	4.23	1.56	1.30	4.37	6.02	0.40	4.29	4.53	0.58	4.88	1.33	33.49
2004	3.29	4.34	1.78	2.44	5.23	5.59	2.02	1.63	1.14	4.89	7.85	1.41	41.61
2005	7.87	2.44	2.54	2.34	2.26	0.92	3.17	0.58	1.09	1.27	0.16	0.12	24.76
2006	3.07	3.34	7.46	1.29	1.28	0.66	0.24	1.25	2.39	5.31	3.67	5.50	35.46
2007	4.08	0.71	2.51	3.95	7.57	11.79	8.56	1.22	2.00	7.05	1.48	3.38	54.30
2008	0.30	4.43	14.23	4.43	3.14	4.52	1.20	3.62	3.05	1.90	2.28	1.18	44.28
2009	2.74	1.20	5.79	7.51	8.21	1.23	5.14	3.28	2.47	15.00	3.19	3.21	58.97
2010	2.97	3.90	3.59	1.65	2.40	3.00	3.15	0.66	5.03	3.25	3.58	1.72	34.90
2011	1.29	2.49	0.32	5.85	6.75	1.19	0.89	1.17	0.87	1.78	2.28	6.56	31.44
2012	6.00	3.87	7.98	4.11	4.02	2.26	1.75	2.65	2.31	2.53	0.65	3.58	41.71
2013	2.92	2.80	1.85	2.12	5.73	4.34	4.27	0.74	4.35	4.62	3.49	2.89	40.12
2014	0.80	0.97	2.32	5.55	5.29	3.74	5.72	1.18	1.00	3.65	0.98	3.11	34.31
2015	4.39	3.87	5.99	6.02	11.54	4.25	0.99	1.68	1.56	6.90	15.17	7.83	70.19
2016	1.60	2.44	4.62	7.17	7.12	1.35	1.36	5.17	3.70	1.10	2.64	1.11	39.38
Average	2.67	3.14	3.97	4.30	5.59	4.49	3.08	2.35	3.69	4.29	3.73	3.40	44.69
Maximum	11.38	11.41	14.23	14.55	19.07	12.92	11.20	6.73	13.39	15.84	15.17	13.68	70.64
Minimum	0.00	0.06	0.32	0.13	1.28	0.22	0.00	0.00	0.00	0.04	0.00	0.12	20.23

MONTHLY RUNOFF FOR RESTORED CHANNEL DRAINAGE AREA BASED SCS RAINFALL-RUNOFF ANALYSIS (AC-FT)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1940	0.0	59.4	0.0	116.9	367.6	0.0	335.7	0.4	0.0	48.2	704.0	432.7	2,065.0
1941	0.0	0.0	0.0	288.7	98.1	810.4	581.2	0.0	0.0	834.9	0.0	0.0	2,613.2
1942	0.0	0.0	0.0	1,138.9	83.0	150.4	0.0	0.0	1,149.9	0.0	18.3	0.0	2,540.5
1943	0.0	0.0	45.8	16.2	0.0	71.9	0.0	0.0	24.2	0.0	0.0	0.0	158.1
1944	0.0	36.3	0.0	0.0	571.8	0.0	0.0	484.8	0.0	0.0	55.6	136.8	1,285.3
1945	4.0	430.8	387.3	3.6	5.0	963.9	63.7	0.0	1,015.9	610.0	0.0	0.0	3,484.2
1946	0.0	0.0	55.5	0.9	306.8	0.0	0.0	196.2	33.5	0.0	1,564.0	437.6	2,594.5
1947	0.0	0.0	0.0	43.0	0.0	91.6	0.0	146.4	0.0	0.0	0.0	177.5	458.5
1948	0.0	192.1	51.1	51.0	648.1	152.9	20.0	0.0	0.0	31.5	0.0	0.0	1,146.8
1949	1,245.0	114.1	0.9	287.3	0.0	480.7	9.6	611.6	0.0	154.7	0.0	0.0	2,903.8
1950	199.1	988.3	0.0	5.7	266.8	0.0	614.2	0.0	101.7	0.0	0.0	0.0	2,175.7
1951	1.9	0.0	0.0	4.6	12.0	1,301.4	0.0	0.0	0.9	45.2	51.1	0.0	1,417.1
1952	0.0	0.0	0.2	729.4	41.3	0.0	86.9	0.0	0.0	0.0	249.8	0.0	1,107.6
1953	0.0	0.0	0.0	172.9	0.6	0.0	74.9	17.4	5.5	28.7	0.5	91.7	392.2
1954	0.3	0.2	0.0	95.4	881.0	0.0	0.0	7.9	0.0	1,669.4	0.0	0.0	2,654.2
1955	0.0	0.0	62.1	10.0	9.6	0.0	543.1	14.7	122.0	82.3	0.0	0.0	843.8
1956	22.0	12.7	0.0	0.0	487.8	0.0	0.0	0.0	0.0	1.1	489.4	0.0	1,013.0
1957	0.0	0.0	35.6	1,758.4	1,612.2	1,123.7	0.0	0.0	182.0	87.4	1,161.3	2.8	5,963.4
1958	169.3	0.0	88.9	0.0	906.7	542.9	0.0	0.0	28.7	0.5	0.0	0.0	1,737.0
1959	0.0	0.0	5.7	0.0	12.7	442.4	984.5	0.0	11.7	32.5	0.0	467.4	1,956.9
1960	22.0	0.0	0.0	0.0	0.0	107.8	150.6	0.0	440.8	24.2	0.0	621.3	1,366.7
1961	14.1	0.0	98.0	0.0	0.0	0.0	8.2	0.0	55.8	0.0	156.3	12.7	345.1
1962	0.0	0.0	0.0	55.1	4.6	573.8	71.2	307.5	1,086.4	50.6	28.7	0.0	2,177.9
1963	0.0	0.0	0.0	68.2	0.0	0.0	16.7	0.0	0.0	0.0	1.4	0.0	86.2
1964	0.0	32.1	257.5	497.3	312.7	646.7	0.0	0.0	689.9	0.0	166.3	0.0	2,602.5
1965	0.0	430.9	0.0	0.0	452.2	0.1	0.0	0.0	227.6	0.0	630.7	0.0	1,741.4
1966	0.0	122.9	0.0	0.5	2,006.2	0.0	0.2	8.8	113.2	0.0	0.0	1.6	2,253.4
1967	0.0	0.0	58.8	307.7	487.8	0.0	73.2	2.0	796.5	353.0	0.0	6.7	2,085.7
1968	0.0	0.0	627.4	174.5	302.3	638.7	96.8	171.0	87.5	1.4	287.3	51.1	2,438.1
1969	464.2	77.4	0.0	0.0	2,069.4	96.8	0.0	0.0	100.8	12.7	0.0	428.3	3,249.6
1970	0.0	22.3	0.0	112.5	18.5	0.0	0.0	0.0	622.9	5.7	22.0	0.0	804.0
1971	0.0	0.0	0.0	0.0	19.9	0.0	216.9	9.8	398.8	974.5	8.2	1,562.1	3,190.1
1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.6	0.0	70.5	715.8	1.1	801.0
1973	1.4	7.4	12.7	12.7	0.0	279.8	77.4	0.0	1,612.4	13.8	7.7	0.0	2,025.3
1974	0.0	0.0	0.0	37.6	1.1	268.4	0.0	144.9	430.8	123.0	137.9	0.0	1,143.6
1975	0.0	574.9	0.0	2.8	186.9	804.0	0.0	0.0	0.0	0.0	0.9	0.0	1,569.4
1976	0.0	0.0	270.9	219.4	93.5	667.6	876.0	36.6	411.2	4.6	0.0	0.6	2,580.3
1977	0.0	0.0	540.3	19.4	0.0	96.8	0.0	0.0	0.0	0.0	0.0	0.0	656.6
1978	0.0	0.3	0.3	0.0	0.7	0.5	0.0	0.0	72.7	0.0	1,315.5	0.0	1,390.1
1979	202.3	13.1	37.1	16.3	24.9	32.8	0.0	0.0	0.0	0.9	0.0	41.8	369.1
1980	0.0	18.9	0.0	0.0	276.8	0.0	0.0	0.0	1,203.9	4.6	0.0	22.0	1,526.3
1981	0.0	0.0	90.3	140.5	117.3	556.3	0.0	0.0	0.0	1,406.9	0.0	0.0	2,311.3
1982	9.3	10.8	16.9	0.0	2,374.0	230.8	13.7	0.0	0.0	332.7	337.7	32.0	3,357.9
1983	0.0	629.1	25.9	0.0	0.0	61.7	339.7	0.0	0.0	8.2	0.1	0.0	1,064.7
1984	0.0	164.4	49.5	0.1	130.5	0.0	0.0	0.0	3.6	412.3	52.0	91.8	904.3
1985	0.0	0.5	125.1	222.3	454.0	44.0	0.0	0.0	0.1	614.2	98.3	0.0	1,558.5
1986	0.0	597.2	0.0	62.8	125.0	5.8	74.6	0.0	420.5	0.0	387.8	0.0	1,673.8
1987	0.0	0.0	27.3	0.0	270.3	0.0	0.0	0.0	885.6	7.7	481.3	202.1	1,874.4
1988	0.0	105.0	9.0	0.6	0.0	0.0	334.2	0.0	2.0	243.4	11.1	0.0	705.3
1989	0.0	332.7	276.8	0.0	779.1	590.1	363.4	0.0	0.0	1.0	0.0	0.0	2,343.1
1990	492.1	579.7	141.1	11.9	757.7	699.7	133.7	0.0	0.0	0.0	84.0	0.0	2,899.9
1991	9.9	93.2	0.0	337.6	0.0	7.2	20.8	454.8	0.0	1,466.7	6.4	350.7	2,747.5
1992	0.0	0.0	15.4	0.0	707.2	722.4	319.4	8.6	49.3	0.0	0.8	189.3	2,012.4
1993	0.0	24.8	170.8	14.0	0.4	338.8	0.0	0.0	0.0	1,254.8	0.0	103.9	1,907.5
1994	0.0	6.4	0.0	179.0	422.2	14.4	51.1	0.0	64.6	71.8	74.1	0.0	883.6
1995	7.8	0.0	0.4	133.6	404.1	151.7	0.4	0.0	267.8	0.0	0.0	0.0	965.8
1996	41.5	0.0	0.0	0.0	0.0	930.2	160.0	379.5	0.0	588.2	585.7	125.1	2,810.1
1997	0.0	447.0	202.1	777.6	0.0	30.6	0.0	253.1	0.0	436.3	0.0	719.2	2,865.9
1998	478.4	7.2	367.9	0.2	0.0	0.0	10.5	0.0	508.3	282.8	5.3	74.3	1,734.9
1999	302.3	0.0	0.0	0.0	2.3	0.0	0.0	0.0	45.1	0.0	41.3	513.1	904.2
2000	0.2	0.0	4.4	0.0	153.8	109.6	0.0	0.0	22.5	101.9	1,107.1	179.8	1,679.3
2001	0.0	1,010.1	67.0	40.7	24.6	0.0	0.0	218.6	139.8	201.2	0.0	322.6	2,024.7
2002	87.2	0.0	1,074.4	29.1	0.0	0.0	232.5	29.6	8.5	1,070.6	0.0	0.0	2,531.9
2003	0.0	3.3	0.0	0.0	87.4	206.4	0.0	0.1	355.6	0.0	110.9	0.0	763.6
2004	129.4	0.3	0.0	15.1	133.5	34.2	88.9	0.0	0.0	62.5	425.2	0.0	889.1
2005	890.5	0.0	106.0	0.9	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	997.5
2006	3.7	44.6	728.7	0.0	0.0	0.0	0.0	0.0	0.0	179.2	0.0	177.4	1,133.6
2007	126.7	0.0	2.8	397.2	408.8	646.9	1,236.3	0.0	4.2	208.0	0.0	0.3	3,031.2
2008	0.0	389.5	1,451.1	7.7	98.9	205.1	0.0	48.9	3.1	0.0	5.1	0.0	2,209.2
2009	0.0	0.0	570.1	558.5	701.2	0.0	250.1	21.8	11.7	1,669.6	98.5	0.0	3,881.6
2010	273.9	44.6	0.0	0.0	0.0	0.0	0.8	0.0	18.8	100.9	4.4	27.4	470.7
2011	0.0	0.0	0.0	305.5	49.3	0.0	0.0	0.0	0.0	0.0	0.0	461.4	816.3
2012	652.6	30.6	961.5	35.5	344.9	0.5	0.0	0.0	0.0	34.2	0.0	30.6	2,090.4
2013	0.0	0.0	0.0	0.0	212.6	46.1	253.8	0.0	137.4	11.6	22.3	77.4	761.2
2014	0.0	0.0	2.6	19.0	195.0	377.4	173.6	0.0	0.0	119.6	0.0	2.8	890.0
2015	0.0	110.8	7.8	21.8	934.4	236.5	0.0	0.0	0.0	785.2	1,609.8	622.8	4,329.2
2016	0.0	78.3	391.0	387.1	5.3	605.2	0.0	84.0	0.0	0.0	0.0	0.0	1,551.0
Average	76.0	101.9	123.7	129.2	291.7	223.3	116.3	47.7	181.5	220.0	173.0	114.3	1,798.6
Maximum	1,245.0	1,010.1	1,451.1	1,758.4	2,374.0	1,301.4	1,236.3	611.6	1,612.4	1,669.6	1,609.8	1,562.1	5,963.4
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	86.2

GEOMETRIC DATA FOR NORTH SULPHUR RIVER RESTORED CHANNEL

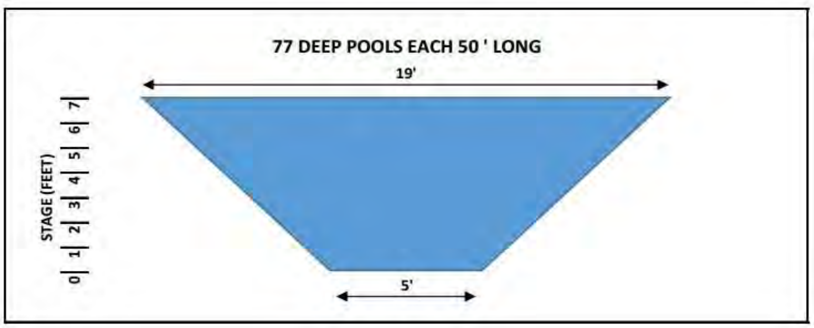
Note: Yellow-shaded cells are for data entry; green-shaded cells are calculated.

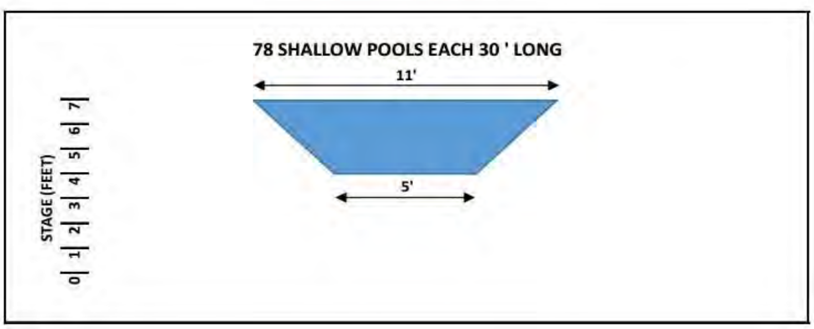
1	Total Length of Restored Channel:	17,100	feet		
2	Number of Deep Pools:	77			
3	Average Top Width of Deep Pools:	19.0	feet		
4	Average Maximum Depth of Deep Pools:	7.0	feet		
5	Average Bottom Width of Deep Pools:	5.0	feet	1.0	: 1.0 side slopes
6	Average Length of Deep Pools:	50	feet		
7	Total Length of Deep Pools:	3,850	feet		
8	Total Surface Area of Deep Pools:	1.68	acres		
9	Total Volume of Deep Pools:	7.4	acre-feet	(trapezoidal x-section)	
10	Number of Shallow Pools:	78			
11	Average Top Width of Shallow Pools:	11.0	feet		
12	Average Maximum Depth of Shallow Pools:	3.0	feet		
13	Average Bottom Width of Shallow Pools:	5.0	feet	1.0	: 1.0 side slopes
14	Average Length of Shallow Pools:	30	feet		
15	Total Length of Shallow Pools:	2,340	feet		
16	Total Surface Area of Shallow Pools:	0.59	acres		
17	Total Volume of Shallow Pools:	1.3	acre-feet	(trapezoidal x-section)	
18	Total Length of Riffle Reaches:	10,910	Feet		
19	Number of Riffle Reaches:	155			
20	Length of Single Riffle Reach:	70	feet		
21	Average Width of Riffle Reaches:	18.0	feet	(vertical side slopes)	
22	Average Depth of Riffle Reaches:	1.0	feet		
23	Total Surface Area of Riffle Reaches:	4.51	acres		
24	Total Volume of Riffle Reaches:	4.5	acre-feet	(rectangle x-section)	
25	Top Width of Shallow Pools at 6' Stage:	9.0	feet		
26	Total Surface Area of Shallow Pools at 6' Stage:	0.48	acres		
27	Total Volume of Shallow Pools at 6' Stage:	0.8	acre=feet		
28	Top Width of Deep Pools at 6' Stage:	17.0	feet		
29	Total Surface Area of Deep Pools at 6' Stage:	1.50	acres		
30	Total Volume of Deep Pools at 6' Stage:	5.8	acre=feet		
31	Top Width of Deep Pools at 4' Stage:	13.0	feet		
32	Total Surface Area of Deep Pools at 4' Stage:	1.1	acres		
33	Total Volume of Deep Pools at 4' Stage:	3.2	acre=feet		
34	Total Surface Area of Restored Channel:	6.78	acres		
35	Total Volume of Restored Channel:	13.2	acre-feet		

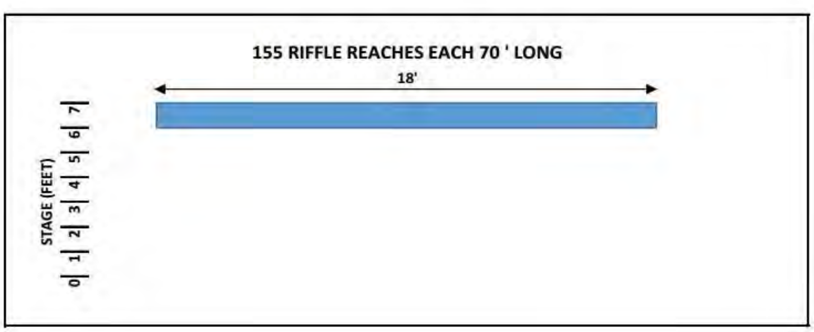
STAGE-STORAGE- AREA DATA
FOR NORTH SULPHUR RIVER RESTORED CHANNEL

(1)	(2)	(3)
Stage (feet)	Storage (ac-ft)	Area (ac)
0	0.00	0.00
1	0.80	0.29
2	1.59	0.57
3	2.39	0.86
4	3.18	1.15
5	4.88	1.57
6	6.59	1.99
7	13.22	6.78

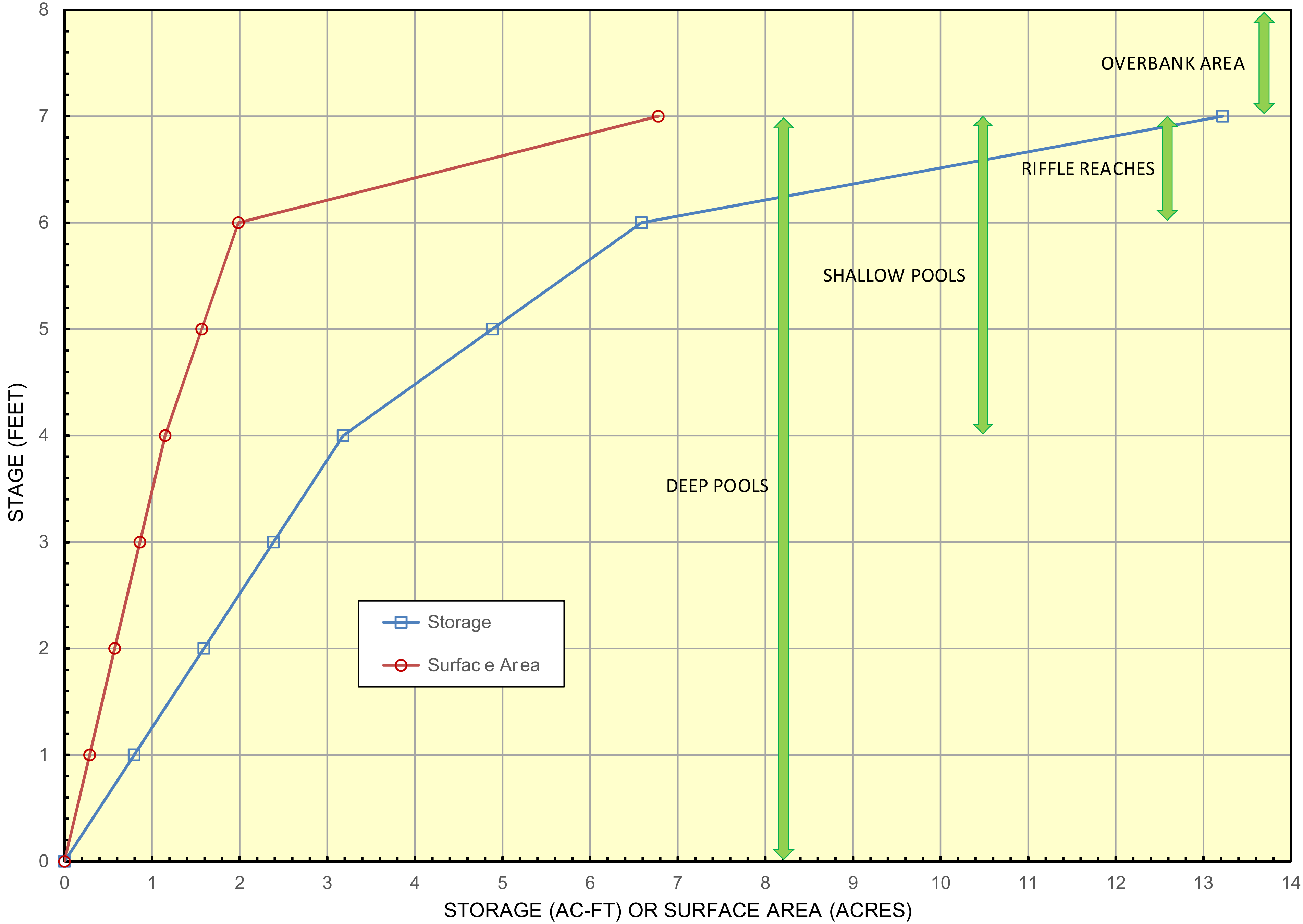
CROSS SECTIONS USED IN REPRESENTING GEOMETRY OF RESTORED CHANNEL







STORAGE AND SURFACE AREA VERSUS STAGE RELATIONSHIPS FOR
SIMPLIFIED APPROXIMATION OF GEOMETRY OF NORTH SULPHUR RIVER RESTORED CHANNEL



DAILY OPERATION OF LRH RESTORED CHANNEL - DAILY RUNOFF FROM SCS CURVE NUMBER METHOD USING 1940-2016 REGIONAL RAINFALL

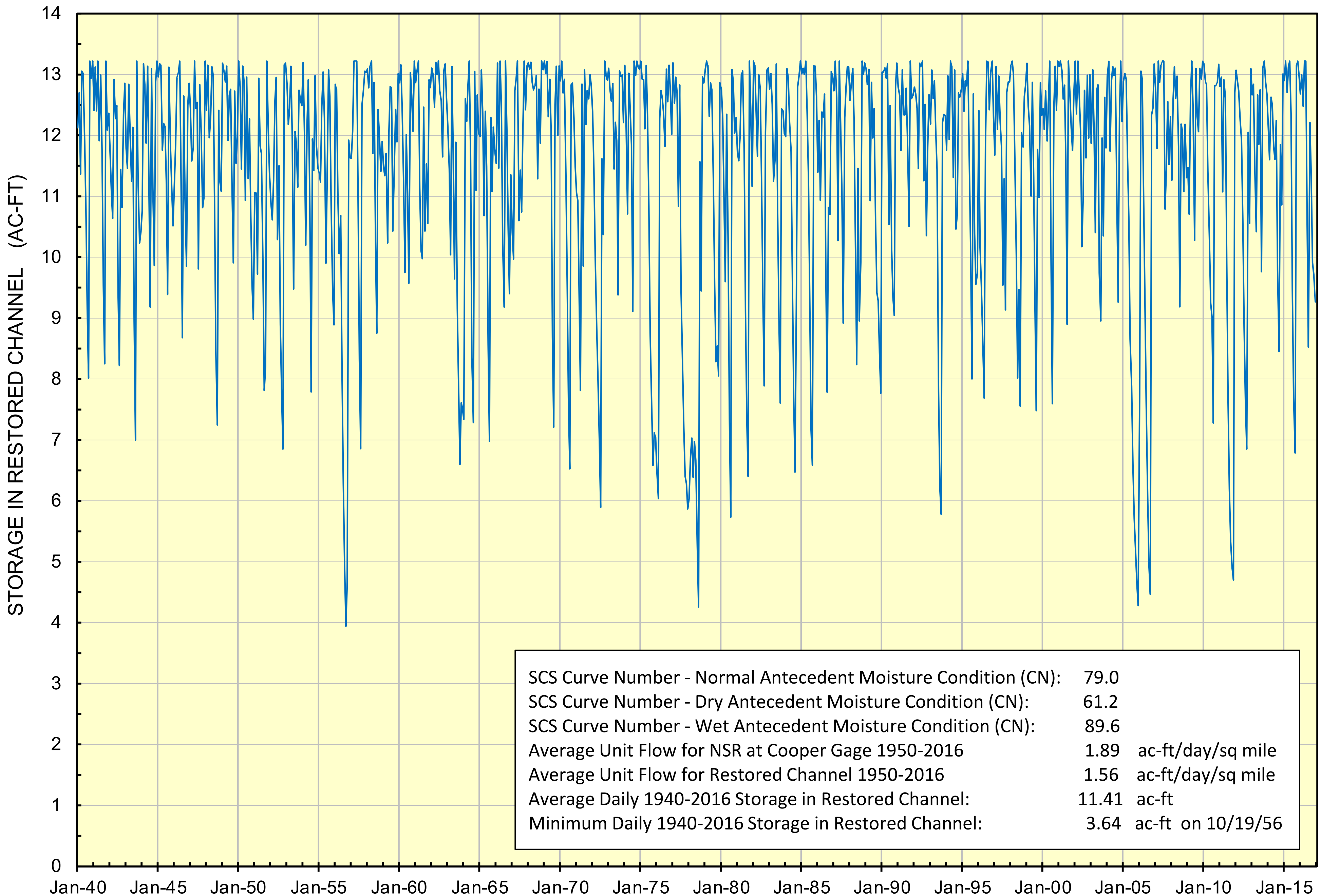
Drainage Area Contributing Runoff to Restored Channel:	1,996.8	acres
Minimum Operational Storage for Pumpage from Basin:	0	ac-ft
Maximum Operational Storage of Restored Channel:	13.22	ac-ft
SCS Curve Number - Normal Antecedent Moisture Condition (CN):	79.0	
SCS Curve Number - Dry Antecedent Moisture Condition (CN):	61.2	
SCS Curve Number - Wet Antecedent Moisture Condition (CN):	89.6	
Average Unit Flow for NSR at Cooper Gage 1950-2016	1.89	ac-ft/day/sq mile
Average Unit Flow for Restored Channel 1950-2016	1.56	ac-ft/day/sq mile
Average 1940-2016 Storage in Restored Channel:	11.41	ac-ft
Minimum 1940-2016 Storage in Restored Channel and Date:	3.64	ac-ft on 10/19/56

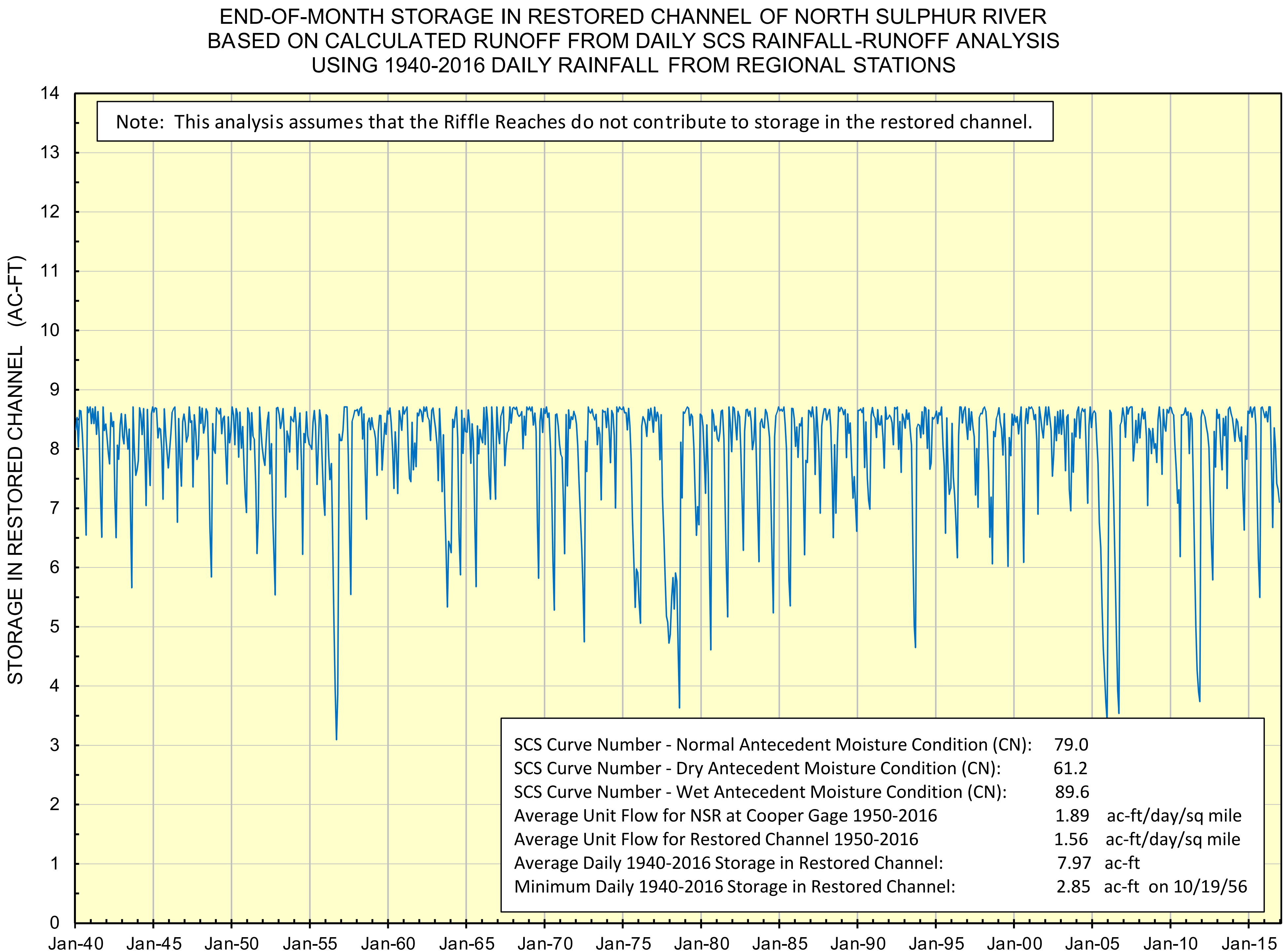
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
DAY	PRECIP (INCHES)	PRECIP FOR CALCS (INCHES)	RUNOFF DEPTH (INCHES)	RUNOFF VOLUME (AC-FT)	INITIAL STORAGE (AC-FT)	INITIAL SURFACE AREA (AC)	MONTHLY HISTORICAL EVAP (INCHES)	DAILY EVAP LOSS (AC-FT)	DAILY PRECIP INFLOW (AC-FT)	FINAL STORAGE (AC-FT)	FINAL SURFACE AREA (AC)	ANNUAL RUNOFF STORED (AC-FT)	CUMUL MONTHLY PRECIP (INCHES)	CUMUL MONTHLY RUNOFF (AC-FT)	MONTHLY RUNOFF STORED (AC-FT)	CUMUL MONTHLY EVAP LOSS (AC-FT)	MON-YEAR	MONTHLY PRECIP (INCHES)	MONTHLY RUNOFF (AC-FT)	MONTHLY RUNOFF STORED (AC-FT)	END-OF-MONTH STORAGE (AC-FT)	MONTHLY EVAP LOSS (AC-FT)
1/1/1940	0.00	0.00	0.00	0.0	13.2	6.78	1.99	0.04	0.00	13.2	6.75	0.0	0.00	0	0	0.0	Jan-40	0.00	0.0	0.0	12.1	1.1
1/2/1940	0.00	0.00	0.00	0.0	13.2	6.75	1.99	0.04	0.00	13.1	6.72	0.0	0.00	0	0	0.1	Feb-40	3.45	59.4	1.6	12.7	1.2
1/3/1940	0.00	0.00	0.00	0.0	13.1	6.72	1.99	0.04	0.00	13.1	6.70	0.0	0.00	0	0	0.1	Mar-40	1.11	0.0	0.3	11.4	1.8
1/4/1940	0.00	0.00	0.00	0.0	13.1	6.70	1.99	0.04	0.00	13.1	6.67	0.0	0.00	0	0	0.1	Apr-40	6.77	116.9	3.6	13.1	2.3
1/5/1940	0.00	0.00	0.00	0.0	13.1	6.67	1.99	0.04	0.00	13.0	6.64	0.0	0.00	0	0	0.2	May-40	8.03	367.6	1.8	13.0	2.6
1/6/1940	0.00	0.00	0.00	0.0	13.0	6.64	1.99	0.04	0.00	13.0	6.62	0.0	0.00	0	0	0.2	Jun-40	4.01	0.0	1.3	11.9	3.1
1/7/1940	0.00	0.00	0.00	0.0	13.0	6.62	1.99	0.04	0.00	13.0	6.59	0.0	0.00	0	0	0.3	Jul-40	4.74	335.7	1.7	10.8	3.6
1/8/1940	0.00	0.00	0.00	0.0	13.0	6.59	1.99	0.04	0.00	12.9	6.57	0.0	0.00	0	0	0.3	Aug-40	1.55	0.4	0.7	9.2	2.5
1/9/1940	0.00	0.00	0.00	0.0	12.9	6.57	1.99	0.04	0.00	12.9	6.54	0.0	0.00	0	0	0.3	Sep-40	1.32	0.0	0.3	8.0	1.5
1/10/1940	0.00	0.00	0.00	0.0	12.9	6.54	1.99	0.04	0.00	12.9	6.51	0.0	0.00	0	0	0.4	Oct-40	3.25	48.2	6.2	13.2	1.1
1/11/1940	0.00	0.00	0.00	0.0	12.9	6.51	1.99	0.04	0.00	12.8	6.49	0.0	0.00	0	0	0.4	Nov-40	6.82	704.0	1.0	12.9	1.7
1/12/1940	0.00	0.00	0.00	0.0	12.8	6.49	1.99	0.04	0.00	12.8	6.46	0.0	0.00	0	0	0.4	Dec-40	6.70	432.7	1.1	13.2	1.3
1/13/1940	0.00	0.00	0.00	0.0	12.8	6.46	1.99	0.04	0.00	12.7	6.44	0.0	0.00	0	0	0.5	Jan-41	0.60	0.0	0.1	12.4	1.1
1/14/1940	0.00	0.00	0.00	0.0	12.7	6.44	1.99	0.04	0.00	12.7	6.41	0.0	0.00	0	0	0.5	Feb-41	3.57	0.0	1.4	13.1	1.2
1/15/1940	0.00	0.00	0.00	0.0	12.7	6.41	1.99	0.04	0.00	12.7	6.38	0.0	0.00	0	0	0.5	Mar-41	2.55	0.0	0.8	12.4	2.1
1/16/1940	0.00	0.00	0.00	0.0	12.7	6.38	1.99	0.04	0.00	12.6	6.36	0.0	0.00	0	0	0.6	Apr-41	7.44	288.7	2.1	13.2	2.2
1/17/1940	0.00	0.00	0.00	0.0	12.6	6.36	1.99	0.04	0.00	12.6	6.33	0.0	0.00	0	0	0.6	May-41	3.96	98.1	0.5	11.9	2.5
1/18/1940	0.00	0.00	0.00	0.0	12.6	6.33	1.99	0.03	0.00	12.6	6.31	0.0	0.00	0	0	0.7	Jun-41	12.27	810.4	3.4	13.0	3.3
1/19/1940	0.00	0.00	0.00	0.0	12.6	6.31	1.99	0.03	0.00	12.5	6.28	0.0	0.00	0	0	0.7	Jul-41	6.14	581.2	2.1	11.7	3.8
1/20/1940	0.00	0.00	0.00	0.0	12.5	6.28	1.99	0.03	0.00	12.5	6.26	0.0	0.00	0	0	0.7	Aug-41	1.68	0.0	0.3	9.5	2.9
1/21/1940	0.00	0.00	0.00	0.0	12.5	6.26	1.99	0.03	0.00	12.5	6.23	0.0	0.00	0	0	0.8	Sep-41	1.05	0.0	0.1	8.2	1.6
1/22/1940	0.00	0.00	0.00	0.0	12.5	6.23	1.99	0.03	0.00	12.4	6.21	0.0	0.00	0	0	0.8	Oct-41	8.06	834.9	6.6	13.2	2.2
1/23/1940	0.00	0.00	0.00	0.0	12.4	6.21	1.99	0.03	0.00	12.4	6.18	0.0	0.00	0	0	0.8	Nov-41	0.92	0.0	0.3	12.1	1.6
1/24/1940	0.00	0.00	0.00	0.0	12.4	6.18	1.99	0.03	0.00	12.4	6.16	0.0	0.00	0	0	0.9	Dec-41	2.90	0.0	1.2	12.4	1.2
1/25/1940	0.00	0.00	0.00	0.0	12.4	6.16	1.99	0.03	0.00	12.3	6.13	0.0	0.00	0	0	0.9	Jan-42	0.80	0.0	0.3	11.7	1.0
1/26/1940	0.00	0.00	0.00	0.0	12.3	6.13	1.99	0.03	0.00	12.3	6.11	0.0	0.00	0	0	0.9	Feb-42	0.80	0.0	0.2	11.1	1.0
1/27/1940	0.00	0.00	0.00	0.0	12.3	6.11	1.99	0.03	0.00	12.3	6.09	0.0	0.00	0	0	1.0	Mar-42	2.78	0.0	0.9	10.6	1.7
1/28/1940	0.00	0.00	0.00	0.0	12.3	6.09	1.99	0.03	0.00	12.2	6.06	0.0	0.00	0	0	1.0	Apr-42	12.40	1,138.9	3.8	12.9	2.3
1/29/1940	0.00	0.00	0.00	0.0	12.2	6.06	1.99	0.03	0.00	12.2	6.04	0.0	0.00	0	0	1.0	May-42	4.62	83.0	1.5	12.3	2.6
1/30/1940	0.00	0.00	0.00	0.0	12.2	6.04	1.99	0.03	0.00	12.2	6.01	0.0	0.00	0	0	1.1	Jun-42	5.89	150.4	2.7	12.5	3.2
1/31/1940	0.00	0.00	0.00	0.0	12.2	6.01	1.99	0.03	0.00	12.1	5.99	0.0	0.00	0	0	1.1	Jul-42	0.00	0.0	0.0	9.4	3.1
2/1/1940	0.00	0.00	0.00	0.0	12.1	5.99	2.36	0.04	0.00	12.1	5.96	0.0	0.00	0	0	0.0	Aug-42	3.20	0.0	0.6	8.2	2.1
2/2/1940	1.05	1.05	0.00	0.0	12.1	5.96	2.36	0.04	0.52	12.6	6.31	0.5	1.05	0	0	0.1	Sep-42	8.38	1,149.9	5.1	11.4	2.4
2/3/1940	0.70	0.70	0.00	0.0	12.6	6.31	2.36	0.04	0.37	12.9	6.54	0.8	1.75	0	1	0.1	Oct-42	2.98	0.0	0.9	10.8	1.9
2/4/1940	0.00	0.00	0.00	0.0	12.9	6.54	2.36	0.04	0.00	12.9	6.51	0.8	1.75	0	1	0.2	Nov-42	2.98	18.3	2.8	12.3	1.6
2/5/1940	0.00	0.00	0.00	0.0	12.9	6.51	2.36	0.04	0.00	12.8	6.48	0.8	1.75	0	1	0.2	Dec-42	3.33	0.0	1.4	12.9	1.2
2/6/1940	0.00	0.00	0.00	0.0	12.8	6.48	2.36	0.04	0.00	12.8	6.45	0.8	1.75	0	1	0.2	Jan-43	0.21	0.0	0.1	11.8	1.2
2/7/1940	0.00	0.00	0.00	0.0	12.8	6.45	2.36	0.04	0.00	12.7	6.42	0.8	1.75	0	1	0.3	Feb-43	1.81	0.0	0.8	11.5	1.2
2/8/1940	0.00	0.00	0.00	0.0	12.7	6.42	2.36	0.04	0.00	12.7	6.39	0.8	1.75	0	1	0.3	Mar-43	4.78	45.8	3.1	12.8	2.2

MONTHLY LAKE EVAPORATION LOSS FROM NSR RESTORED CHANNEL (AC-FT)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1940	1.1	1.2	1.8	2.3	2.6	3.1	3.6	2.5	1.5	1.1	1.7	1.3	23.8
1941	1.1	1.2	2.1	2.2	2.5	3.3	3.8	2.9	1.6	2.2	1.6	1.2	25.7
1942	1.0	1.0	1.7	2.3	2.6	3.2	3.1	2.1	2.4	1.9	1.6	1.2	23.9
1943	1.2	1.2	2.2	2.6	2.4	3.4	3.2	2.0	1.0	2.5	1.5	1.0	24.1
1944	0.9	1.0	2.1	2.2	2.5	3.1	2.9	2.3	2.6	1.8	1.5	1.3	24.2
1945	1.1	1.2	2.1	2.3	2.4	3.1	3.6	2.8	1.7	2.3	1.4	1.0	25.2
1946	0.9	1.0	1.9	2.2	2.6	3.0	2.7	2.1	2.6	1.7	1.6	1.2	23.5
1947	1.1	1.1	1.8	2.0	2.6	3.0	3.2	3.2	2.8	2.0	1.3	1.2	25.5
1948	1.2	1.3	2.1	2.4	2.7	3.2	3.9	2.6	1.4	1.7	1.6	1.1	25.2
1949	1.0	1.2	2.0	2.3	2.4	3.1	3.5	3.6	2.1	1.7	1.5	1.1	25.7
1950	1.1	1.2	1.9	1.9	2.6	3.0	3.8	3.3	2.6	2.0	1.1	0.7	25.3
1951	0.8	1.0	1.5	1.6	2.6	3.3	3.2	2.2	1.4	1.3	1.7	1.1	21.7
1952	1.0	1.0	1.7	2.3	2.5	3.0	3.2	2.8	1.5	1.0	1.4	1.3	22.7
1953	1.2	1.2	2.0	2.4	2.6	2.5	3.3	3.5	2.7	1.9	1.7	1.3	26.3
1954	0.7	2.0	2.2	2.6	2.3	3.6	3.1	2.9	3.1	2.3	1.6	1.2	27.7
1955	0.8	0.8	2.0	2.6	2.8	3.1	3.4	3.6	3.2	3.1	1.6	0.8	27.9
1956	0.8	1.2	2.3	2.1	2.9	2.6	1.9	1.6	1.0	0.6	1.5	1.2	19.8
1957	0.9	0.8	1.5	1.5	1.9	2.9	2.8	1.6	1.4	1.9	1.0	1.2	19.3
1958	0.8	0.9	1.4	1.9	2.1	3.1	3.7	2.3	1.6	1.7	1.4	0.7	21.6
1959	0.6	0.9	2.5	2.0	2.3	2.8	3.1	3.0	2.8	2.2	1.2	1.1	24.6
1960	0.8	1.1	1.6	2.2	2.3	3.6	3.5	2.5	1.6	2.0	1.4	0.8	23.4
1961	0.8	0.9	2.2	2.5	2.1	1.9	2.4	3.0	2.6	1.9	1.1	1.0	22.5
1962	0.9	1.3	1.9	2.1	3.0	2.9	3.6	3.7	2.4	2.3	1.3	0.9	26.3
1963	0.9	1.0	2.1	1.7	2.5	2.7	3.0	3.1	1.6	1.3	0.7	0.4	20.9
1964	0.5	1.1	2.1	2.2	2.6	3.5	3.4	1.8	1.6	2.2	1.3	1.2	23.5
1965	1.1	1.0	1.6	2.4	2.1	2.6	3.1	1.9	1.8	2.0	1.3	1.0	21.8
1966	0.7	0.7	2.3	2.1	2.4	2.8	2.7	1.8	2.2	2.1	1.3	0.6	21.8
1967	1.1	1.0	2.7	2.1	2.6	3.2	3.3	3.3	2.0	2.7	1.4	1.1	26.5
1968	0.7	1.0	1.9	2.2	2.3	2.9	3.3	3.8	2.7	2.4	1.4	1.5	26.1
1969	1.2	1.1	1.8	2.3	2.3	3.7	3.4	1.8	1.8	2.3	1.5	1.1	24.3
1970	0.6	1.3	1.6	2.0	2.6	2.3	2.1	1.5	2.7	2.1	1.7	1.3	21.9
1971	1.0	1.1	2.0	1.6	1.4	3.3	2.8	2.8	2.4	2.0	1.7	1.0	23.2
1972	0.9	1.3	1.8	1.8	1.5	1.5	1.3	2.6	2.4	1.9	1.3	0.9	19.4
1973	0.7	1.0	2.2	1.7	2.8	2.7	3.3	2.9	2.1	1.9	1.6	1.4	24.5
1974	0.7	1.6	2.1	2.4	2.8	3.5	3.3	1.8	1.8	2.0	1.4	0.8	24.2
1975	1.1	1.2	1.9	2.3	2.1	3.1	3.1	2.4	1.3	1.0	0.7	0.4	20.4
1976	0.6	0.6	1.7	2.2	2.3	2.9	3.4	2.9	2.6	2.0	1.3	1.5	24.0
1977	0.8	1.5	2.6	2.5	2.5	2.7	3.6	2.1	1.4	0.9	0.5	0.6	21.6
1978	0.2	0.2	0.6	0.9	0.8	1.3	1.5	1.0	2.0	2.1	1.2	1.4	13.4
1979	1.3	0.8	2.1	2.2	2.6	3.3	3.2	2.5	1.6	1.3	0.8	0.9	22.7
1980	1.2	1.4	1.9	2.0	2.1	3.2	3.0	1.6	1.1	2.6	1.5	1.2	23.0
1981	1.2	1.1	2.2	2.3	2.7	3.3	3.1	1.9	1.1	2.1	1.7	1.4	24.1
1982	1.1	0.9	2.0	2.1	2.3	3.0	3.5	2.7	1.7	1.8	1.4	1.0	23.4
1983	1.0	1.0	2.1	2.0	2.1	2.9	3.5	2.4	1.7	1.9	1.8	0.9	23.1
1984	0.7	1.6	2.2	2.6	2.8	2.8	2.1	1.5	1.5	1.7	2.2	1.1	22.7
1985	0.9	0.7	1.9	2.2	2.7	3.4	3.0	2.2	1.2	1.3	1.7	0.9	22.0
1986	1.3	1.4	2.3	2.2	2.5	3.1	3.8	2.4	2.8	1.3	1.0	0.8	24.8
1987	1.2	1.2	1.7	2.4	2.3	2.9	3.2	2.9	2.0	2.3	1.4	0.8	24.1
1988	1.1	1.1	1.8	2.6	2.6	2.4	2.8	2.7	1.9	1.5	1.6	1.1	23.3
1989	1.1	1.1	2.0	2.4	2.5	2.7	3.0	3.0	2.0	1.5	1.1	0.8	23.2
1990	1.0	1.3	1.7	2.1	2.3	3.2	2.8	3.1	1.8	1.3	1.4	0.9	22.9
1991	1.2	1.2	2.2	1.9	2.6	3.5	3.6	3.6	2.4	2.1	1.9	2.4	28.6
1992	1.6	1.3	2.3	2.1	2.2	2.7	3.7	3.0	2.3	2.3	1.4	1.4	26.2
1993	1.5	1.3	1.9	2.4	2.4	2.9	3.6	1.7	1.0	1.7	1.5	1.6	23.5
1994	1.4	1.0	2.0	2.1	2.3	3.4	4.2	3.5	3.0	2.2	1.9	1.2	28.2
1995	1.6	1.3	1.9	2.3	2.4	3.0	2.9	2.3	1.8	2.6	1.4	0.8	24.3
1996	1.4	2.3	1.6	1.8	1.5	3.3	2.6	2.9	2.1	2.6	2.3	1.6	25.9
1997	1.2	1.1	2.4	2.4	2.4	2.8	2.9	3.1	2.4	2.2	1.3	1.8	25.9
1998	1.0	1.0	1.9	2.6	2.3	2.5	4.0	2.1	2.2	2.3	1.7	0.9	24.5
1999	1.1	1.2	2.0	2.1	2.6	2.7	2.9	2.1	2.4	2.2	1.3	2.0	24.7
2000	1.2	1.3	1.5	2.6	3.2	4.5	3.3	2.4	1.8	2.3	4.0	0.8	29.0
2001	1.3	1.0	1.6	1.9	2.3	2.7	2.8	1.7	2.0	2.0	1.3	1.1	21.6
2002	1.3	1.3	1.8	2.2	2.3	2.6	3.0	2.7	2.6	1.8	1.4	1.4	24.4
2003	1.1	1.2	1.8	2.3	1.8	2.8	3.2	2.2	2.3	1.9	2.0	1.5	24.1
2004	1.1	1.2	2.3	1.8	2.5	2.5	3.0	2.9	2.1	2.0	1.2	1.5	24.1
2005	1.2	1.1	2.1	2.3	2.0	2.3	1.7	1.4	1.0	0.7	0.6	0.4	16.9
2006	0.5	0.7	2.5	2.4	2.2	1.9	1.6	1.3	0.8	1.6	1.7	1.4	18.8
2007	1.6	1.3	1.8	2.0	2.2	2.8	2.8	3.0	2.3	2.0	1.7	1.1	24.5
2008	1.2	1.4	2.2	2.3	2.2	3.2	3.2	2.4	2.1	1.9	1.9	1.4	25.5
2009	1.1	1.3	2.1	2.4	2.0	2.7	2.4	3.3	2.0	1.9	1.6	1.0	23.7
2010	1.2	1.3	2.0	2.2	2.1	2.2	1.9	1.9	2.1	2.0	1.5	1.5	21.7
2011	1.0	1.2	2.0	2.4	2.8	3.2	2.5	1.7	1.0	0.7	0.5	1.4	20.3
2012	1.1	1.2	1.9	2.1	2.7	2.9	2.4	1.9	1.2	2.2	1.8	1.1	22.5
2013	1.3	1.3	2.2	2.0	2.1	3.4	3.2	3.3	2.4	1.8	1.6	1.4	26.0
2014	0.9	1.0	1.5	2.7	2.8	2.8	3.0	3.0	1.7	2.0	1.4	0.9	23.8
2015	1.2	1.3	1.8	2.6	2.5	3.7	3.4	2.2	1.2	1.3	1.7	2.4	25.4
2016	1.2	1.2	2.1	2.4	2.6	3.1	2.6	2.6	2.6	1.8	1.1	0.8	24.2
1940-2016													
Average	1.0	1.1	2.0	2.2	2.4	2.9	3.0	2.5	2.0	1.9	1.5	1.1	23.6
Maximum	1.6	2.3	2.7	2.7	3.2	4.5	4.2	3.8	3.2	3.1	4.0	2.4	29.0
Minimum	0.2	0.2	0.6	0.9	0.8	1.3	1.3	1.0	0.8	0.6	0.5	0.4	13.4

END-OF-MONTH STORAGE IN RESTORED CHANNEL OF NORTH SULPHUR RIVER
BASED ON CALCULATED RUNOFF FROM DAILY SCS RAINFALL-RUNOFF ANALYSIS
USING 1940-2016 DAILY RAINFALL FROM REGIONAL STATIONS




END-OF-MONTH STORAGE IN RESTORED CHANNEL OF NORTH SULPHUR RIVER
BASED ON CALCULATED RUNOFF FROM DAILY SCS RAINFALL-RUNOFF ANALYSIS
USING 1940-2016 DAILY RAINFALL FROM REGIONAL STATIONS
Note: This analysis assumes that the Riffle Reaches do not contribute to storage in the restored channel.
STORAGE IN RESTORED CHANNEL (AC-FT)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Jan-40
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Jan-10
Jan-15
SCS Curve Number - Normal Antecedent Moisture Condition (CN): 79.0
SCS Curve Number - Dry Antecedent Moisture Condition (CN): 61.2
SCS Curve Number - Wet Antecedent Moisture Condition (CN): 89.6
Average Unit Flow for NSR at Cooper Gage 1950-2016 1.89 ac-ft/day/sq mile
Average Unit Flow for Restored Channel 1950-2016 1.56 ac-ft/day/sq mile
Average Daily 1940-2016 Storage in Restored Channel: 7.97 ac-ft
Minimum Daily 1940-2016 Storage in Restored Channel: 2.85 ac-ft on 10/19/56

Analysis of Stream Mitigation Design Criteria for Lake Ralph Hall Mitigation Area

Date: July 12, 2019 (updated from October 2018 version)

Prepared For: Upper Trinity Regional Water District

Prepared By: Ecosystem Planning and Restoration, LLC

1. INTRODUCTION

This memorandum has been prepared to document the design criteria that were used in the development of stream mitigation design plans for the Lake Ralph Hall Mitigation Site in Fannin County, Texas. The document presents an analysis of design channel analog data from the site, including observations regarding stable channel conditions and geomorphological parameters that describe stream pattern, dimension, and profile. The data are used to develop design criteria for sizing the design channels and determining their alignments, and to provide appropriate bedform diversity and aquatic habitats. The hydraulic geometry methods presented here were used to establish design parameters for stream reaches to be restored. This memorandum also describes hydraulic and sediment transport analyses that were conducted as part of the design work to provide increased confidence that the designs will be stable.

NOTE: *This memorandum does not address the restoration design development for the Main Channel North Sulfur River restoration. This design work has been developed by Freese and Nichols, Inc. (FNI) and is described in detail in their Stream Restoration Basis of Design Report for the Main Channel North Sulfur River dated June 2019*.

2. METHODS

Design Channel Analog Surveys

During the month of May 2018, staff from Alan Plummer and Associates, Inc (APAI) and Ecosystem Planning and Restoration, LLC (EPR) assessed the conditions of streams within the boundary of proposed mitigation work for the project. One goal of these assessments was to identify stable or quasi-stable stream segments that could be assessed in greater detail as potential design channel analogs. To be considered as a design channel analog, a segment of stream was required to meet the following criteria:

- *Stable stream bed and banks*. The majority of the identified reach must exhibit stable stream bed and bank conditions that show no indications of active erosion and instability.
- *Presence of mobile bed material*. Reaches must have predominantly mobile bed materials (e.g. sand, gravel), and not be predominantly bedrock. Because of the geology of the region, bedrock outcrops were not identified on any reaches.
- *Channel well connected to its adjacent floodplain*. Flows greater than the bankfull stage must regularly access the adjacent floodplain. This condition was assumed to be met if bankfull stage was identified at or near the top of the stream bank.

- *Natural stream pattern*. The reach should exhibit a natural stream pattern, with no obvious past modifications, such as dredging or channelization.
- *Must have a wooded canopy*. Vegetation affects stream morphology; therefore, only reaches that had a wooded canopy (an end goal of the proposed mitigation work) were considered.
- *At least 20 bankfull widths in length*. Identified reaches must be at least 20 bankfull widths in length to qualify as design analogs, with longer reaches preferable.

At the conclusion of the field assessments, four stable stream segments were identified as design channel analogs within the project area and were surveyed in more detail to evaluate geomorphological parameters. Drainage areas for the four reaches ranged from 0.0032 to 0.84 square miles, which spans the range of many of the channels proposed for mitigation on the site. Field indicators of bankfull stage (generally the top of bank for the surveyed reaches) were identified and flagged. For each reach, a detailed field survey was conducted that included a longitudinal profile, three to four cross section surveys (generally two riffles and one pool), and photographs along the reach.

An additional stable reach (T2-BAKER-(1)) was identified that exhibited a stable cross-section and bedform but exhibited a straight channel pattern that may have been manipulated in the past. This fifth reach was surveyed only for bankfull dimension (i.e. cross sectional) data. Design channel analog locations are shown in Figure 1.

Historic Plan Form Assessment

Aerial photographs and photogrammetry survey data of the area were reviewed to identify stream segments that appeared to exhibit historic meander geometry. Data were reviewed in GIS and identified stream segments were digitized and measured to determine plan form geometry measurements and channel sinuosities. This analysis was used exclusively to evaluate historic meander geometry for streams that flowed through and across the historic North Sulphur River floodplain. Three stream segments were identified and measured:

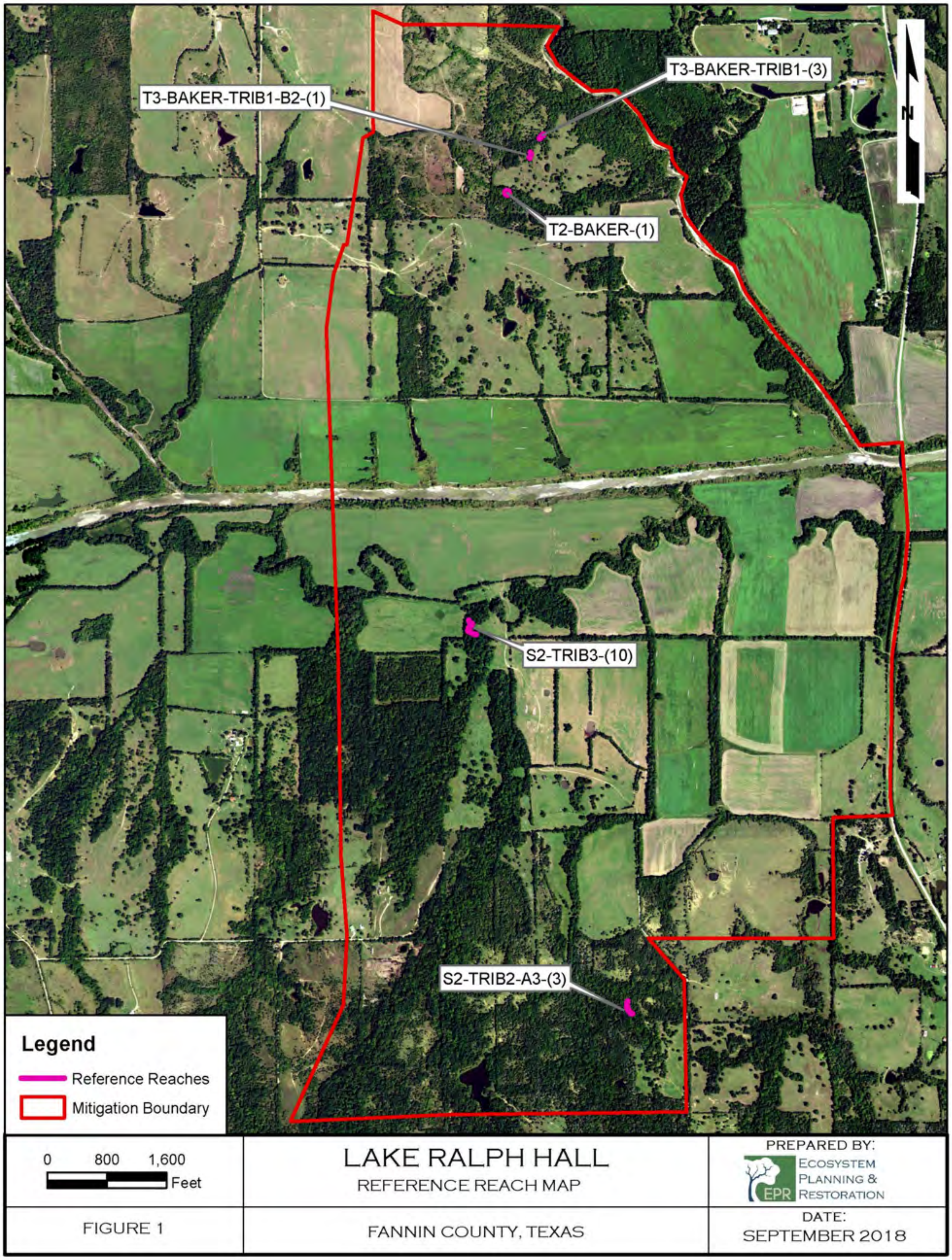
1) S2-TRIB3-(10) – the assessed reach of this tributary included the surveyed design channel analog but extended upstream and downstream to a length of approximately 868 feet (approximately 56 times the bankfull width).
2) Two remnant channel segments of the historic pattern of North Sulphur River - Segment 1 (approximately 3,609 feet in length) is located in Mitigation Zone A near the downstream end of S2-TRIB3-(10). Segment 2 is located approximately 2.3 miles west of Mitigation Zone A and includes a remnant piece of the historic North Sulphur River that is approximately 2,490 feet in length.

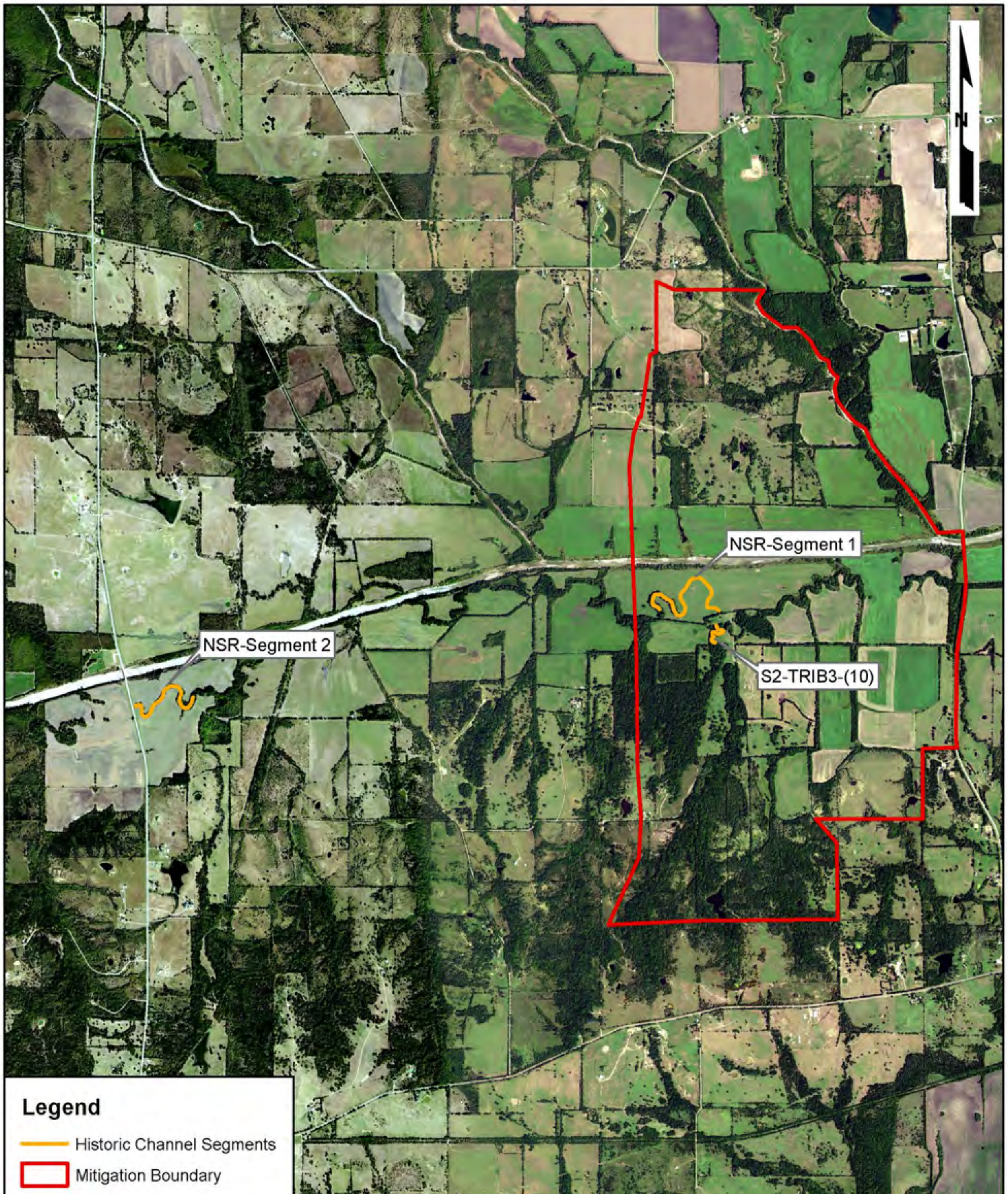
The locations of the three historic channel segments are shown in Figure 2.

3. ANALYSES

Regional Curve Analysis

Collected survey data were processed in spreadsheets developed by the Ohio Department of Natural Resources (Mecklenburg spreadsheets) and RiverMorph software. This section will discuss the evaluation of bankfull dimension parameters for the purpose of developing regional hydraulic geometry relationships for the project area that were used to guide design channel sizing.


T3-BAKER-TRIB1-(3)
T3-BAKER-TRIB1-B2-(1)
T2-BAKER-(1)
S2-TRIB3-(10)
S2-TRIB2-A3-(3)
Legend
Reference Reaches
Mitigation Boundary
0 800 1,600
Feet
LAKE RALPH HALL
REFERENCE REACH MAP
PREPARED BY:
ECOSYSTEM PLANNING & RESTORATION
FIGURE 1
FANNIN COUNTY, TEXAS
DATE:
SEPTEMBER 2018



0 2,000 4,000 Feet	LAKE RALPH HALL HISTORIC STREAM PATTERN REACHES MAP	PREPARED BY: ECOSYSTEM PLANNING & RESTORATION
FIGURE 2	FANNIN COUNTY, TEXAS	DATE: SEPTEMBER 2018

For the five identified stable reaches that exhibited strong bankfull indicators and access to an active floodplain, the collected geomorphological data were processed to calculate bankfull area, width, and mean depth for each reach. Drainage areas for each reach were evaluated using available photogrammetry topography data available for the mitigation area and spatial analyst GIS tools. The bankfull parameters calculated were then plotted against drainage area to develop bankfull regional curve relationships for the project area.

As a means of checking the data against other published data for the region, the field data were plotted against other regional curve relationships developed and published by Bieger et al. (2015) for the surrounding physiographic regions. Bieger et al. used published regional curves from numerous sources to develop relationships for major physiographic regions of the U.S. The Lake Ralph Hall project site falls within the Atlantic Plain (APL) region, but is located in close proximity to the boundary between the APL and the Interior Plains (IPL), as described by Bieger et al. Therefore, the regression relationships for both the APL and IPL were plotted against the data collected by the project team on the mitigation site to visually compare how the field data matched with the published data from Bieger et al. for surrounding regions. Results are provided in Figures 3 through 5.

In Figure 3, the riffle bankfull area data collected for the Lake Ralph Hall site all plot relatively close to the best-fit regression line through the data (red dashed line) with a scatter pattern that is not unusual for regional curve data. The data also fall within the regression lines for both the APL and IPL, as provided by Bieger et al., though the slope of the regression line through the collected data more closely matches the slope of the relationship for the IPL. This result is reasonable since the Lake Ralph Hall site lies near the boundary of the APL and IPL physiographic regions.

Figure 3. Bankfull Riffle Cross-Sectional Area Relationships for Lake Ralph Hall Design Channel Analogs.

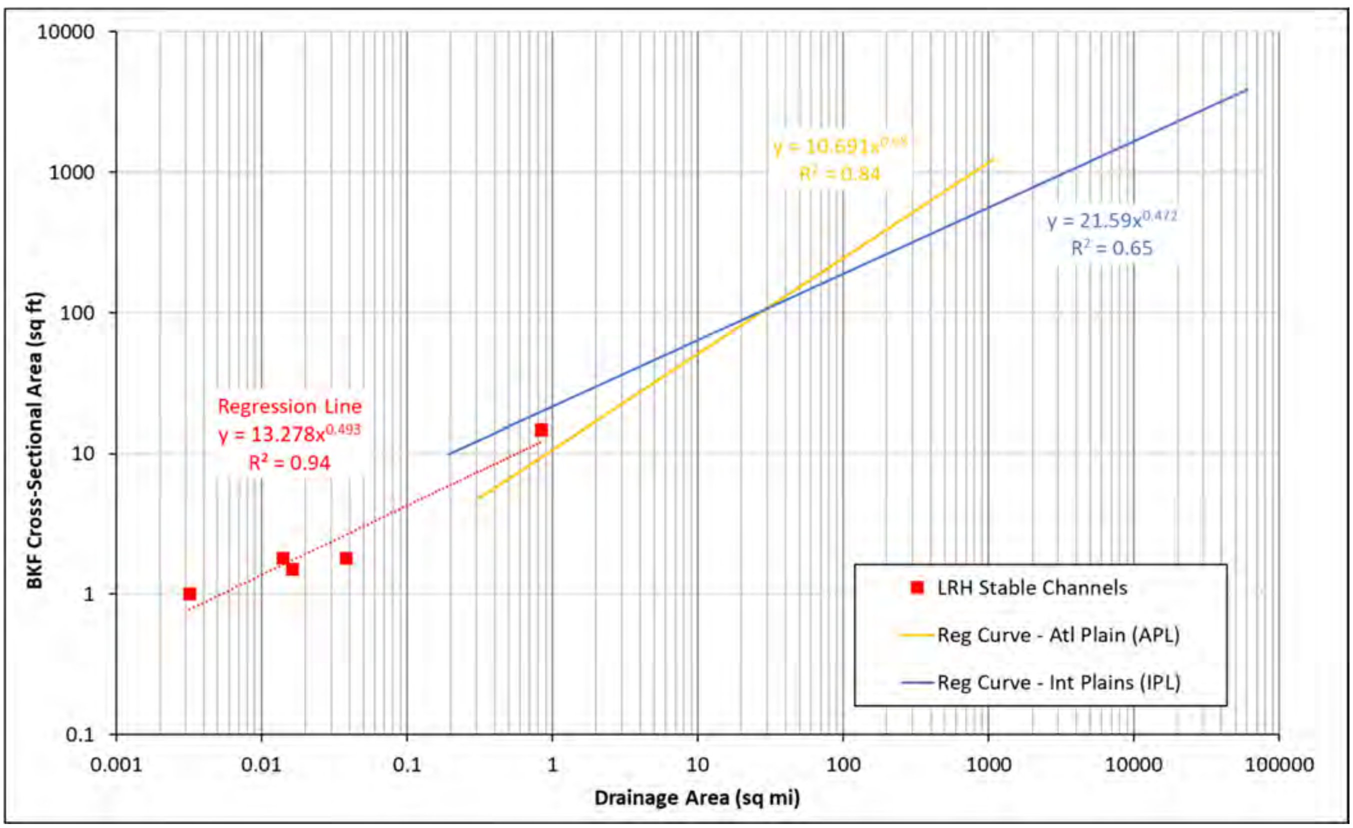


Figure 4. Bankfull Riffle Width Relationships for Lake Ralph Hall Design Channel Analogs.

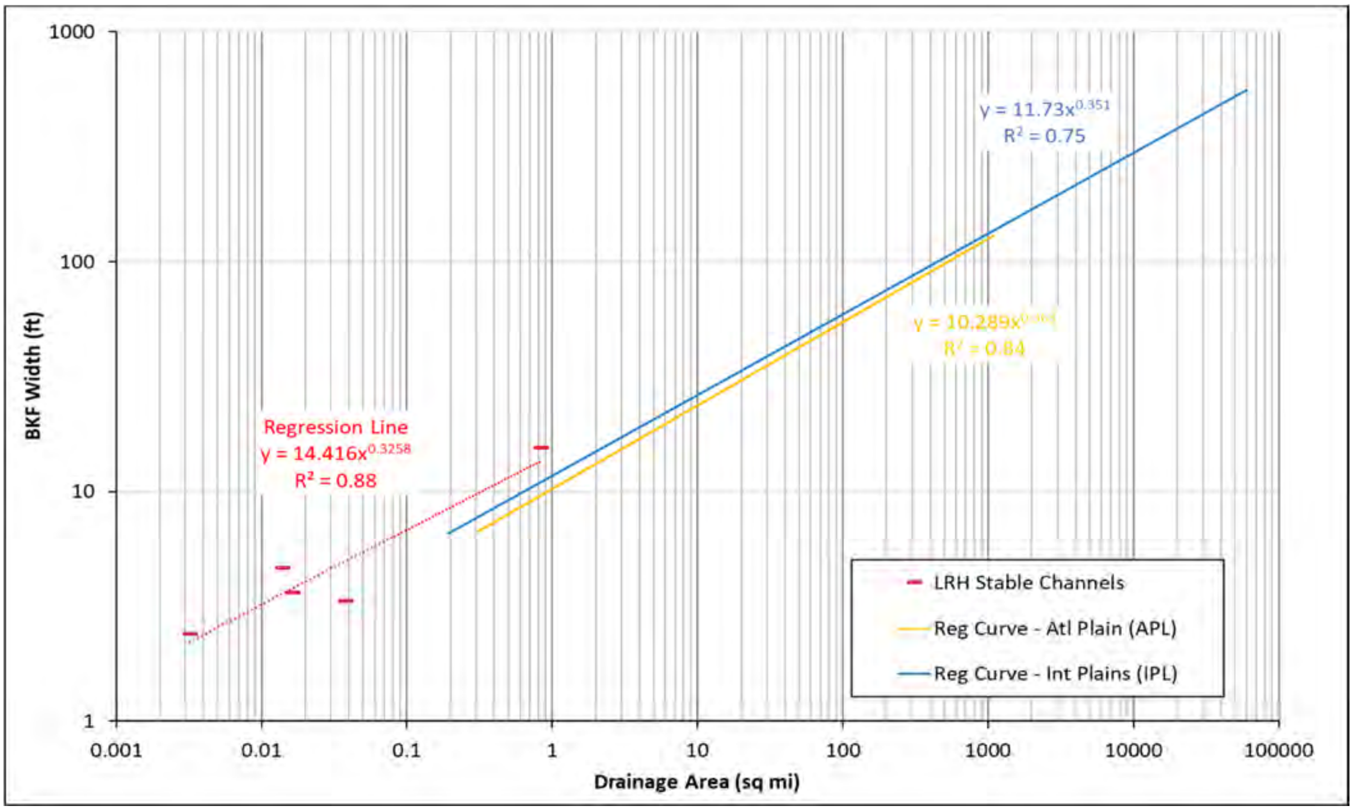
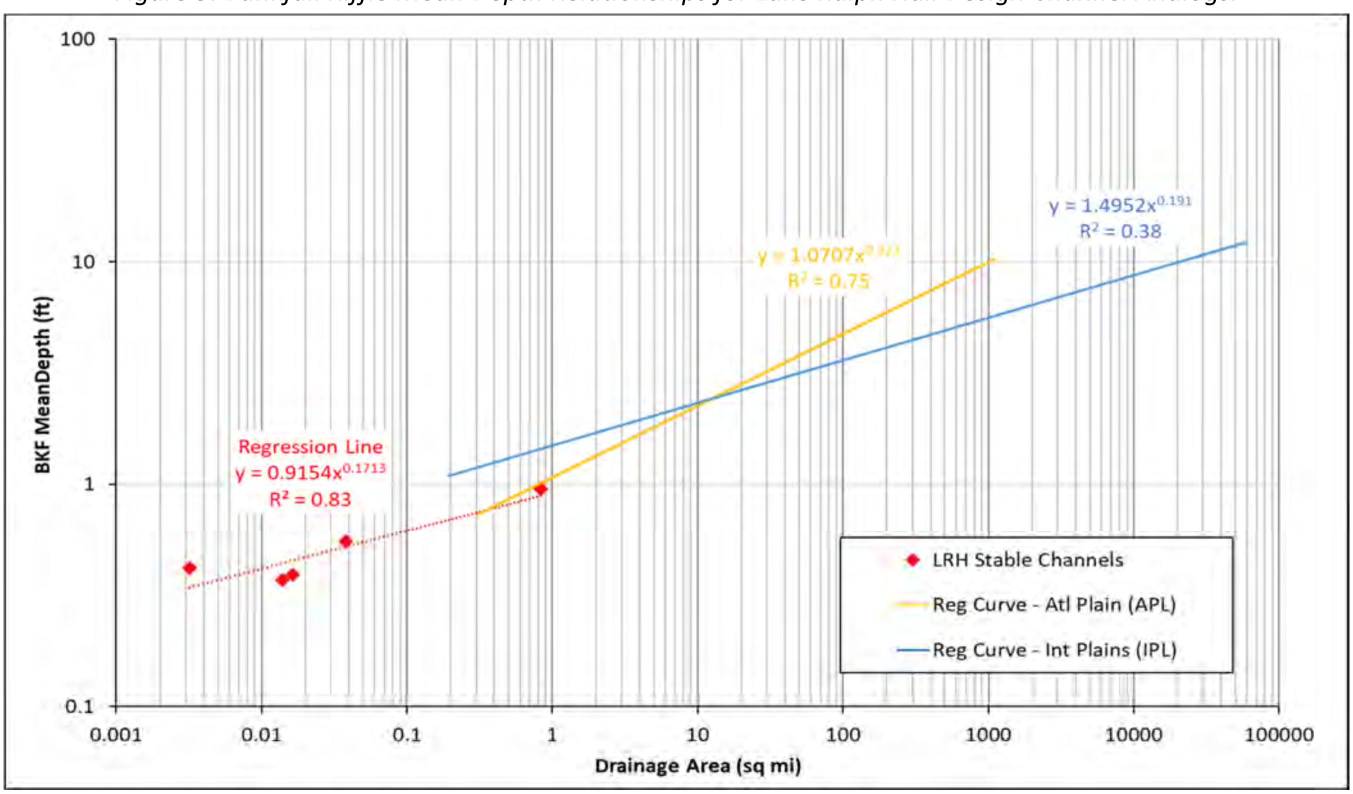


Figure 5. Bankfull Riffle Mean Depth Relationships for Lake Ralph Hall Design Channel Analogs.



In Figures 4 and 5, it is apparent that the bankfull width and mean depth relationships for the Lake Ralph Hall area match reasonably well with published relationships for the APL and IPL, considering that width and depth often show more variability than area in these relationships. The bankfull widths for the Lake Ralph Hall area appear to be slightly higher and the bankfull depths slightly lower than the published curves.

It should be noted that the regional curve relationships presented by Bieger et al. were developed for stream systems larger than many of those on the Lake Ralph Hall project site, although there is some overlap in the data for drainage areas larger than 0.2 – 0.3 square miles. There is some debate in the academic and research literature about the appropriateness of "bankfull discharge" relationships in small, ephemeral streams and whether such relationships truly drive channel geometry and size. We make several observations in regards to this consideration: 1) the streams do exhibit a documented trend of increased channel size with increased drainage area that appears predictable for the project watersheds, 2) the authors are unaware of a better methodology for predicting channel size and geometry in such stream systems, and 3) further analysis of predicted shear stresses, particle movement, and sediment transport processes will be conducted during the formal design phase to confirm the size and geometry estimations predicted by the regional relationships presented here.

Design Channel Analog Assessments

Data are provided in Appendix 1 of this memo for each of the five surveyed design channel analogs, and summary tables of key geomorphological parameters are provided in Tables 1, 2, and 3. A brief discussion of key parameters is provided following the tables.

Table 1. Key Geomorphological Riffle Dimension and Profile Parameters for Surveyed Design Channel Analogs.

Reach	Drainage area (sq mi)	Channel Slope (ft/ft)	Sinuosity	Rosgen Stream Type	Riffle Bankfull Area (sq ft)	Riffle Width (ft)	Riffle Mean Depth (ft)	Width-to-Depth Ratio
T3-BAKER-TRIB1-B2-(1)	0.0032	0.03	1.13	Eb	1.0	2.4	0.42	5.8
S2-TRIB2-A3-(3)	0.014	0.018	1.20	C	1.7	4.6	0.37	12.4
T3-BAKER-TRIB1-(3)	0.0164	0.0089	1.21	Bc	1.4	3.6	0.39	9.3
T2-BAKER-(1)	0.0399	*not measured*	*not measured*	E	1.8	3.3	0.55	6.1
S2-TRIB3-(10)	0.838	0.00014	1.48	Cc-	14.7	15.5	0.95	16.3

Table 2. Key Geomorphological Pool Dimension and Spacing Parameters for Surveyed Design Channel Analogs.

Reach	Pool Bankfull Area (sq ft)	Pool Width (ft)	Max Pool Depth (ft)	Pool-to-Pool Spacing (ft)	Pool Area Ratio[1]	Pool Width Ratio[2]	Max Pool Depth Ratio[3]	Pool-to-Pool Spacing Ratio[4]
T3-BAKER-TRIB1-B2-(1)	1.7	2.7	0.9	17 - 52	1.7	1.1	2.1	7.1 – 21.7
S2-TRIB2-A3-(3)	2.4	5.3	1.30	25 - 98	1.4	1.2	3.5	5.4 – 21.3
T3-BAKER-TRIB1-(3)	2.1	4.3	0.90	21 - 36	1.5	1.2	2.3	5.8 – 10.0
T2-BAKER-(1)	*not measured*							
S2-TRIB3-(10)	22.9	12.9	2.6	95 - 100	1.6	0.8	2.7	6.1 – 6.5

Notes: 1) Pool area ratio = bankfull pool area / bankfull riffle area
2) Pool width ratio = pool width / riffle width
3) Max pool depth ratio = max pool depth / riffle mean depth
4) Pool-to-pool spacing ratio = pool-to-pool spacing / riffle width

Table 3. Summary of Key Geomorphological Pattern Parameters for Surveyed Design Channel Analogs.

Reach	Meander Length (ft)	Meander Width (ft)	Radius of Curvature (ft)	Meander Length Ratio[1]	Meander Width Ratio[2]	Radius of Curvature Ratio[3]	Arc Angle (degrees)
T3-BAKER-TRIB1-B2-(1)	24 – 25	5 – 5.5	2.5 – 2.7	10 – 10.4	2.1 – 2.3	1 – 1.1	42 - 70
S2-TRIB2-A3-(3)	44 – 60	9 – 17	5.5 – 10	9.6 – 13	2 – 3.7	1.2 – 2.2	49 - 68
T3-BAKER-TRIB1-(3)	32 - 43	11.6 – 16	2.8 – 4.5	8.9 – 11.9	3.2 – 4.4	0.8 – 1.3	80 - 95
T2-BAKER-(1)	*not measured*						
S2-TRIB3-(10)	138 - 164	65 – 101	22 - 34	8.9 – 10.6	4.2 – 6.5	1.4 – 2.2	123 - 146

Notes: 1) Meander length ratio = meander length / riffle width
2) Meander width ratio = meander width / riffle width
3) Radius of curvature ratio = radius of curvature / riffle width

Dimension - Bankfull cross-sectional areas, widths, and mean depths were discussed earlier in this section and compared to published regional relationships. The surveyed reaches exhibited width-to-depth ratios ranging from approximately 6 to 16. The lowest width-to-depth ratio was recorded for T3-BAKER-TRIB1-B2-(1), which also had the highest channel slope and smallest drainage area. The highest width-to-depth ratio was recorded for S2-TRIB3-(10), which had the largest drainage area and the lowest channel slope. Most of the reaches classified as Rosgen type E or C channels, indicating that they have relatively high entrenchment ratios and relatively broad floodplains. One reach, T3-BAKER-TRIB1-(3), classified as a B type channel due to being somewhat entrenched within a more confined floodplain valley. Calculated pool ratios for all four reaches were similar for pool area ratio, pool width ratio, and pool depth ratio (Table 2).

Profile - Channel profile information was evaluated primarily to determine slopes and bedform diversity. Surveyed channel slopes ranged from approximately 0.000143 ft/ft to 0.03 ft/ft and cover the majority of the channel slopes that were experienced during the formal mitigation design stage. In reviewing the bedform diversity data and observations made during the field surveys, it is apparent that the reaches with the smallest drainage areas typically have pools associated with tree roots or debris jams and are not necessarily associated with meander geometry. For the larger tributary S2-TRIB3-(10), two small pools associated with debris jams and two pools associated with meander bends were captured in the profile. Pool-to-pool spacing ratios varied considerably between the reaches. Minimum pool-to-pool spacing ratios were similar for all reaches; however, the maximum spacing ratios were significantly higher for the smaller streams, most likely due to more ephemeral flow conditions as compared to the larger drainage area streams.

Pattern - Measured along the alignment of their respective valleys, the four surveyed reaches exhibited sinuosities ranging from 1.13 to 1.48. The greatest sinuosity was exhibited by reach S2-TRIB3-(10), which also had the largest drainage area (0.838 square miles) and the lowest channel slope (0.00014 ft/ft). The higher slope and smaller drainage area channels exhibited sinuosities ranging from 1.13 to 1.21. Meander length ratios were rather consistent for the surveyed design analog reaches, generally ranging from 9 to 13. However, meander width ratios and arc angles increased with increased sinuosity, with an overall measured range from 2 to 6.5 for meander width ratio and 42 to 146 degrees for arc angle. Radius of curvature ratios were similar between reaches and ranged from 0.8 to 2.2. All of the surveyed reaches are considered ephemeral.

Historic Stream Pattern Assessment

Three stream segments (one on S2-TRIB3-(10) and two on historic North Sulphur River (NSR) channel remnants) were evaluated to estimate historic channel sinuosity and meander pattern geometry. The results of the calculations are provided in Table 4.

Table 4. Summary of Meander Pattern Geometry for Historic Stream Segments.

Reach	Meander Length (ft)	Meander Width (ft)	Radius of Curvature (ft)	Meander Length Ratio[1]	Meander Width Ratio[1]	Radius of Curvature Ratio[1]	Arc Angle (degrees)	Sinuosity
S2-TRIB3-(10)	121 - 243	52 - 106	22 - 53	7.8 – 15.7	3.4 – 6.8	1.4 – 3.4	69 - 150	2.18
NSR – Segment 1	238 - 704	218 - 395	103 - 229	4.0 – 11.9	3.7 – 6.7	1.7 – 3.9	83 - 143	2.62
NSR – Segment 2	324 - 578	272 - 383	97 – 180	5.5 – 9.8	4.6 – 6.5	1.6 – 3.1	47 - 135	1.84

Notes: 1) See footnotes for Table 3 for an explanation of how ratios are calculated. The surveyed riffle width from the design analog survey was used for S2-TRIB3-(10), and an estimated riffle width of 59 feet (based on regional curve relationships presented in Figure 4) was used for the two North Sulphur River segments.

The assessed segment of S2-TRIB3-(10) was nearly three times longer than the surveyed design analog reach section of the same stream, allowing for a longer distance to capture more meander bends and evaluate the overall historic sinuosity of the stream. For the North Sulphur River segments, the regional curve relationship for riffle width in the Interior Plains region, described by Bieger et al. and graphed in Figure 4, was used to estimate the likely channel width of the historic North Sulphur River and calculate meander pattern ratios. The segments assessed would have historically had drainage areas of 100 square miles, resulting in an estimated bankfull riffle width of approximately 59 feet. This width corresponds well to the width of the historic channel segments visible from aerial photographs. Overall, measured sinuosities ranged from 1.84 to 2.62 for the three segments, indicating that the historic streams across the North Sulphur River valley were highly meandering.

4. DESIGN CRITERIA

Design Philosophy

The design team used principles of Natural Channel Design (NCD) to develop design approaches for each project stream and stream reach. The design philosophy for the site was to use conservative values for the selected stream types and to allow natural variability in stream dimension, facet slopes, and bed features to form and stabilize over time under the processes of flooding, re-colonization of vegetation, and watershed influences. Data collected from design channel analogs was used to help inform the design process, but careful consideration was given to the differences between a newly constructed channel restoration and mature stable sites (Harman and Starr, 2011).

Emphasis was placed on designing channels to carry the bankfull discharge and allowing larger flows to spill onto an active floodplain. For existing channels that are incised, reconnection with the stream's historic floodplain was given preference when practical (i.e. Priority 1 restoration approaches). When reconnection with the historic floodplain was not practical, floodplain benches were designed at a lower elevation to provide floodplain access, generally with a target minimum of three to five times the bankfull riffle width. Pattern and profile designs were based on design analog information from the project watershed, design analog information from similar streams in other regions, and professional judgement gained from past restoration projects. The expectation is that the restored streams will be dominated by sand-size bed material or smaller for most project reaches. Stable riffle slopes were determined through sediment transport analyses, and where valley/stream gradient exceeded these predicted stable slopes, grade control structures, such as logs and rock riffles, were incorporated into the design. Over the long term, grade control is expected to be provided by tree roots and debris jams. Woody buffers will be established along all mitigation reaches.

Enhancement versus Restoration Practices

Because of the degraded existing condition of the mitigation reaches on the site, restoration practices (meaning the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded aquatic resource [DOACOE, 2008]) account for the majority of the mitigation work that will be conducted on-site, and this memorandum focuses mainly on the design criteria and approaches for restored channels. However, there are some sections of existing stream channels that are stable to partially stable that do not require full restoration practices. Enhancement practices will be used on these reaches and involve a combination of in-stream structure placement, localized grading and bank sloping, bend realignment, and supplemental plantings. Depending on the enhancement practices proposed, some of the design steps presented in this memorandum may have been used. For example, if a stream meander is cutting into a hillslope resulting in a highly eroding outer bend, an enhancement approach may be to realign the bend and create a floodplain bench along the outer bank to promote bank stability and decrease shear stresses on the bank, leaving the upstream and downstream reaches untouched. The elevation of the floodplain bench would be informed by the proper bankfull design dimensions for the stream reach (as described below), but detailed pattern and profile adjustments may not be required. Another example would be localized and minor bank erosion areas on relatively stable stream segments that simply require cattle exclusion, bank grading, soil stabilization, and/or planting. Design calculations and the criteria discussed below would not be required for such simple enhancement approaches. Specific enhancement approaches, by stream reach, are shown in the design plans, included as **Appendix F**.

Channel Dimension

One of the most critical aspects of NCD is the sizing of the bankfull channel. For design purposes, the regression relationship presented in Figure 3 was used to estimate the appropriate bankfull riffle area (A_{BKF}) for restored, re-established, and constructed stream channels, using Equation 1:

(1) $A_{BKF} = 13.278(DA)^{0.493}$

where A_{BKF} = design riffle cross-sectional area (ft^2)
DA = drainage area of the reach (mi^2)

Drainage areas for design reaches were determined by using site-specific LiDAR topographic data to delineate contributing watersheds. To establish appropriate reach lengths for design, one design reach ended and another began when a significant tributary stream entered the reach, thus increasing the drainage area. Some design reaches were subdivided further by site conditions that required a change in design approach, such as a significant change in slope, floodplain width, channel condition, or other considerations.

Once the channel riffle area was sized, the shape of the channel was determined. Design riffle width (w_{BKF}) estimates were calculated from the A_{BKF} and a chosen design riffle width-to-depth ratio (WDR), based on design analog information that most closely matched the design stream type. WDR ratios reported in Table 1 for the surveyed design channel analogs range from 5.8 to 16.3 with an average ratio value of 10.0. Based on past project experience, WDR's less than 8.0 for newly constructed channels will not be used, as lower WDR's can lead to steep banks that are difficult to stabilize immediately following construction when vegetation is becoming established. Experience has also shown that WDR's higher than 18 to 20 can lead to sediment aggradation and bend cut-offs, so 18 was chosen as the highest potential WDR to be used. The calculation of w_{BKF} is shown in Equation 2.

(2) $w_{BKF} = (A_{BKF} * WDR)^{0.5}$

where w_{BKF} = design riffle width (ft)
WDR = design riffle width-to-depth ratio

Once area and width were estimated using Equations 1 and 2, design riffle mean depth (d_{BKF}) was determined by Equation 3:

(3) $d_{BKF} = A_{BKF} / w_{BKF}$

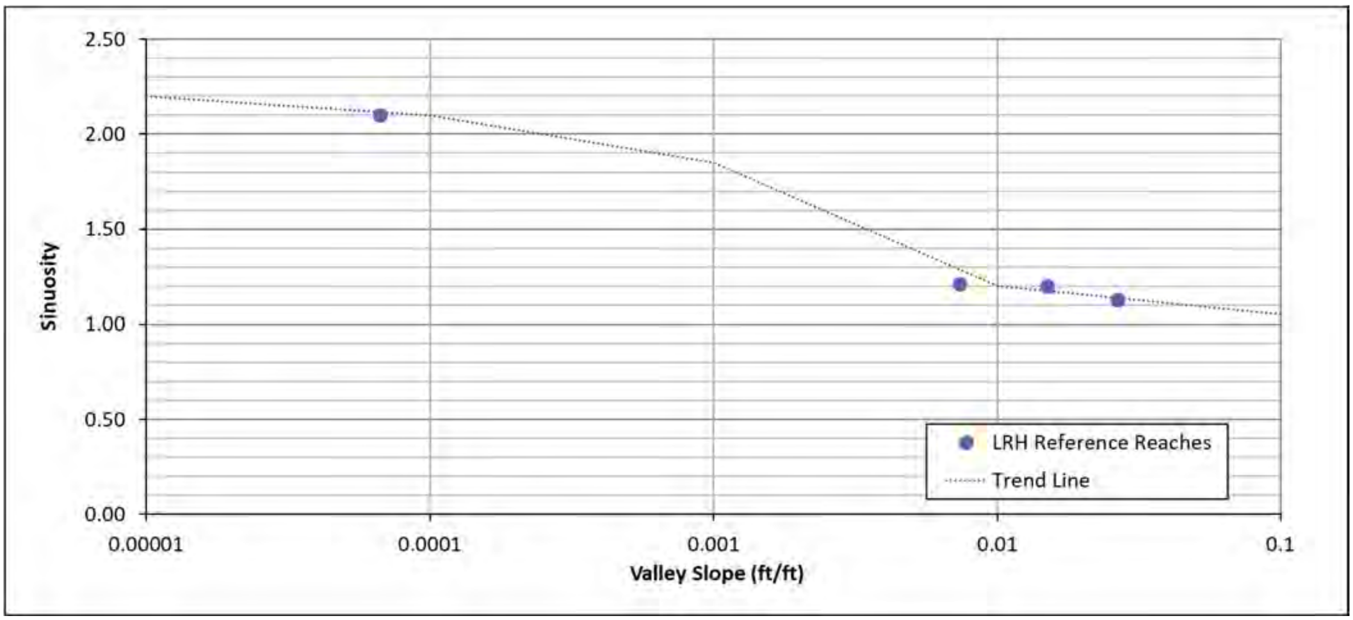
where d_{BKF} = design riffle mean depth (ft)

The cross-sectional area of design pools was estimated using the pool area ratios developed from the design analogs and provided in Table 2 (range of 1.4 – 1.7). Design pool widths and depths were also estimated using the ratios provided in Table 2; however, a pool width ratio of less than 1.1 was not used. It is not uncommon for design channel analogs to exhibit pool width ratios less than 1.0, due to the influence of mature vegetation. Newly constructed channels are more prone to erosion and establishing pools that are wider than riffles promotes stability until vegetation can become established. Design pool depth ratios will generally follow those provided in Table 2, ranging from 2.1 to 3.5.

Stream Sinuosity and Slope

The design channel analog data collected from the site, as well as the three historic plan form assessment reaches, indicate that channel sinuosity generally increases with decreased valley and channel slope. While sinuosity (K) is influenced by other parameters in addition to slope, the design analog and historic pattern data collected for the project area provide insight into the range of appropriate sinuosities for given valley slopes (S_v). This relationship is graphed in Figure 6. A step-wise series of regression equations were developed for the trend line shown in Figure 6, and used to estimate a target design sinuosity for each design stream reach, based on design valley slope. Valley slopes were measured using site specific topographic data along the valley alignment of each design reach. A minimum design sinuosity of 1.05 and a maximum sinuosity of 2.2 – 2.3 was used for all design reaches on the mitigation site.

Figure 6. Relationship Between Valley Slope and Channel Sinuosity for Lake Ralph Hall Design Channel Analogs and Historic Pattern Reaches.



Once the valley slope and sinuosity were determined for a design reach, an estimate of design channel slope was calculated with Equation 4:

(4) $S_{ch} = S_v / K$

where S_{ch} = channel slope (ft/ft)
S_v = valley slope (ft/ft)
K = sinuosity (*dimensionless*)

Channel Pattern

Design parameters that define channel pattern (meander length, meander width, and radius of curvature ratios; arc angles) were estimated from design analog ratios provided in Tables 3 and 4. An appropriate design analog was chosen for a given design reach by matching channel slope and drainage area as closely as possible. For design reaches that fell between the conditions of the available design channel analogs, interpolation, past project experience, and professional judgement were used to estimate appropriate pattern ratios. The pattern alignments were developed to stay within appropriate pattern ratios while also matching closely to the estimated design sinuosities appropriate for the valley slope, as discussed in the previous step.

Radius of curvature ratios for design purposes were not be less than 1.5, even though several design channel analogs exhibited curvature ratios less than 1.5. This approach provided a more conservative design that will reduce the stress placed on newly constructed stream banks. As vegetation becomes established and the restored site stabilizes, it is likely that radii will decrease through the processes of vegetation establishment and sediment/debris deposition.

Channel Profile

Profile depths (depths of riffles and pools) were determined from the steps described above for channel dimension. Pool-to-pool spacing was based primarily on meander geometry for streams with sinuosities greater than 1.4. For streams with sinuosities less than 1.2, pool spacing and placement was driven by the placement of in-stream structures that provide grade control and induce downstream scour pools. For streams with design sinuosities between 1.2 and 1.4, pool spacing and placement was driven by a combination of meander geometry and structure placement.

Profile design is an iterative process, particularly for streams where a floodplain is being excavated. Driving considerations include connections with design reaches up- and downstream, balancing cut and fill quantities, excavation limits and constraints, and number of in-stream structures to be used.

Shear Stress and Stream Power Analyses

To assess the stability and sediment transport relationships for the channel designs described above, analyses of design shear stress and stream power were conducted. The purpose of a sediment transport analysis is to ensure that the stream restoration design creates a stable channel that does not aggrade or degrade over time. In small sand-bed systems like the majority of the mitigation stream reaches, the fine-textured bed material is mobile during bankfull flows; therefore, there is no need to determine the competency or maximum particle size that the stream can transport. However, comparing the design shear stress and stream power values for a project reach to those computed for stable design channel analogs is useful to evaluate whether the values predicted for the design channels are within the range of those found in stable systems. Shear stress and stream power values were calculated for the surveyed Lake Ralph Hall design channel analogs (described above) and are plotted against channel slope in Figures 7 and 8, respectively. By calculating shear stress and stream power values for the mitigation design reaches and comparing them to the relationships in Figures 7 and 8, an assessment was made for each design reach regarding its potential for stability after construction. If design shear stress and/or stream power values for a design reach were higher than the design analog relationship, WDR for the design channel was increased resulting in a wider, shallower channel design to reduce predicted shear stress and stream power and reduce the potential for channel degradation. If shear stress and/or stream power values for a design reach were lower than the design analog relationship, WDR was decreased resulting in a narrower, deeper channel design to increase shear stress and stream power to reduce the chances of sediment deposition and channel aggradation. A minimum WDR of 8 and a maximum WDR of 18 were used for these adjustments; as previously discussed, design WDR's outside of this range can cause instability in newly constructed channels.

Figure 7. Shear Stress and Channel Slope Relationship for Surveyed Lake Ralph Hall Design Channel Analogs.

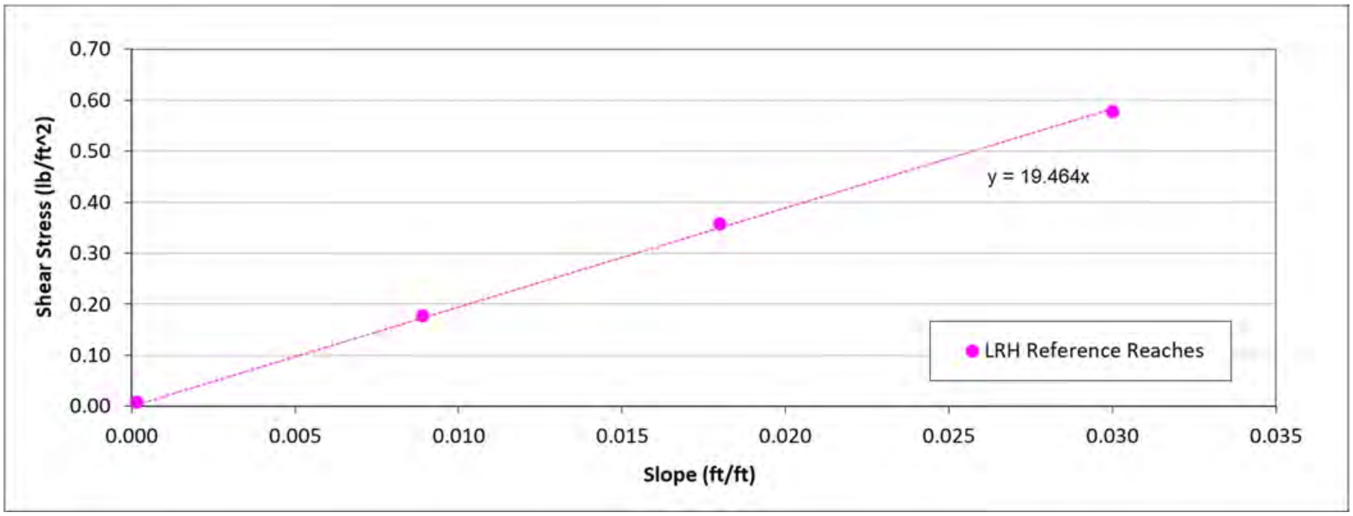
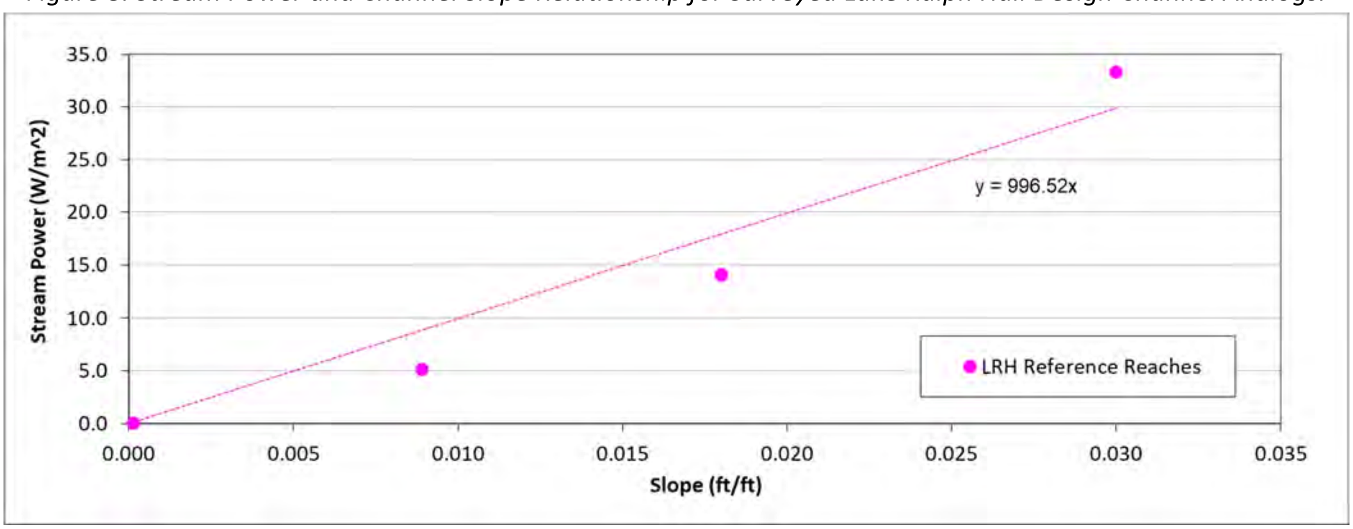


Figure 8. Stream Power and Channel Slope Relationship for Surveyed Lake Ralph Hall Design Channel Analogs.



After adjusting the channel design parameters described above to match design analog shear stress and stream power values as closely as possible, some design reaches still exhibited relatively high shear stress and/or stream power values. Design reaches were divided into three categories based on final shear stress and stream power estimates: 1) low potential for degradation, 2) moderate potential for degradation, and 3) high potential for degradation. These classifications were used in the selection and design of in-stream structures for each design reach. Simply put, streams with lower shear stress and stream power do not require as much in-stream structure for grade control as streams with higher stear stress and stream power. Streams with the highest shear stress and stream power have grade control structures spaced regularly along the design channel to protect against incision while the channel stabilizes after construction. Streams with moderate to low shear stress and stream power have less designed grade control. The need for grade control also influenced the type of grade control structure proposed; rock structures are used more often on higher energy streams and wood structures are used more often on lower energy streams.

Design Flexibility

The design criteria provided in this memorandum should be viewed as a general summary of the steps used to develop designs for the LRH Mitigation Plan. The criteria presented are based on collected design channel analog data, design analog data for similar streams from other regions, past project experience, and best professional judgement. Stream design is a dynamic process and numerous steps are required before a design is finalized. Through the formal design process, there may have been constraints or considerations for specific design reaches that required changes to the design criteria presented here; however, such changes were limited in scope and extent. For example, design sinuosity and pattern ratios may have been altered for a given reach to provide an appropriate confluence with a downstream reach.

REFERENCES

Bieger, K., H. Rathjens, P.M. Allen, and J.G. Arnold. 2015. "Development and Evaluation of Bankfull Hydraulic Geometry Relationships for the Physiographic Regions of the United States.. Publications from USDA-ARS / UNL Faculty. 1515. http://digitalcommons.unl.edu/usdaarsfacpub/1515

Department of the Army, Corps of Engineers (DOACOE), Environmental Protection Agency. April 10, 2008. Compensatory Mitigation for Losses of Aquatic Resources. Federal Register Vol. 73, No. 70.

Harman, W., R. Starr. 2011. Natural Channel Design Review Checklist. US Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD and US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Wetlands Division. Washington, D.C. EPA 843-B-12-005.

APPENDIX 1

DETAILED DESIGN CHANNEL ANALOG DATA

Reach S2-TRIB2-A3-(3)

Summary

Stream:	S2-TRIB2-A3 (3)
Watershed:	North Sulfur River
Location:	Lake Ralph Hall Mitigation Area
Latitude:	33.44374
Longitude:	-95.89080
State:	TX
County:	Fannon
Date:	May 10, 2018
Observers:	Rich Starr, Josh Wheeler
Channel type:	C
Drainage area (sq.mi.):	0.014
notes:	---

Dimension		bankfull channel			
		typical	min	max	
floodplain:	width flood prone area (ft)	55.0	30.0	80.0	
	low bank height (ft)	0.8	0.7	0.8	
riffle-run:	x-area bankfull (sq.ft.)	1.7	1.7	1.8	
	width bankfull (ft)	4.6	4.2	5.1	
	mean depth (ft)	0.37	0.3	0.4	
	max depth (ft)	0.7	0.7	0.8	
	hydraulic radius (ft)	0.4			
pool:	x-area pool (sq.ft.)	2.4	2.0	2.9	
	width pool (ft)	5.3	3.5	7.2	
	max depth pool (ft)	1.3	0.9	1.8	
	hydraulic radius (ft)	0.4			
dimensionless ratios:		typical	min	max	
	width depth ratio	12.4	9.6	15.8	
	entrenchment ratio	12.0	6.5	17.4	
	riffle max depth ratio	1.9	1.9	2.2	
	bank height ratio	1.1	1.0	1.1	
	pool area ratio	1.4	1.2	1.7	
	pool width ratio	1.2	0.8	1.6	
	pool max depth ratio	3.5	2.4	4.9	
hydraulics:		typical	min	max	
	discharge rate (cfs)		---	---	
	channel slope (%)	1.8			
		riffle-run	min	max	pool
	velocity (ft/s)	---	---	---	---
	Froude number	---	---	---	---
	shear stress (lbs/sq.ft.)				
	shear velocity (ft/s)				
	stream power (lb/s)	---	---	---	
	unit stream power (lb/ft/s)	---	---	---	
	relative roughness	---	---	---	
	friction factor u/u*	---	---	---	
	threshold grain size (t*=0.06) (mm)				
	Shield's parameter	---			

Pattern	typical	min	max
meander length (ft)	53.0	44.0	60.0
belt width (ft)	13.0	9.0	17.0
amplitude (ft)	---	---	---
radius (ft)	7.8	5.5	10.0
arc angle (degrees)	59.0	49.0	68.0
stream length (ft)	217.0		
valley length (ft)	181.0		
Sinuosity	1.2		
Meander Length Ratio	11.5	9.6	13.0
Meander Width Ratio	2.8	2.0	3.7
Radius Ratio	1.7	1.2	2.2

Profile	typical	min	max
pool-pool spacing (ft)	---	---	---
riffle length (ft)	---	---	---
pool length (ft)	---	---	---
run length (ft)	---	---	---
glide length (ft)	---	---	---
channel slope (%)	1.8		
riffle slope (%)	---	---	---
pool slope (%)	---	---	---
run slope (%)	---	---	---
glide slope (%)	---	---	---
measured valley slope (%)	---		
valley slope from sinuosity (%)	2.2		
Riffle Length Ratio	---	---	---
Pool Length Ratio	---	---	---
Run Length Ratio	---	---	---
Glide Length Ratio	---	---	---
Riffle Slope Ratio	---	---	---
Pool Slope Ratio	---	---	---
Run Slope Ratio	---	---	---
Glide Slope Ratio	---	---	---
Pool Spacing Ratio	---	---	---

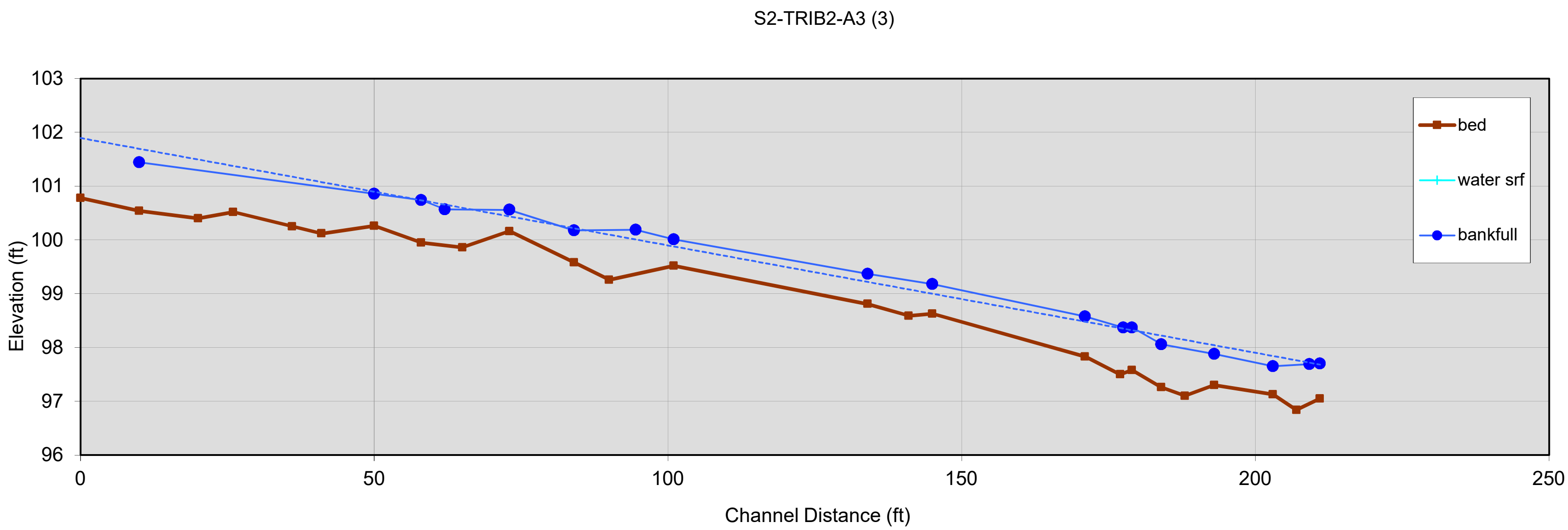
Reference Reach

Stream:	S2-TRIB2-A3 (3)
Watershed:	North Sulfur River
Location:	Lake Ralph Hall Mitigation Area
Latitude:	33.4437
Longitude:	-95.8908
County:	Fannon
Date:	May 10, 2018
Observers:	Rich Starr, Josh Wheeler
Channel Type:	C
Drainage Area (sq.mi)	0.014

Profile Summary

	typical	min	max
bankfull width (ft)	4.6		
pool-pool spacing (ft)	---	---	---
riffle length (ft)	---	---	---
pool length (ft)	---	---	---
run length (ft)	---	---	---
glide length (ft)	---	---	---
channel slope (%)	1.8		
riffle slope (%)	---	---	---
pool slope (%)	---	---	---
run slope (%)	---	---	---
glide slope (%)	---	---	---
measured valley slope (%)	---		
valley slope from sinuosity (%)	2.2		
Riffle Length Ratio	---	---	---
Pool Length Ratio	---	---	---
Run Length Ratio	---	---	---
Glide Length Ratio	---	---	---
Riffle Slope Ratio	---	---	---
Pool Slope Ratio	---	---	---
Run Slope Ratio	---	---	---
Glide Slope Ratio	---	---	---
Pool Spacing Ratio	---	---	---

Longitudinal Slope Profile



	slope (%)	slope ratio	length (ft)	length ratio	pool-pool spacing (ft)	p-p ratio
reach	1.8	---	211.0 (45.9 channel widt	---	---	---
riffle	---	---	---	---	---	---
pool	---	---	---	---	---	---
	---	---	---	---	---	---
	---	---	---	---	---	---

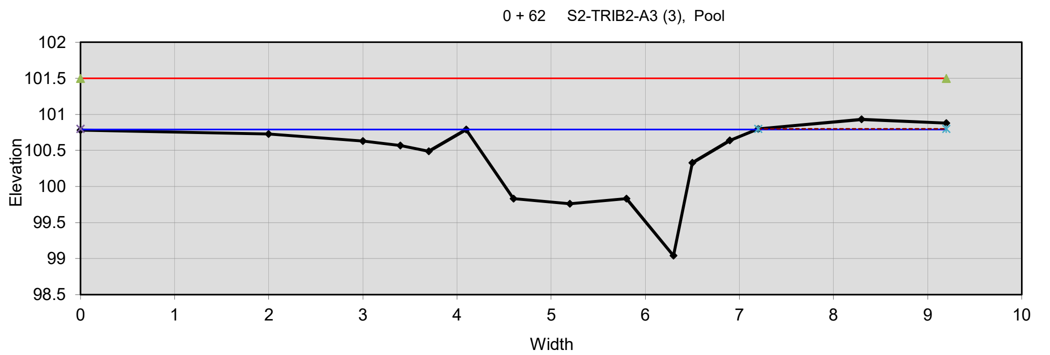
notes	cross section ID	bed feature	station	station	Benchmark Elevation 100 — Turning Points BS	HI	FS	FS bed	water	FS bankfull	user defined FS	user defined FS	user defined FS	azimuth AZ	ELEV bed	ELEV water srf	ELEV bankfull	ELEV ---	ELEV ---	ELEV ---
back sight to benchmark					7.37	107.37														
			0			107.37		6.59							100.78					
			10			107.37		6.83		5.93					100.54		101.44			
			20			107.37		6.97							100.4					
			26			107.37		6.85							100.52					
			36			107.37		7.12							100.25					
			41			107.37		7.25							100.12					
			50			107.37		7.11		6.51					100.26		100.86			
			58			107.37		7.42		6.63					99.95		100.74			
	1	pool	62			107.37				6.8							100.57			
			65			107.37		7.51							99.86					
			73			107.37		7.21		6.81					100.16		100.56			
			84			107.37		7.79		7.19					99.58		100.18			
			90			107.37		8.11							99.26					
	2	glide	94.5			107.37				7.18							100.19			
			101			107.37		7.85		7.36					99.52		100.01			
			134			107.37		8.56		8					98.81		99.37			
			141			107.37		8.78							98.59					
			145			107.37		8.74		8.19					98.63		99.18			
						107.37	7.37													
					5.6	105.6														
	3	riffle	163			105.6														
			171			105.6		7.77		7.02					97.83		98.58			
			177			105.6		8.1							97.5					
	4	pool	177.5			105.6				7.23							98.37			
			179			105.6		8.02		7.23					97.58		98.37			
			184			105.6		8.34		7.54					97.26		98.06			
			188			105.6		8.5							97.1					
			193			105.6		8.3		7.72					97.3		97.88			
			203			105.6		8.47		7.95					97.13		97.65			
			207			105.6		8.76							96.84					
	5	riffle	209.2			105.6				7.91							97.69			
			211			105.6		8.55		7.9					97.05		97.7			

Reference Reach			hints
Stream:	S2-TRIB2-A3 (3)		
Watershed:	North Sulfur River		
Location:	Lake Ralph Hall Mitigation Area		
Latitude:	33.4437		
Longitude:	-95.8908		
County:	Fannon		
Date:	May 10, 2018		
Observers:	Rich Starr, Josh Wheeler		
Channel type:	C		
Drainage area (sq.km)	0.014		

Dimension		bankfull channel	
	typical	min	max
floodplain: width flood prone area (ft)	55.0	30.0	80.0
low bank height (ft)	0.8	0.7	0.8
riffle - run x-area bankfull (sq.ft)	1.7	1.7	1.8
width bankfull (ft)	4.6	4.2	5.1
mean depth (ft)	0.37	0.3	0.4
max depth (ft)	0.7	0.7	0.8
hydraulic radius (ft)	0.4		
pool: x-area pool (sq.ft)	2.4	2.0	2.9
width pool (ft)	5.3	3.5	7.2
max depth pool (ft)	1.3	0.9	1.8
hydraulic radius (ft)	0.4		
dimensionless ratios:	typical	min	max
width depth ratio	12.4	9.6	15.8
entrenchment ratio	12.0	6.5	17.4
bank height ratio	1.1	1.0	1.1
riffle max depth ratio	1.9	1.9	2.2
pool area ratio	1.4	1.2	1.7
pool width ratio	1.2	0.8	1.6
pool max depth ratio	3.5	2.4	4.9

hydraulics:	bankfull channel		
discharge rate (cfs)		---	
channel slope (%)	1.8		
	riffle-run & (range)		pool
velocity (ft/s)	---	---	---
Froude number	---	---	---
shear stress (lbs/sq.ft)			
shear velocity (ft/s)			
stream power (lb/s)	---	(-------)	
unit stream power (lb/s/ft)	---	---	
relative roughness	---	(-------)	
friction factor u/u*	---	---	
threshold grain size (t*=0.06) (mm)			
Shield's parameter	---		

Cross Section 1



Bankfull Dimensions

2.9	x-section area (ft.sq.)
7.2	width (ft)
0.4	mean depth (ft)
1.8	max depth (ft)
9.6	wetted parimeter (ft)
0.3	hyd radi (ft)
18.0	width-depth ratio

Flood Dimensions

30.0	W flood prone area (ft)
4.2	entrenchment ratio
1.8	low bank height (ft)
1.0	low bank height ratio

Materials

---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow

---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance

---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power

1.8	channel slope (%)
	shear stress (lb/sq.ft.)
	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID	1	
instrument height	105.59	107.37
longitudinal station	62	62.0

Bankfull Stage

FS		---
elevation	100.79	100.66

Low Bank Height

FS		---
elevation	100.8	

Flood Prone Area

width fpa	30	9.2

Channel Slope

percent slope	1.8	1.8

Flow Resistance

Manning's "n"		---
D'Arcy - Weisbach "f"		---

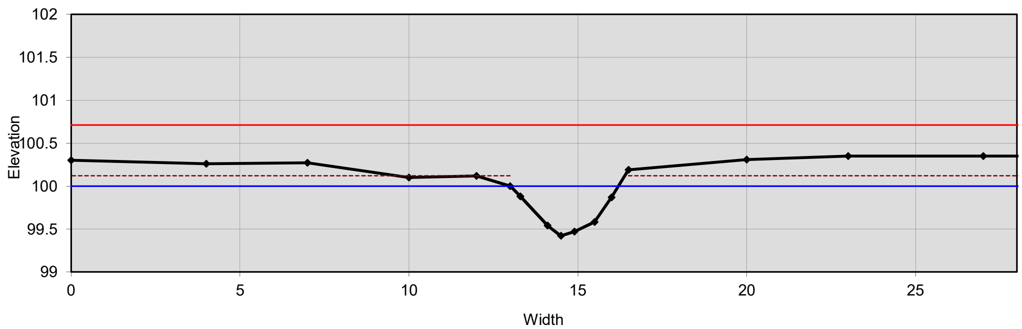
Note:

Width fpa

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes
0		105.59	4.81	100.78		GS
2		105.59	4.86	100.73		GS
3		105.59	4.96	100.63		GS
3.4		105.59	5.02	100.57		TOP OF E
3.7		105.59	5.1	100.49		SLP BRK
4.1		105.59	4.8	100.79		CS
4.6		105.59	5.76	99.83		CS
5.2		105.59	5.83	99.76		TW
5.8		105.59	5.76	99.83		CS
6.3		105.59	6.55	99.04		CS
6.5		105.59	5.26	100.33		CS
6.9		105.59	4.95	100.64		SLP BRK
7.2		105.59	4.79	100.8		TOP OF E
8.3		105.59	4.66	100.93		GS
9.2		105.59	4.71	100.88		GS

Cross Section 2

0 + 94.5 S2-TRIB2-A3 (3), Glide



Bankfull Dimensions	
1.1	x-section area (ft.sq.)
3.2	width (ft)
0.3	mean depth (ft)
0.6	max depth (ft)
3.4	wetted parimeter (ft)
0.3	hyd radi (ft)
9.2	width-depth ratio

Flood Dimensions	
40.0	W flood prone area (ft)
12.5	entrenchment ratio
0.7	low bank height (ft)
1.2	low bank height ratio

Materials	
---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow	
---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance	
---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power	
1.8	channel slope (%)
	shear stress (lb/sq.ft.)
	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID	2	
instrument height	105.59	107.37
longitudinal station	94.5	94.5

Bankfull Stage

FS		---
elevation	100	100.01

Low Bank Height

FS		---
elevation	100.12	

Flood Prone Area

width fpa	40	28.8

Channel Slope

percent slope	1.8	1.8

Flow Resistance

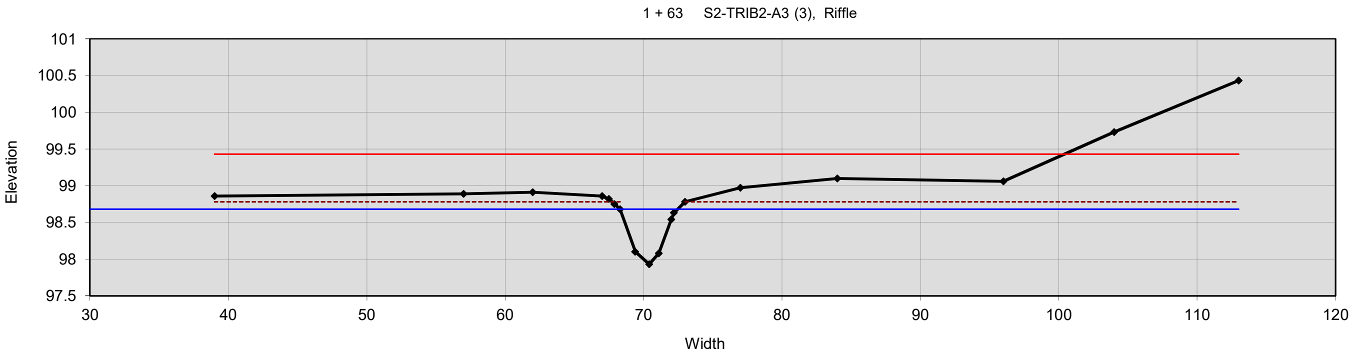
Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

Width fpa estimated.

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes
-6		105.59	5.15	100.44		GS
-12		105.59	4.92	100.67		GS
-22		105.59	5.25	100.34		GS
-29		105.59	5.35	100.24		GS
-30		105.59	5.25	100.34		GS
-35		105.59	4.36	101.23		GS
0		105.59	5.29	100.3		GS
4		105.59	5.33	100.26		GS
7		105.59	5.32	100.27		GS
10		105.59	5.49	100.1		GS
12		105.59	5.47	100.12		GS
13		105.59	5.59	100		BF
13.3		105.59	5.71	99.88		SLP BRK
14.1		105.59	6.05	99.54		CS
14.5		105.59	6.17	99.42		TW
14.9		105.59	6.12	99.47		CS
15.5		105.59	6.01	99.58		CS
16		105.59	5.72	99.87		CS
16.5		105.59	5.4	100.19		TOB
20		105.59	5.28	100.31		GS
23		105.59	5.24	100.35		GS
27		105.59	5.24	100.35		GS
31		105.59	5.24	100.35		GS
33		105.59	5.2	100.39		GS
40		105.59	4.85	100.74		GS
47		105.59	4.28	101.31		GS
50		105.59	3.9	101.69		GS

Cross Section 3



Bankfull Dimensions		Flood Dimensions		Materials	
1.8	x-section area (ft.sq.)	80.0	W flood prone area (ft)	---	D50 (mm)
4.2	width (ft)	19.2	entrenchment ratio	---	D84 (mm)
0.4	mean depth (ft)	0.8	low bank height (ft)		threshold grain size (mm):
0.8	max depth (ft)	1.1	low bank height ratio		
4.5	wetted parimeter (ft)				
0.4	hyd radi (ft)				
9.6	width-depth ratio				

Bankfull Flow		Flow Resistance		Forces & Power	
---	velocity (ft/s)	---	Manning's roughness	1.8	channel slope (%)
---	discharge rate (cfs)	---	D'Arcy-Weisbach fric.		shear stress (lb/sq.ft.)
---	Froude number	---	resistance factor u/u*		shear velocity (ft/s)
		---	relative roughness	---	unit strm power (lb/ft/s)

Cross Section

reference ID	3	
instrument height	105.59	105.6
longitudinal station	163	163.0

Bankfull Stage

FS		---
elevation	98.68	98.64

Low Bank Height

FS		---
elevation	98.78	

Flood Prone Area

width fpa	80	61.4

Channel Slope

percent slope	1.8	1.8

Flow Resistance

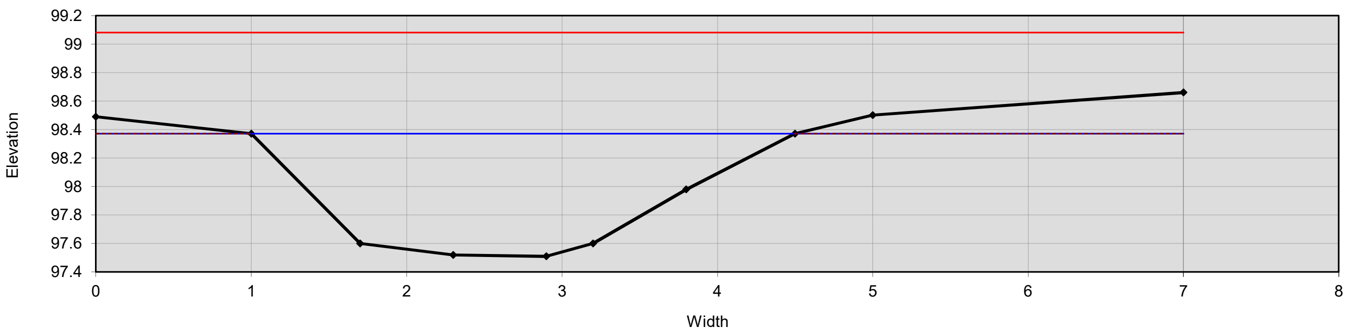
Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

Width fpa estimated

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes	dist	elev	to find d max	98.68 bkf	w	a
		105.59				GS	0	#N/A	1105.59	98.7		
		105.59				GS	0	#N/A	1105.59	98.7	0.0	0.0
		105.59				GS	0	#N/A	1105.59	98.7	0.0	0.0
		105.59				GS	0	#N/A	1105.59	98.7	0.0	0.0
		105.59				GS	0	#N/A	1105.59	98.7	0.0	0.0
39		105.59	6.73	98.86		GS	39	98.86	98.86	98.7	0.0	0.0
57		105.59	6.7	98.89		GS	57	98.89	98.89	98.7	0.0	0.0
62		105.59	6.68	98.91		GS	62	98.91	98.91	98.7	0.0	0.0
67		105.59	6.73	98.86		TOP OF E	67	98.86	98.86	98.7	0.0	0.0
67.5		105.59	6.77	98.82		SLP BRK	67.5	98.82	98.82	98.7	0.0	0.0
67.9		105.59	6.84	98.75		SLP BRK	67.9	98.75	98.75	98.7	0.0	0.0
68.3		105.59	6.91	98.68		CS	68.3	98.68	98.68	98.7	0.0	0.0
69.4		105.59	7.49	98.1		TW	69.4	98.1	98.1	98.7	1.1	0.3
70.4		105.59	7.66	97.93		CS	70.4	97.93	97.93	98.7	1.0	0.7
71.1		105.59	7.51	98.08		SLP BRK	71.1	98.08	98.08	98.7	0.7	0.5
72		105.59	7.05	98.54		SLP BRK	72	98.54	98.54	98.7	0.9	0.3
72.2		105.59	6.96	98.63		TOP OF E	72.2	98.63	98.63	98.7	0.2	0.0
73		105.59	6.81	98.78		GS	73	98.78	98.78	98.7	0.3	0.0
77		105.59	6.62	98.97		GS	77	98.97	98.97	98.7	0.0	0.0
84		105.59	6.49	99.1		GS	84	99.1	99.1	98.7	0.0	0.0
96		105.59	6.53	99.06		GS	96	99.06	99.06	98.7	0.0	0.0
104		105.59	5.86	99.73		GS	104	99.73	99.73	98.7	0.0	0.0
113		105.59	5.16	100.43		GS	113	100.43	100.43	98.7	0.0	0.0
							#N/A	#N/A	1105.59	98.7	0.0	0.0
							#N/A	#N/A	1105.59	98.7	0.0	0.0
							#N/A	#N/A	1105.59	98.7	0.0	0.0
							#N/A	#N/A	1105.59	98.7	0.0	0.0
							#N/A	#N/A	1105.59	98.7	0.0	0.0

Cross Section 4



Bankfull Dimensions	
2.0	x-section area (ft.sq.)
3.5	width (ft)
0.6	mean depth (ft)
0.9	max depth (ft)
4.1	wetted parimeter (ft)
0.5	hyd radi (ft)
6.1	width-depth ratio

Flood Dimensions	
30.0	W flood prone area (ft)
8.6	entrenchment ratio
0.9	low bank height (ft)
1.0	low bank height ratio

Materials	
---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow	
---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance	
---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power	
1.8	channel slope (%)
	shear stress (lb/sq.ft.)
	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID	4	
instrument height	105.59	105.6
longitudinal station	177.5	177.5

Bankfull Stage

FS		---
elevation	98.37	98.35

Low Bank Height

FS		---
elevation	98.37	

Flood Prone Area

width fpa	30	7.0

Channel Slope

percent slope	1.8	1.8

Flow Resistance

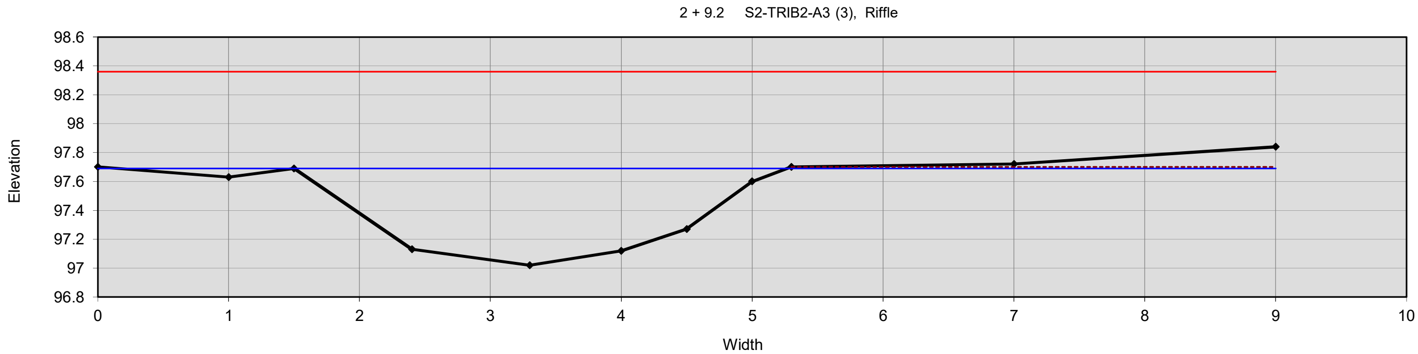
Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

Width fpa estimated

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes	dist	elev	to find d max	98.37 bkf	w	a
0		105.59	7.1	98.49		GS	0	98.49	98.49	98.4		
1		105.59	7.22	98.37		BF	1	98.37	98.37	98.4	0.0	0.0
1.7		105.59	7.99	97.6		CS	1.7	97.6	97.6	98.4	0.7	0.3
2.3		105.59	8.07	97.52		TW	2.3	97.52	97.52	98.4	0.6	0.5
2.9		105.59	8.08	97.51		CS	2.9	97.51	97.51	98.4	0.6	0.5
3.2		105.59	7.99	97.6		CS	3.2	97.6	97.6	98.4	0.3	0.2
3.8		105.59	7.61	97.98		CS	3.8	97.98	97.98	98.4	0.6	0.3
4.5		105.59	7.22	98.37		SLP BRK	4.5	98.37	98.37	98.4	0.7	0.1
5		105.59	7.09	98.5		TOP OF E	5	98.5	98.5	98.4	0.0	0.0
7		105.59	6.93	98.66		GS	7	98.66	98.66	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0
							#N/A	#N/A	1105.59	98.4	0.0	0.0

Cross Section 5



Bankfull Dimensions

1.7	x-section area (ft.sq.)
5.1	width (ft)
0.3	mean depth (ft)
0.7	max depth (ft)
5.4	wetted parimeter (ft)
0.3	hyd radi (ft)
15.8	width-depth ratio

Flood Dimensions

30.0	W flood prone area (ft)
5.9	entrenchment ratio
0.7	low bank height (ft)
1.0	low bank height ratio

Materials

---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow

---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance

---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power

1.8	channel slope (%)
	shear stress (lb/sq.ft.)
	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID	5	
instrument height	105.59	105.6
longitudinal station	209.2	209.2

Bankfull Stage

FS		---
elevation	97.69	97.72

Low Bank Height

FS		---
elevation	97.7	

Flood Prone Area

width fpa	30	9.0

Channel Slope

percent slope	1.8	1.8

Flow Resistance

Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

Width fpa estimated

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes	dist	elev	to find d max	97.69 bkf	w	a	p
0		105.59	7.89	97.7		GS	0	97.7	97.7	97.7			
1		105.59	7.96	97.63		GS	1	97.63	97.63	97.7	0.9	0.0	0.9
1.5		105.59	7.9	97.69		TOP OF E	1.5	97.69	97.69	97.7	0.5	0.0	0.5
2.4		105.59	8.46	97.13		CS	2.4	97.13	97.13	97.7	0.9	0.3	1.1
3.3		105.59	8.57	97.02		TW	3.3	97.02	97.02	97.7	0.9	0.6	0.9
4		105.59	8.47	97.12		CS	4	97.12	97.12	97.7	0.7	0.4	0.7
4.5		105.59	8.32	97.27		CS	4.5	97.27	97.27	97.7	0.5	0.2	0.5
5		105.59	7.99	97.6		SLP BRK	5	97.6	97.6	97.7	0.5	0.1	0.6
5.3		105.59	7.89	97.7		TOP OF E	5.3	97.7	97.7	97.7	0.3	0.0	0.3
7		105.59	7.87	97.72		GS	7	97.72	97.72	97.7	0.0	0.0	0.0
9		105.59	7.75	97.84		GS	9	97.84	97.84	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0
							#N/A	#N/A	1105.59	97.7	0.0	0.0	0.0

Meander Pattern - Channel Plan Form

This Worksheet

1) This sheet will graph the distance and azimuth entered in the profile worksheet.

2) Fill in the values below using the graphed pattern, aerial photos, topo maps, etc.

3) Before printing the graph, its width or height may need adjusting. "Square" the graph by clicking and dragging.

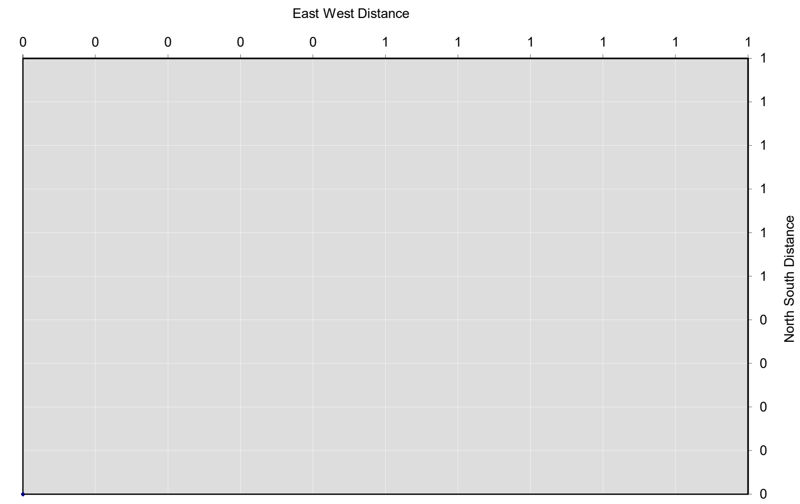
4) more info

		min	max
Meander Length			
meander length (ft)	53	44	60
Meander Width			
belt width (ft)	13	9	17
amplitude (ft)			
Bends			
radius (ft)	7.75	5.5	10
arc angle (degrees)	59	49	68
Sinuosity			
stream length (ft)	217		
valley length (ft)	181		
Graph Format			
Z scale:	10		

show banks

show centerline

S2-TRIB2-A3 (3) North Sulfur River Lake Ralph Hall Mitigation Area



Dimensions (ft)

Bankfull Width: 4.6
Meander Length: 53 (44 - 60)
Belt Width: 13 (9 - 17)
Radius of Curvature: 7.75 (5.5 - 10)

Ratios

Sinuosity: 1.2
Meander Length Ratio: 11.5 (9.6 - 13)
Meander Width Ratio: 2.8 (2 - 3.7)
Radius / BkF Width: 1.7 (1.2 - 2.2)

Reference Reach

Stream:	S2-TRIB2-A3 (3)
Watershed:	North Sulfur River
Location:	Lake Ralph Hall Mitigation Area
Latitude:	33.4437
Longitude:	-95.8908
County:	Fannon
Date:	May 10, 2018
Observers:	Rich Starr, Josh Wheeler
Channel Type:	C
Drainage Area (sq.mi):	0.014

Pattern

	typical	min	max
bankfull width (ft)	4.60		
meander length (ft)	53.0	44.0	60.0
belt width (ft)	13.0	9.0	17.0
amplitude (ft)	---	---	---
radius (ft)	7.8	5.5	10.0
arc angle (degrees)	59.0	49.0	68.0
stream length (ft)	217.0		
valley length (ft)	181.0		
Sinuosity	1.20		
Meander Length Ratio	11.5	9.6	13.0
Meander Width Ratio	2.8	2.0	3.7
Radius Ratio	1.7	1.2	2.2

Reach S2-TRIB2-A3-(3)






Reach S2-TRIB3-(10)

Summary

Stream:	S2-TRIB3-(10)
Watershed:	North Sulfur River
Location:	LRH Mitigation Area
Latitude:	33.45754
Longitude:	-95.89710
State:	Texas
County:	Fannin
Date:	May 10, 2018
Observers:	Tweedy, Starr, Voight
Channel type:	Cc-
Drainage area (sq.mi.):	0.838
notes:	---

Dimension		bankfull channel			
		typical	min	max	
floodplain:	width flood prone area (ft)	29.0	29.0	29.0	
	low bank height (ft)	1.8	1.6	2.1	
riffle-run:	x-area bankfull (sq.ft.)	14.7	14.7	14.7	
	width bankfull (ft)	15.5	15.3	15.7	
	mean depth (ft)	0.95	0.9	1.0	
	max depth (ft)	1.6	1.4	1.8	
	hydraulic radius (ft)	0.9			
pool:	x-area pool (sq.ft.)	22.9	22.9	22.9	
	width pool (ft)	12.9	12.9	12.9	
	max depth pool (ft)	2.6	2.6	2.6	
	hydraulic radius (ft)	1.6			
dimensionless ratios:		typical	min	max	
	width depth ratio	16.3	15.9	16.8	
	entrenchment ratio	1.9	1.9	1.9	
	riffle max depth ratio	1.7	1.5	1.9	
	bank height ratio	1.1	1.0	1.3	
	pool area ratio	1.6	1.6	1.6	
	pool width ratio	0.8	0.8	0.8	
	pool max depth ratio	2.7	2.7	2.7	
hydraulics:		typical	min	max	
	discharge rate (cfs)		---	---	
	channel slope (%)	0.014			
		riffle-run	min	max	pool
	velocity (ft/s)	---	---	---	---
	Froude number	---	---	---	---
	shear stress (lbs/sq.ft.)				
	shear velocity (ft/s)				
	stream power (lb/s)	---	---	---	
	unit stream power (lb/ft/s)	---	---	---	
	relative roughness	---	---	---	
	friction factor u/u*	---	---	---	
	threshold grain size (t*=0.06) (mm)				
	Shield's parameter	---			

Pattern			
	typical	min	max
meander length (ft)	151.0	138.0	164.0
belt width (ft)	83.0	65.0	101.0
amplitude (ft)	---	---	---
radius (ft)	28.0	22.0	34.0
arc angle (degrees)	135.0	123.0	146.0
stream length (ft)	319.0		
valley length (ft)	216.0		
Sinuosity	1.5		
Meander Length Ratio	9.7	8.9	10.6
Meander Width Ratio	5.4	4.2	6.5
Radius Ratio	1.8	1.4	2.2

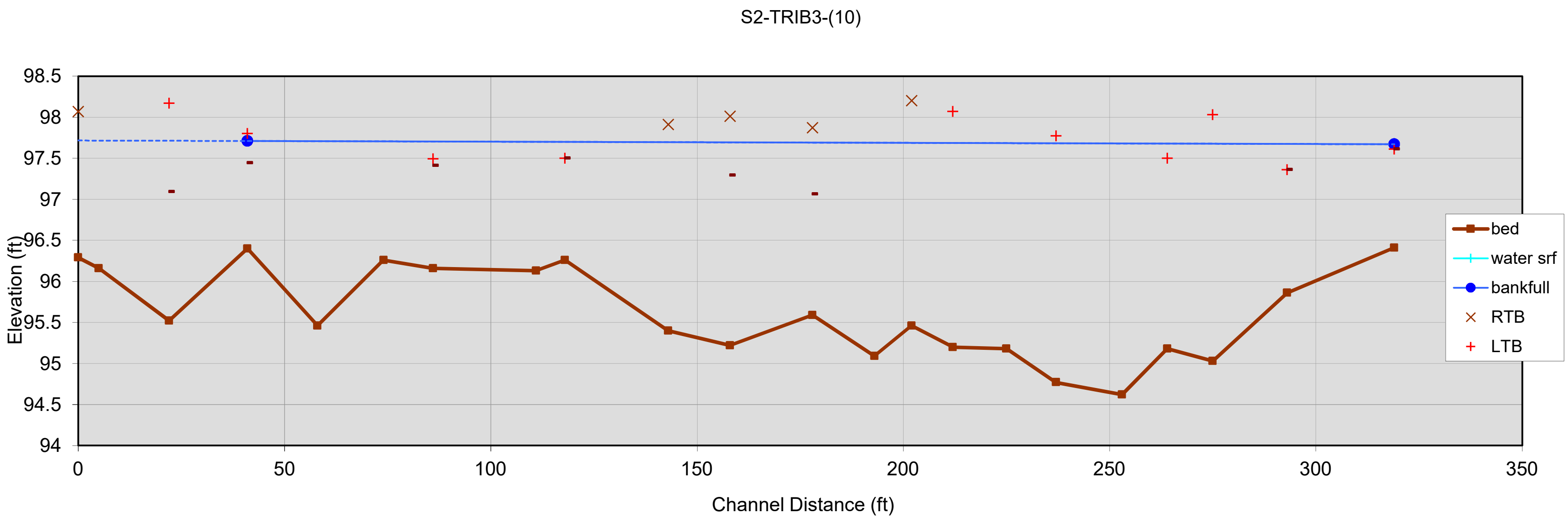
Profile			
	typical	min	max
pool-pool spacing (ft)	---	---	---
riffle length (ft)	---	---	---
pool length (ft)	---	---	---
run length (ft)	---	---	---
glide length (ft)	---	---	---
channel slope (%)	0.014		
riffle slope (%)	---	---	---
pool slope (%)	---	---	---
run slope (%)	---	---	---
glide slope (%)	---	---	---
measured valley slope (%)	---		
valley slope from sinuosity (%)	0.0		
Riffle Length Ratio	---	---	---
Pool Length Ratio	---	---	---
Run Length Ratio	---	---	---
Glide Length Ratio	---	---	---
Riffle Slope Ratio	---	---	---
Pool Slope Ratio	---	---	---
Run Slope Ratio	---	---	---
Glide Slope Ratio	---	---	---
Pool Spacing Ratio	---	---	---

Reference Reach	
Stream:	S2-TRIB3-(10)
Watershed:	North Sulfur River
Location:	LRH Mitigation Area
Latitude:	33.4575
Longitude:	-95.8971
County:	Fannin
Date:	May 10, 2018
Observers:	Tweedy, Starr, Voight
Channel Type:	Cc-
Drainage Area (sq.mi)	0.838

Profile Summary

	typical	min	max
bankfull width (ft)	15.5		
pool-pool spacing (ft)	---	---	---
riffle length (ft)	---	---	---
pool length (ft)	---	---	---
run length (ft)	---	---	---
glide length (ft)	---	---	---
channel slope (%)	0.014		
riffle slope (%)	---	---	---
pool slope (%)	---	---	---
run slope (%)	---	---	---
glide slope (%)	---	---	---
measured valley slope (%)	---		
valley slope from sinuosity (%)	0.021		
Riffle Length Ratio	---	---	---
Pool Length Ratio	---	---	---
Run Length Ratio	---	---	---
Glide Length Ratio	---	---	---
Riffle Slope Ratio	---	---	---
Pool Slope Ratio	---	---	---
Run Slope Ratio	---	---	---
Glide Slope Ratio	---	---	---
Pool Spacing Ratio	---	---	---

Longitudinal Slope Profile



	slope (%)	slope ratio	length (ft)	length ratio	pool-pool spacing (ft)	p-p ratio
reach	0.014	---	319.0 (20.6 channel widt	---	---	---
riffle	---	---	---	---	---	---
pool	---	---	---	---	---	---
	---	---	---	---	---	---
	---	---	---	---	---	---

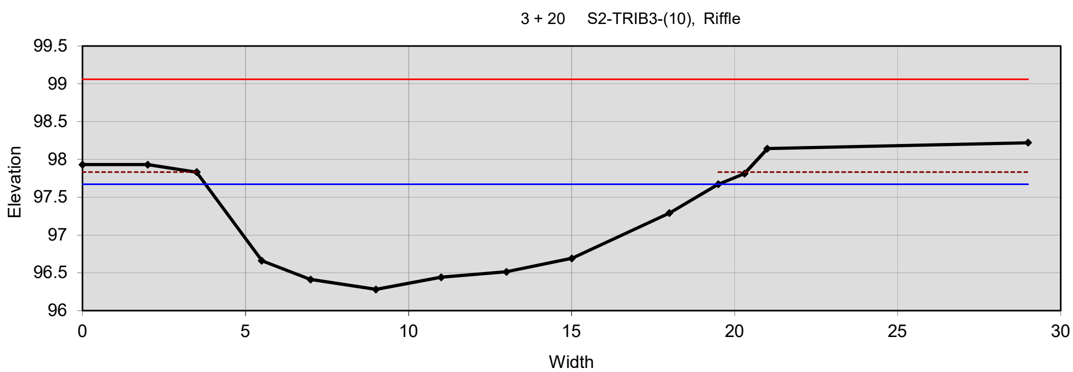
notes	cross section ID	bed feature	station	station	Benchmark Elevation 100 / Turning Points BS	HI	FS	FS bed	water	FS bankfull	user defined FS RTB	FS LTB	FS	azimuth AZ	ELEV bed	ELEV water srf	ELEV bankfull	ELEV RTB	ELEV LTB	ELEV ---
back sight to benchmark					3.62	103.62														
			0			103.62		7.33							96.29					
			0			103.62					5.55							98.07		
			5			103.62		7.46							96.16					
			22			103.62		8.1							95.52					
			22			103.62							6.53							97.09
			22			103.62						5.45							98.17	
			41			103.62		7.22							96.4					
			41			103.62							6.18							97.44
			41			103.62				5.91		5.82					97.71		97.8	
			58			103.62		8.16							95.46					
			74			103.62		7.36							96.26					
			86			103.62		7.46							96.16					
			86			103.62							6.21							97.41
			86			103.62						6.13							97.49	
			111			103.62		7.49							96.13					
			118			103.62		7.36							96.26					
			118			103.62						6.12							97.5	
			118			103.62							6.12							97.5
			143			103.62		8.22							95.4					
			143			103.62					5.71							97.91		
			158			103.62		8.4							95.22					
			158			103.62					5.61							98.01		
scouring			158			103.62							6.33							97.29
			178			103.62		8.03							95.59					
			178			103.62							6.56							97.06
			178			103.62					5.75							97.87		
			193			103.62		8.53							95.09					
			202			103.62		8.16							95.46					
			202			103.62					5.42							98.2		
			212			103.62		8.42							95.2					
			212			103.62						5.55							98.07	
			225			103.62		8.44							95.18					
			237			103.62		8.85							94.77					
			237			103.62						5.85							97.77	
			253			103.62		9							94.62					
			264			103.62		8.44							95.18					
			264			103.62						6.12							97.5	
			275			103.62		8.59							95.03					
			275			103.62						5.59							98.03	
			293			103.62		7.76							95.86					
			293			103.62						6.26							97.36	
			293			103.62							6.26							97.36
			319			103.62		7.21							96.41					
			319			103.62						6.01							97.61	
			319			103.62				5.95			6.01				97.67			97.61

Reference Reach				hints
Stream:	S2-TRIB3-(10)			
Watershed:	North Sulfur River			
Location:	LRH Mitigation Area			
Latitude:	33.4575			
Longitude:	-95.8971			
County:	Fannin			
Date:	May 10, 2018			
Observers:	Tweedy, Starr, Voight			
Channel type:	Cc-			
Drainage area (sq.km)	0.838			

Dimension		bankfull channel		
		typical	min	max
floodplain:	width flood prone area (ft)	29.0	29.0	29.0
	low bank height (ft)	1.8	1.6	2.1
riffle - run	x-area bankfull (sq.ft)	14.7	14.7	14.7
	width bankfull (ft)	15.5	15.3	15.7
	mean depth (ft)	0.95	0.9	1.0
	max depth (ft)	1.6	1.4	1.8
	hydraulic radius (ft)	0.9		
pool:	x-area pool (sq.ft)	22.9	22.9	22.9
	width pool (ft)	12.9	12.9	12.9
	max depth pool (ft)	2.6	2.6	2.6
	hydraulic radius (ft)	1.6		
dimensionless ratios:		typical	min	max
	width depth ratio	16.3	15.9	16.8
	entrenchment ratio	1.9	1.9	1.9
	bank height ratio	1.1	1.0	1.3
	riffle max depth ratio	1.7	1.5	1.9
	pool area ratio	1.6	1.6	1.6
	pool width ratio	0.8	0.8	0.8
	pool max depth ratio	2.7	2.7	2.7

hydraulics:	bankfull channel		
discharge rate (cfs)		---	
channel slope (%)	0.014		
	riffle-run & (range)		pool
velocity (ft/s)	---	---	---
Froude number	---	---	---
shear stress (lbs/sq.ft)			
shear velocity (ft/s)			
stream power (lb/s)	---	(-------)	
unit stream power (lb/s/ft)	---	---	
relative roughness	---	(-------)	
friction factor u/u*	---	---	
threshold grain size (t*=0.06) (mm)			
Shield's parameter	---		

Cross Section



Bankfull Dimensions

14.7	x-section area (ft.sq.)
15.7	width (ft)
0.9	mean depth (ft)
1.4	max depth (ft)
16.1	wetted parimeter (ft)
0.9	hyd radi (ft)
16.8	width-depth ratio

Flood Dimensions

29.0	W flood prone area (ft)
1.8	entrenchment ratio
1.6	low bank height (ft)
1.1	low bank height ratio

Materials

---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow

---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance

---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power

0.014	channel slope (%)
------	shear stress (lb/sq.ft.)
-----	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID		
instrument height	103.73	---
longitudinal station	320	---

Bankfull Stage

FS		---
elevation	97.67	97.67

Low Bank Height

FS		---
elevation	97.83	

Flood Prone Area

width fpa	29	29.0

Channel Slope

percent slope	0.014	0.014

Flow Resistance

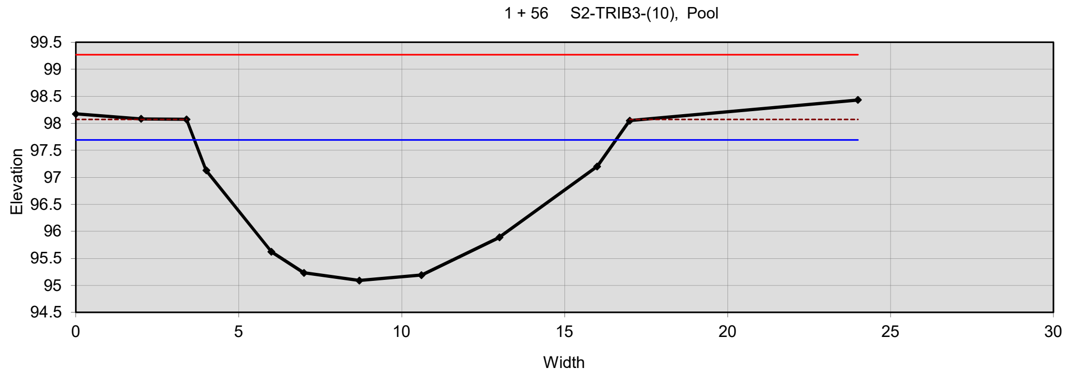
Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

Width fpa is wider than surveyed

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes
0		103.73	5.8	97.93		GS
2		103.73	5.8	97.93		GS
3.5		103.73	5.9	97.83		BF
5.5		103.73	7.07	96.66		CS
7		103.73	7.32	96.41		CS
9		103.73	7.45	96.28		CS/TW
11		103.73	7.29	96.44		CS
13		103.73	7.22	96.51		CS
15		103.73	7.04	96.69		CS
18		103.73	6.44	97.29		CS
19.5		103.73	6.06	97.67		SLPBRK (
20.3		103.73	5.92	97.81		SLPBRK
21		103.73	5.59	98.14		SLPBRK
29		103.73	5.51	98.22		GS

Cross Section 2



Bankfull Dimensions	
22.9	x-section area (ft.sq.)
12.9	width (ft)
1.8	mean depth (ft)
2.6	max depth (ft)
14.4	wetted parimeter (ft)
1.6	hyd radi (ft)
7.3	width-depth ratio

Flood Dimensions	
24.0	W flood prone area (ft)
1.9	entrenchment ratio
3.0	low bank height (ft)
1.1	low bank height ratio

Materials	
---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow	
---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance	
---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power	
0.014	channel slope (%)
-----	shear stress (lb/sq.ft.)
-----	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID	2	
instrument height	103.73	---
longitudinal station	156	---

Bankfull Stage

FS		---
elevation	97.69	97.69

Low Bank Height

FS		---
elevation	98.07	

Flood Prone Area

width fpa	24	24.0

Channel Slope

percent slope	0.014	0.014

Flow Resistance

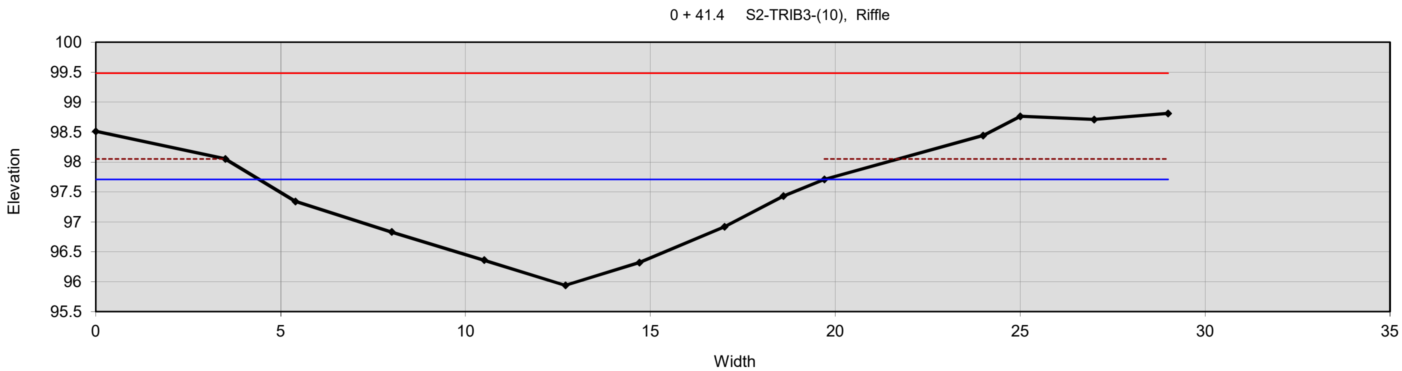
Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

Width fpa is wider than surveyed

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes
0		103.73	5.56	98.17		GS
2		103.73	5.65	98.08		GS
3.4		103.73	5.66	98.07		TOP OF E
4		103.73	6.6	97.13		SCOUR L
6		103.73	8.11	95.62		CS
7		103.73	8.5	95.23		CS
8.7		103.73	8.64	95.09		TW
10.6		103.73	8.54	95.19		CS
13		103.73	7.84	95.89		CS
16		103.73	6.53	97.2		BF
17		103.73	5.68	98.05		TOP OF E
24		103.73	5.3	98.43		GS

Cross Section 3



Bankfull Dimensions	
14.7	x-section area (ft.sq.)
15.3	width (ft)
1.0	mean depth (ft)
1.8	max depth (ft)
15.7	wetted parimeter (ft)
0.9	hyd radi (ft)
15.9	width-depth ratio

Flood Dimensions	
29.0	W flood prone area (ft)
1.9	entrenchment ratio
2.1	low bank height (ft)
1.2	low bank height ratio

Materials	
---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow	
---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance	
---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power	
0.014	channel slope (%)
-----	shear stress (lb/sq.ft.)
-----	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID	3	
instrument height	103.66	---
longitudinal station	41.4	---

Bankfull Stage

FS		---
elevation	97.71	97.71

Low Bank Height

FS		---
elevation	98.05	

Flood Prone Area

width fpa	29	29.0

Channel Slope

percent slope	0.014	0.014

Flow Resistance

Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

Width fpa is wider than surveyed

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes	dist	elev	to find d max	97.71 bkf	w	a
0		103.66	5.15	98.51		GS	0	98.51	98.51	97.7		
3.5		103.66	5.61	98.05		TOP OF E	3.5	98.05	98.05	97.7	0.0	0.0
5.4		103.66	6.32	97.34			5.4	97.34	97.34	97.7	1.0	0.2
8		103.66	6.83	96.83		CS	8	96.83	96.83	97.7	2.6	1.6
10.5		103.66	7.3	96.36		CS	10.5	96.36	96.36	97.7	2.5	2.8
12.7		103.66	7.72	95.94		TW	12.7	95.94	95.94	97.7	2.2	3.4
14.7		103.66	7.34	96.32		CS	14.7	96.32	96.32	97.7	2.0	3.2
17		103.66	6.74	96.92		CS	17	96.92	96.92	97.7	2.3	2.5
18.6		103.66	6.23	97.43		BF	18.6	97.43	97.43	97.7	1.6	0.9
19.7		103.66	5.95	97.71		TOP OF E	19.7	97.71	97.71	97.7	1.1	0.2
24		103.66	5.22	98.44		GS	24	98.44	98.44	97.7	0.0	0.0
25		103.66	4.9	98.76		GS	25	98.76	98.76	97.7	0.0	0.0
27		103.66	4.95	98.71		GS	27	98.71	98.71	97.7	0.0	0.0
29		103.66	4.85	98.81		GS	29	98.81	98.81	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0
							#N/A	#N/A	1103.66	97.7	0.0	0.0

Meander Pattern - Channel Plan Form

This Worksheet

1) This sheet will graph the distance and azimuth entered in the profile worksheet.

2) Fill in the values below using the graphed pattern, aerial photos, topo maps, etc.

3) Before printing the graph, its width or height may need adjusting. "Square" the graph by clicking and dragging.

4) more info

Meander Length

		min	max
meander length (ft)	151	138	164

Meander Width

		min	max
belt width (ft)	83	65	101
amplitude (ft)			

Bends

		min	max
radius (ft)	28	22	34
arc angle (degrees)	135	123	146

Sinuosity

stream length (ft)	319
valley length (ft)	216

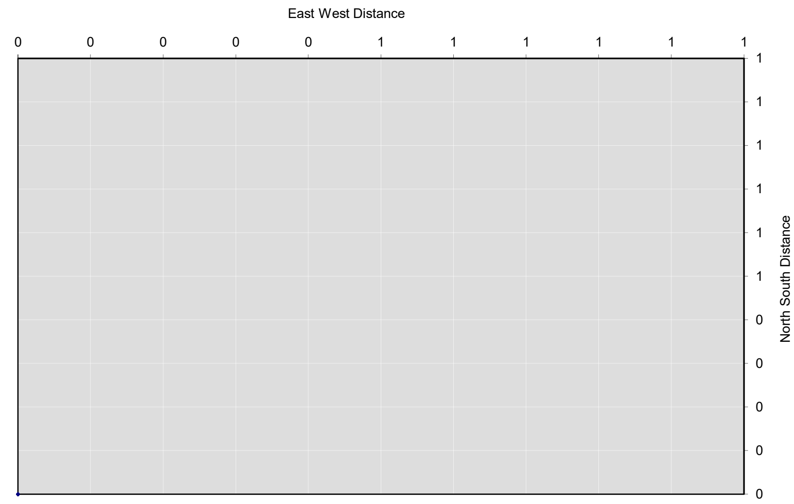
Graph Format

Z scale:	10

show banks

show centerline

S2-TRIB3-(10) North Sulfur River LRH Mitigation Area



Dimensions (ft)	
Bankfull Width:	15.5
Meander Length:	151 (138 - 164)
Belt Width:	83 (65 - 101)
Radius of Curvature:	28 (22 - 34)

Ratios	
Sinuosity:	1.5
Meander Length Ratio:	9.7 (8.9 - 10.6)
Meander Width Ratio:	5.4 (4.2 - 6.5)
Radius / BkF Width:	1.8 (1.4 - 2.2)

Reference Reach

Stream:	S2-TRIB3-(10)
Watershed:	North Sulfur River
Location:	LRH Mitigation Area
Latitude:	33.4575
Longitude:	-95.8971
County:	Fannin
Date:	May 10, 2018
Observers:	Tweedy, Starr, Voight
Channel Type:	Cc-
Drainage Area (sq.mi):	0.838

Pattern

	typical	min	max
bankfull width (ft)	15.50		
meander length (ft)	151.0	138.0	164.0
belt width (ft)	83.0	65.0	101.0
amplitude (ft)	---	---	---
radius (ft)	28.0	22.0	34.0
arc angle (degrees)	135.0	123.0	146.0
stream length (ft)	319.0		
valley length (ft)	216.0		
Sinuosity	1.48		
Meander Length Ratio	9.7	8.9	10.6
Meander Width Ratio	5.4	4.2	6.5
Radius Ratio	1.8	1.4	2.2

Reach S2-TRIB3-(10)






Reach T2-BAKER-(1)

Summary

Stream:	T2-BAKER-(1)
Watershed:	North Sulfur River
Location:	LRH Mitigation Area
Latitude:	33.47339
Longitude:	-95.89498
State:	Texas
County:	Fannin
Date:	May 10, 2018
Observers:	Tweedy, Starr, Voight
Channel type:	E
Drainage area (sq.mi.):	0.0399
notes:	reference for dimension (cross-section) only. Pattern appears to straight and manipulated.

Dimension		bankfull channel			
		typical	min	max	
floodplain:	width flood prone area (ft)	7.6	---	---	
	low bank height (ft)	0.8	---	---	
riffle-run:	x-area bankfull (sq.ft.)	1.8	---	---	
	width bankfull (ft)	3.3	---	---	
	mean depth (ft)	0.55	---	---	
	max depth (ft)	0.8	---	---	
	hydraulic radius (ft)	0.5			
pool:	x-area pool (sq.ft.)	---	---	---	
	width pool (ft)	---	---	---	
	max depth pool (ft)	---	---	---	
	hydraulic radius (ft)	---			
dimensionless ratios:		typical	min	max	
	width depth ratio	6.1	---	---	
	entrenchment ratio	2.3	---	---	
	riffle max depth ratio	1.5	---	---	
	bank height ratio	1.0	---	---	
	pool area ratio	---	---	---	
	pool width ratio	---	---	---	
	pool max depth ratio	---	---	---	
hydraulics:		typical	min	max	
	discharge rate (cfs)		---	---	
	channel slope (%)	---			
		riffle-run	min	max	pool
	velocity (ft/s)	---	---	---	---
	Froude number	---	---	---	---
	shear stress (lbs/sq.ft.)	---	---	---	---
	shear velocity (ft/s)	---	---	---	---
	stream power (lb/s)	---	---	---	
	unit stream power (lb/ft/s)	---	---	---	
	relative roughness	---	---	---	
	friction factor u/u*	---	---	---	
	threshold grain size (t*=0.06) (mm)	---	---	---	
	Shield's parameter	---			

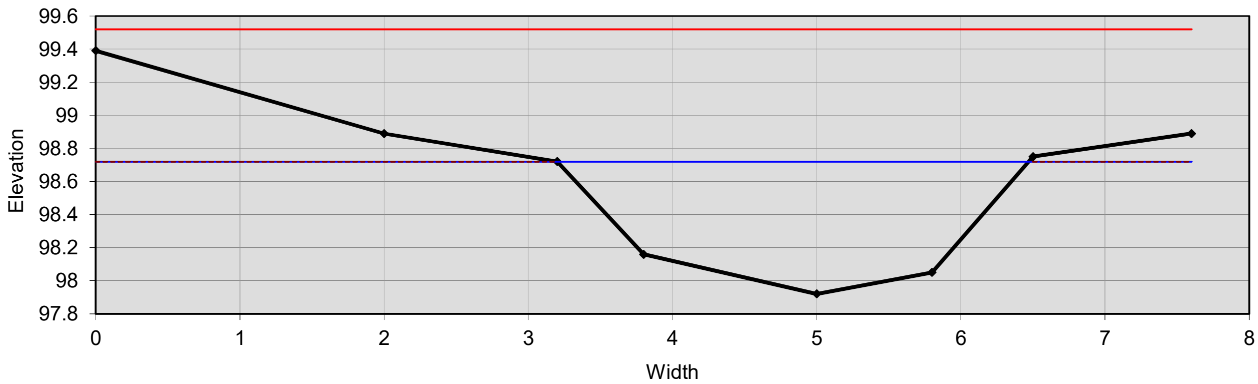
Reference Reach	hints
Stream:	T2-BAKER-(1)
Watershed:	North Sulfur River
Location:	LRH Mitigation Area
Latitude:	33.4734
Longitude:	-95.8950
County:	Fannin
Date:	May 10, 2018
Observers:	Tweedy, Starr, Voight
Channel type:	E
Drainage area (sq.km)	0.0399

Dimension		bankfull channel		
		typical	min	max
floodplain:	width flood prone area (ft)	7.6	---	---
	low bank height (ft)	0.8	---	---
riffle - run	x-area bankfull (sq.ft)	1.8	---	---
	width bankfull (ft)	3.3	---	---
	mean depth (ft)	0.55	---	---
	max depth (ft)	0.8	---	---
	hydraulic radius (ft)	0.5		
pool:	x-area pool (sq.ft)	---	---	---
	width pool (ft)	---	---	---
	max depth pool (ft)	---	---	---
	hydraulic radius (ft)	---		
dimensionless ratios:		typical	min	max
	width depth ratio	6.1	---	---
	entrenchment ratio	2.3	---	---
	bank height ratio	1.0	---	---
	riffle max depth ratio	1.5	---	---
	pool area ratio	---	---	---
	pool width ratio	---	---	---
	pool max depth ratio	---	---	---

hydraulics:	bankfull channel		
discharge rate (cfs)		---	
channel slope (%)	---		
	riffle-run & (range)		pool
velocity (ft/s)	---	---	---
Froude number	---	---	---
shear stress (lbs/sq.ft)	---	---	---
shear velocity (ft/s)	---	---	---
stream power (lb/s)	---	(-------)	
unit stream power (lb/s/ft)	---	---	
relative roughness	---	(-------)	
friction factor u/u*	---	---	
threshold grain size (t*=0.06) (mm)	---	---	
Shield's parameter	---		

Cross Section

0 + 1 T2-BAKER-(1), Riffle



Bankfull Dimensions

1.8	x-section area (ft.sq.)
3.3	width (ft)
0.5	mean depth (ft)
0.8	max depth (ft)
3.8	wetted parimeter (ft)
0.5	hyd radi (ft)
6.0	width-depth ratio

Flood Dimensions

7.6	W flood prone area (ft)
2.3	entrenchment ratio
0.8	low bank height (ft)
1.0	low bank height ratio

Materials

---	D50 (mm)
---	D84 (mm)
---	threshold grain size (mm):

Bankfull Flow

---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance

---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power

---	channel slope (%)
---	shear stress (lb/sq.ft.)
---	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID		
instrument height	105	---
longitudinal station	1	---

Bankfull Stage

FS		---
elevation	98.72	---

Low Bank Height

FS		---
elevation	98.72	

Flood Prone Area

width fpa	7.6	7.6

Channel Slope

percent slope		---

Flow Resistance

Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

dimension reference only - no pattern or profile data collected.

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes
0		105	5.61	99.39		GS
2		105	6.11	98.89		GS
3.2		105	6.28	98.72		LBK
3.8		105	6.84	98.16		LCH
5		105	7.08	97.92		TW
5.8		105	6.95	98.05		RCH
6.5		105	6.25	98.75		RBKF
7.6		105	6.11	98.89		GS

Reach T2-BAKER-(1)

T2-BAKER-(1) - Looking upstream.

T2-BAKER-(1) - Looking downstream.

Reach T3-BAKER-TRIB1-(3)

Summary

Stream:	T3-BAKER-TRIB1-(3)
Watershed:	North Sulfer River
Location:	LRH Mitigation Area
Latitude:	33.47547
Longitude:	-95.89341
State:	Texas
County:	Fannin
Date:	May 10, 2018
Observers:	Tweedy, Starr, Voight
Channel type:	Bc
Drainage area (sq.mi.):	0.01641
notes:	---

Dimension		bankfull channel			
		typical	min	max	
floodplain:	width flood prone area (ft)	5.9	5.7	6.0	
	low bank height (ft)	0.6	0.5	0.6	
riffle-run:	x-area bankfull (sq.ft.)	1.4	1.0	1.9	
	width bankfull (ft)	3.6	3.0	4.2	
	mean depth (ft)	0.39	0.3	0.4	
	max depth (ft)	0.6	0.5	0.6	
	hydraulic radius (ft)	0.4			
pool:	x-area pool (sq.ft.)	2.1	2.1	2.1	
	width pool (ft)	4.3	4.3	4.3	
	max depth pool (ft)	0.9	0.9	0.9	
	hydraulic radius (ft)	0.4			
dimensionless ratios:		typical	min	max	
	width depth ratio	9.3	9.0	9.7	
	entrenchment ratio	1.6	1.6	1.7	
	riffle max depth ratio	1.5	1.3	1.5	
	bank height ratio	1.0	0.8	1.0	
	pool area ratio	1.5	1.5	1.5	
	pool width ratio	1.2	1.2	1.2	
	pool max depth ratio	2.3	2.3	2.3	
hydraulics:		typical	min	max	
	discharge rate (cfs)		---	---	
	channel slope (%)	0.89			
		riffle-run	min	max	pool
	velocity (ft/s)	---	---	---	---
	Froude number	---	---	---	---
	shear stress (lbs/sq.ft.)				
	shear velocity (ft/s)				
	stream power (lb/s)	---	---	---	
	unit stream power (lb/ft/s)	---	---	---	
	relative roughness	---	---	---	
	friction factor u/u*	---	---	---	
	threshold grain size (t*=0.06) (mm)				
	Shield's parameter	---			

Pattern	typical	min	max
meander length (ft)	37.0	32.0	43.0
belt width (ft)	13.8	11.6	16.0
amplitude (ft)	---	---	---
radius (ft)	3.7	2.8	4.5
arc angle (degrees)	88.0	80.0	95.0
stream length (ft)	102.0		
valley length (ft)	84.0		
Sinuosity	1.2		
Meander Length Ratio	10.3	8.9	11.9
Meander Width Ratio	3.8	3.2	4.4
Radius Ratio	1.0	0.8	1.3

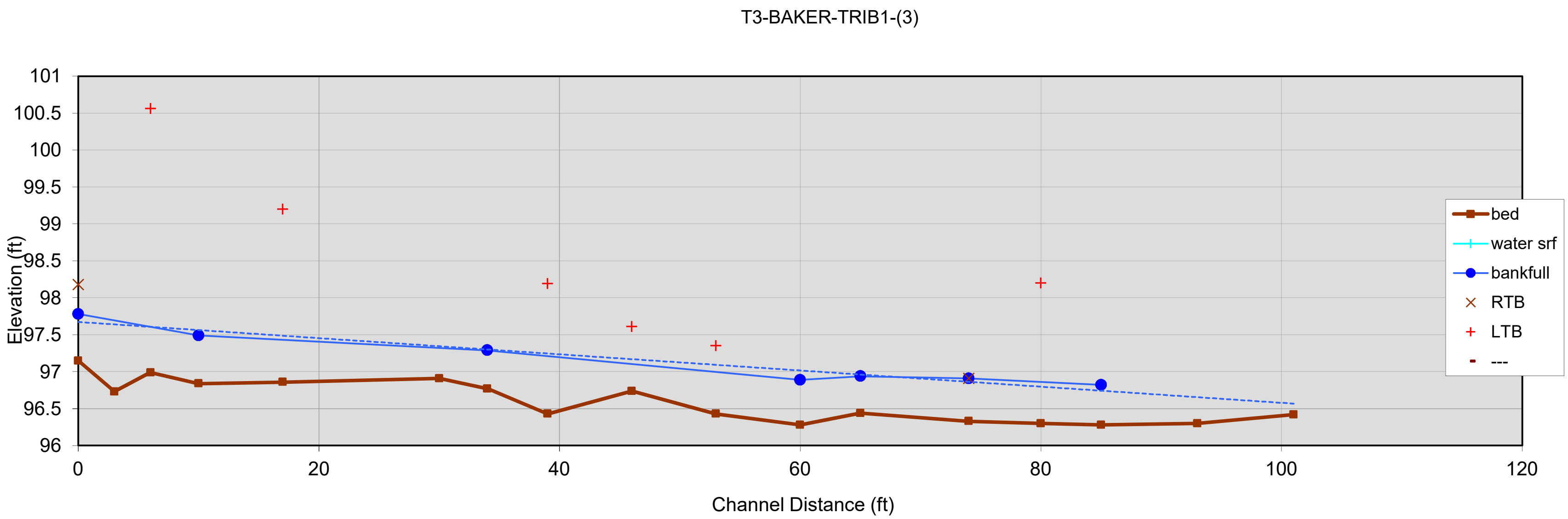
Profile	typical	min	max
pool-pool spacing (ft)	---	---	---
riffle length (ft)	---	---	---
pool length (ft)	---	---	---
run length (ft)	---	---	---
glide length (ft)	---	---	---
channel slope (%)	0.89		
riffle slope (%)	---	---	---
pool slope (%)	---	---	---
run slope (%)	---	---	---
glide slope (%)	---	---	---
measured valley slope (%)	---		
valley slope from sinuosity (%)	1.1		
Riffle Length Ratio	---	---	---
Pool Length Ratio	---	---	---
Run Length Ratio	---	---	---
Glide Length Ratio	---	---	---
Riffle Slope Ratio	---	---	---
Pool Slope Ratio	---	---	---
Run Slope Ratio	---	---	---
Glide Slope Ratio	---	---	---
Pool Spacing Ratio	---	---	---

Reference Reach	
Stream:	T3-BAKER-TRIB1-(3)
Watershed:	North Sulfer River
Location:	LRH Mitigation Area
Latitude:	33.4755
Longitude:	-95.8934
County:	Fannin
Date:	May 10, 2018
Observers:	Tweedy, Starr, Voight
Channel Type:	Bc
Drainage Area (sq.mi)	0.01641

Profile Summary

	typical	min	max
bankfull width (ft)	3.6		
pool-pool spacing (ft)	---	---	---
riffle length (ft)	---	---	---
pool length (ft)	---	---	---
run length (ft)	---	---	---
glide length (ft)	---	---	---
channel slope (%)	0.89		
riffle slope (%)	---	---	---
pool slope (%)	---	---	---
run slope (%)	---	---	---
glide slope (%)	---	---	---
measured valley slope (%)	---		
valley slope from sinuosity (%)	1.1		
Riffle Length Ratio	---	---	---
Pool Length Ratio	---	---	---
Run Length Ratio	---	---	---
Glide Length Ratio	---	---	---
Riffle Slope Ratio	---	---	---
Pool Slope Ratio	---	---	---
Run Slope Ratio	---	---	---
Glide Slope Ratio	---	---	---
Pool Spacing Ratio	---	---	---

Longitudinal Slope Profile



	slope (%)	slope ratio	length (ft)	length ratio	pool-pool spacing (ft)	p-p ratio
reach	0.89	---	101.0 (28.1 channel widt	---	---	---
riffle	---	---	---	---	---	---
pool	---	---	---	---	---	---
	---	---	---	---	---	---
	---	---	---	---	---	---

notes	cross section ID	bed feature	station	station	Benchmark Elevation 100 / Turning Points BS	HI	FS	FS bed	water	FS bankfull	user defined FS RTB	FS LTB	FS	azimuth AZ	ELEV bed	ELEV water srf	ELEV bankfull	ELEV RTB	ELEV LTB	ELEV ---
back sight to benchmark					2.19	102.19														
						102.19														
			0			102.19		5.04							97.15					
			0			102.19				4.41							97.78			
			0			102.19					4.01							98.18		
			3			102.19		5.46							96.73					
			6			102.19		5.2							96.99					
			6			102.19						1.63							100.56	
			10			102.19		5.35							96.84					
			10			102.19				4.7							97.49			
			17			102.19		5.33							96.86					
			17			102.19						2.99							99.2	
			30			102.19		5.28							96.91					
			34			102.19		5.42							96.77					
			34			102.19				4.9							97.29			
			39			102.19		5.76							96.43					
			39			102.19						4							98.19	
			46			102.19		5.45							96.74					
			46			102.19						4.58							97.61	
			53			102.19		5.76							96.43					
			53			102.19						4.84							97.35	
			60			102.19		5.91							96.28					
			60			102.19				5.3							96.89			
			65			102.19		5.75							96.44					
			65			102.19				5.25							96.94			
			74			102.19		5.86							96.33					
			74			102.19				5.28							96.91			
			74			102.19					5.28							96.91		
						102.19	2.19													
			80		1.16	101.16														
			80			101.16		4.86							96.3					
			80			101.16						2.96							98.2	
			85			101.16		4.88							96.28					
			85			101.16				4.34							96.82			
			93			101.16		4.86							96.3					
			101			101.16		4.74							96.42					

Reference Reach

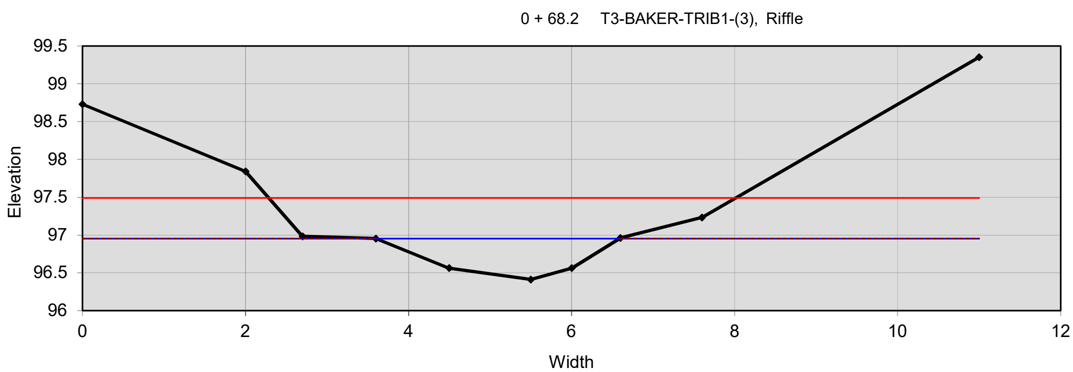
hints

Stream:	T3-BAKER-TRIB1-(3)
Watershed:	North Sulfer River
Location:	LRH Mitigation Area
Latitude:	33.4755
Longitude:	-95.8934
County:	Fannin
Date:	May 10, 2018
Observers:	Tweedy, Starr, Voight
Channel type:	Bc
Drainage area (sq.km)	0.01641

Dimension		bankfull channel		
		typical	min	max
floodplain:	width flood prone area (ft)	5.9	5.7	6.0
	low bank height (ft)	0.6	0.5	0.6
riffle - run	x-area bankfull (sq.ft)	1.4	1.0	1.9
	width bankfull (ft)	3.6	3.0	4.2
	mean depth (ft)	0.39	0.3	0.4
	max depth (ft)	0.6	0.5	0.6
	hydraulic radius (ft)	0.4		
pool:	x-area pool (sq.ft)	2.1	2.1	2.1
	width pool (ft)	4.3	4.3	4.3
	max depth pool (ft)	0.9	0.9	0.9
	hydraulic radius (ft)	0.4		
dimensionless ratios:		typical	min	max
	width depth ratio	9.3	9.0	9.7
	entrenchment ratio	1.6	1.6	1.7
	bank height ratio	1.0	0.8	1.0
	riffle max depth ratio	1.5	1.3	1.5
	pool area ratio	1.5	1.5	1.5
	pool width ratio	1.2	1.2	1.2
	pool max depth ratio	2.3	2.3	2.3

hydraulics:	bankfull channel		
discharge rate (cfs)		---	
channel slope (%)	0.89		
	riffle-run & (range)		pool
velocity (ft/s)	---	---	---
Froude number	---	---	---
shear stress (lbs/sq.ft)			
shear velocity (ft/s)			
stream power (lb/s)	---	(-------)	
unit stream power (lb/s/ft)	---	---	
relative roughness	---	(-------)	
friction factor u/u*	---	---	
threshold grain size (t*=0.06) (mm)			
Shield's parameter	---		

Cross Section



Bankfull Dimensions	
1.0	x-section area (ft.sq.)
3.0	width (ft)
0.3	mean depth (ft)
0.5	max depth (ft)
3.2	wetted parimeter (ft)
0.3	hyd radi (ft)
9.0	width-depth ratio

Flood Dimensions	
5.7	W flood prone area (ft)
1.9	entrenchment ratio
0.5	low bank height (ft)
1.0	low bank height ratio

Materials	
---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow	
---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance	
---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power	
0.89	channel slope (%)
------	shear stress (lb/sq.ft.)
-------	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID:
instrument height: 106.28 ---
longitudinal station: 68.2 ---

Bankfull Stage

FS: ---
elevation: 96.95 96.93

Low Bank Height

FS: ---
elevation: 96.95

Flood Prone Area

width fpa: 5.7 5.7

Channel Slope

percent slope: 0.89 0.89

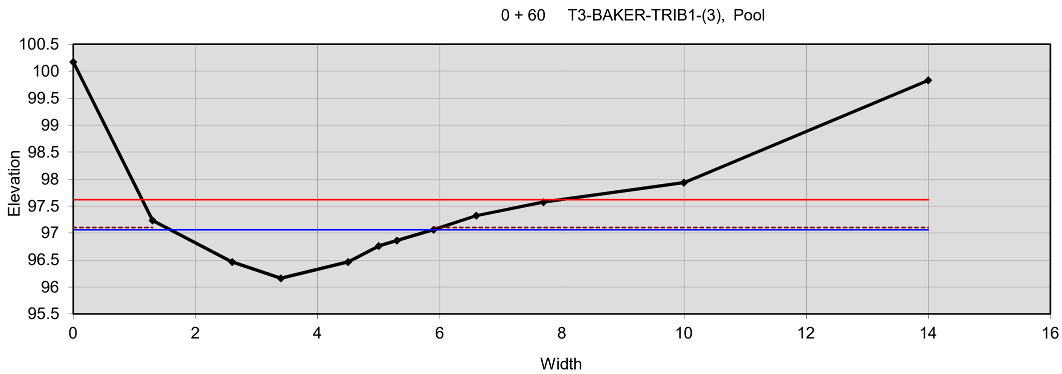
Flow Resistance

Manning's "n": ---
D'Arcy - Weisbach "f": ---

Note:

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes
0		106.28	7.55	98.73		GS
2		106.28	8.44	97.84		GS
2.7		106.28	9.3	96.98		SLP BRK
3.6		106.28	9.33	96.95		BF
4.5		106.28	9.72	96.56		CS
5.5		106.28	9.87	96.41		TW
6		106.28	9.72	96.56		CS
6.6		106.28	9.32	96.96		BF
7.6		106.28	9.05	97.23		GS
11		106.28	6.93	99.35		GS

Cross Section 2



Bankfull Dimensions	
2.1	x-section area (ft.sq.)
4.3	width (ft)
0.5	mean depth (ft)
0.9	max depth (ft)
4.7	wetted parimeter (ft)
0.4	hyd radi (ft)
8.9	width-depth ratio

Flood Dimensions	
6.9	W flood prone area (ft)
1.6	entrenchment ratio
0.9	low bank height (ft)
1.0	low bank height ratio

Materials	
---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow	
---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance	
---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power	
0.89	channel slope (%)
------	shear stress (lb/sq.ft.)
------	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID	2	
instrument height	106.28	---
longitudinal station	60	---

Bankfull Stage

FS		---
elevation	97.06	97.02

Low Bank Height

FS		---
elevation	97.1	

Flood Prone Area

width fpa	6.9	6.9

Channel Slope

percent slope	0.89	0.89

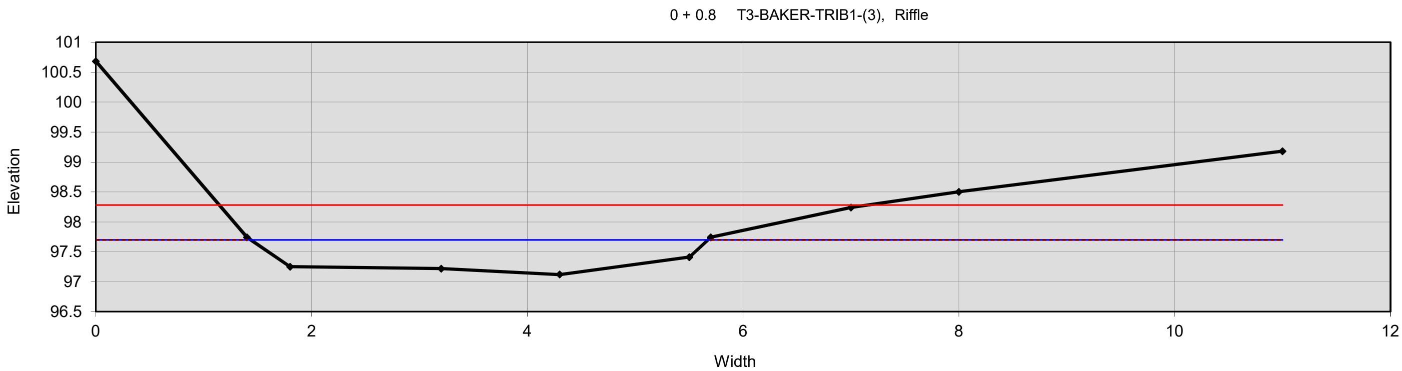
Flow Resistance

Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes
0		106.28	6.11	100.17		GS
1.3		106.28	9.05	97.23		CS
2.6		106.28	9.82	96.46		CS
3.4		106.28	10.12	96.16		TW
4.5		106.28	9.82	96.46		CS
5		106.28	9.52	96.76		BF
5.3		106.28	9.42	96.86		SLP BRK
5.9		106.28	9.22	97.06		SLP BRK
6.6		106.28	8.96	97.32		SLP BRK
7.7		106.28	8.71	97.57		GS
10		106.28	8.35	97.93		GS
14		106.28	6.45	99.83		GS

Cross Section 3



Bankfull Dimensions	
1.9	x-section area (ft.sq.)
4.2	width (ft)
0.4	mean depth (ft)
0.6	max depth (ft)
4.7	wetted parimeter (ft)
0.4	hyd radi (ft)
9.7	width-depth ratio

Flood Dimensions	
6.0	W flood prone area (ft)
1.4	entrenchment ratio
0.6	low bank height (ft)
1.0	low bank height ratio

Materials	
---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow	
---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance	
---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power	
0.89	channel slope (%)
------	shear stress (lb/sq.ft.)
------	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID	3	
instrument height	106.28	---
longitudinal station	0.8	---

Bankfull Stage

FS		---
elevation	97.7	97.66

Low Bank Height

FS		---
elevation	97.7	

Flood Prone Area

width fpa	6	6.0

Channel Slope

percent slope	0.89	0.89

Flow Resistance

Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes	dist	elev	to find d max	97.70 bkf	w	a
0		106.28	5.6	100.68		GS	0	100.68	100.68	97.7		
1.4		106.28	8.54	97.74			1.4	97.74	97.74	97.7	0.0	0.0
1.8		106.28	9.03	97.25		CS	1.8	97.25	97.25	97.7	0.4	0.1
3.2		106.28	9.06	97.22		CS	3.2	97.22	97.22	97.7	1.4	0.7
4.3		106.28	9.16	97.12		TW	4.3	97.12	97.12	97.7	1.1	0.6
5.5		106.28	8.87	97.41		SLP B RK	5.5	97.41	97.41	97.7	1.2	0.5
5.7		106.28	8.54	97.74		SLP BRK	5.7	97.74	97.74	97.7	0.2	0.0
7		106.28	8.04	98.24		GS	7	98.24	98.24	97.7	0.0	0.0
8		106.28	7.78	98.5		GS	8	98.5	98.5	97.7	0.0	0.0
11		106.28	7.1	99.18		GS	11	99.18	99.18	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0
							#N/A	#N/A	1106.28	97.7	0.0	0.0

Meander Pattern - Channel Plan Form

This Worksheet

1) This sheet will graph the distance and azimuth entered in the profile worksheet.

2) Fill in the values below using the graphed pattern, aerial photos, topo maps, etc.

3) Before printing the graph, its width or height may need adjusting. "Square" the graph by clicking and dragging.

4) more info

Meander Length

		min	max
meander length (ft)	37	32	43

Meander Width

		min	max
belt width (ft)	13.8	11.6	16
amplitude (ft)			

Bends

		min	max
radius (ft)	3.7	2.8	4.5
arc angle (degrees)	88	80	95

Sinuosity

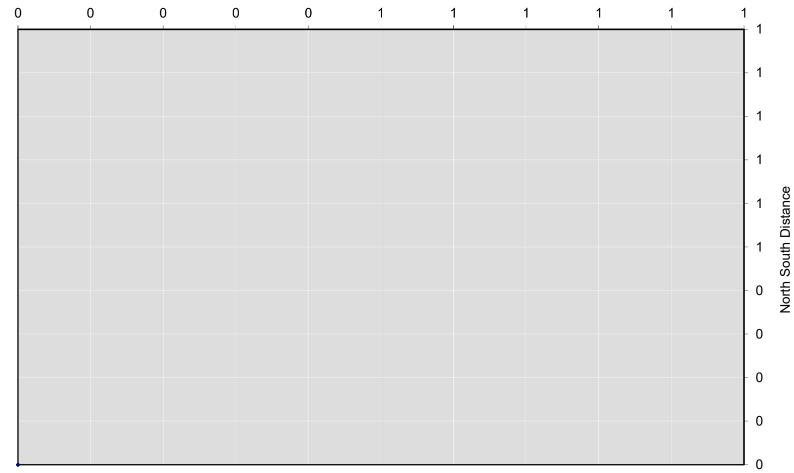
stream length (ft)	102
valley length (ft)	84

Graph Format

Z scale: 10

show banks

show centerline



Dimensions (ft)	
Bankfull Width:	3.6
Meander Length:	37 (32 - 43)
Belt Width:	13.8 (11.6 - 16)
Radius of Curvature:	3.7 (2.8 - 4.5)

Ratios	
Sinuosity:	1.2
Meander Length Ratio:	10.3 (8.9 - 11.9)
Meander Width Ratio:	3.8 (3.2 - 4.4)
Radius / BkF Width:	1 (0.8 - 1.3)

Reference Reach

Stream:	T3-BAKER-TRIB1-(3)
Watershed:	North Sulfer River
Location:	LRH Mitigation Area
Latitude:	33.4755
Longitude:	-95.8934
County:	Fannin
Date:	May 10, 2018
Observers:	Tweedy, Starr, Voight
Channel Type:	Bc
Drainage Area (sq.mi):	0.01641

Pattern

	typical	min	max
bankfull width (ft)	3.60		
meander length (ft)	37.0	32.0	43.0
belt width (ft)	13.8	11.6	16.0
amplitude (ft)	---	---	---
radius (ft)	3.7	2.8	4.5
arc angle (degrees)	88.0	80.0	95.0
stream length (ft)	102.0		
valley length (ft)	84.0		
Sinuosity	1.21		
Meander Length Ratio	10.3	8.9	11.9
Meander Width Ratio	3.8	3.2	4.4
Radius Ratio	1.0	0.8	1.3

Reach T3-BAKER-TRIB1-(3)

Reach T3-BAKER-TRIB1-B2-(1)

Summary

Stream:	T3-BAKER-TRIB1-B2-(1)
Watershed:	North Sulfur River
Location:	LRH Mitigation Area
Latitude:	33.47477
Longitude:	-95.89392
State:	Texas
County:	Fannin
Date:	May 10, 2018
Observers:	Tweedy, Starr, Voight
Channel type:	Eb
Drainage area (sq.mi.):	0.0032
notes:	---

Dimension		bankfull channel			
		typical	min	max	
floodplain:	width flood prone area (ft)	6.2	5.8	6.6	
	low bank height (ft)	0.6	0.6	0.7	
riffle-run:	x-area bankfull (sq.ft.)	1.0	1.0	1.0	
	width bankfull (ft)	2.4	2.0	2.9	
	mean depth (ft)	0.42	0.4	0.5	
	max depth (ft)	0.7	0.6	0.7	
	hydraulic radius (ft)	0.3			
pool:	x-area pool (sq.ft.)	1.7	1.7	1.7	
	width pool (ft)	2.7	2.7	2.7	
	max depth pool (ft)	0.9	0.9	0.9	
	hydraulic radius (ft)	0.5			
dimensionless ratios:		typical	min	max	
	width depth ratio	5.8	3.9	8.3	
	entrenchment ratio	2.6	2.4	2.8	
	riffle max depth ratio	1.7	1.4	1.7	
	bank height ratio	0.9	0.9	1.0	
	pool area ratio	1.7	1.7	1.7	
	pool width ratio	1.1	1.1	1.1	
	pool max depth ratio	2.2	2.2	2.2	
hydraulics:		typical	min	max	
	discharge rate (cfs)		---	---	
	channel slope (%)	3			
		riffle-run	min	max	pool
	velocity (ft/s)	---	---	---	---
	Froude number	---	---	---	---
	shear stress (lbs/sq.ft.)				
	shear velocity (ft/s)				
	stream power (lb/s)	---	---	---	
	unit stream power (lb/ft/s)	---	---	---	
	relative roughness	---	---	---	
	friction factor u/u*	---	---	---	
	threshold grain size (t*=0.06) (mm)				
	Shield's parameter	---			
Pattern					
		typical	min	max	
	meander length (ft)	24.5	24.0	25.0	
	belt width (ft)	5.3	5.0	5.5	
	amplitude (ft)	---	---	---	
	radius (ft)	2.6	2.5	2.7	
	arc angle (degrees)	56.0	42.0	70.0	
	stream length (ft)	89.0			
	valley length (ft)	79.0			
	Sinuosity	1.1			
	Meander Length Ratio	10.2	10.0	10.4	
	Meander Width Ratio	2.2	2.1	2.3	
	Radius Ratio	1.1	1.0	1.1	
Profile					
		typical	min	max	
	pool-pool spacing (ft)	---	---	---	
	riffle length (ft)	---	---	---	
	pool length (ft)	---	---	---	
	run length (ft)	---	---	---	
	glide length (ft)	---	---	---	
	channel slope (%)	3			
	riffle slope (%)	---	---	---	
	pool slope (%)	---	---	---	
	run slope (%)	---	---	---	
	glide slope (%)	---	---	---	
	measured valley slope (%)	---			
	valley slope from sinuosity (%)	3.4			
	Riffle Length Ratio	---	---	---	
	Pool Length Ratio	---	---	---	
	Run Length Ratio	---	---	---	
	Glide Length Ratio	---	---	---	
	Riffle Slope Ratio	---	---	---	
	Pool Slope Ratio	---	---	---	
	Run Slope Ratio	---	---	---	
	Glide Slope Ratio	---	---	---	
	Pool Spacing Ratio	---	---	---	

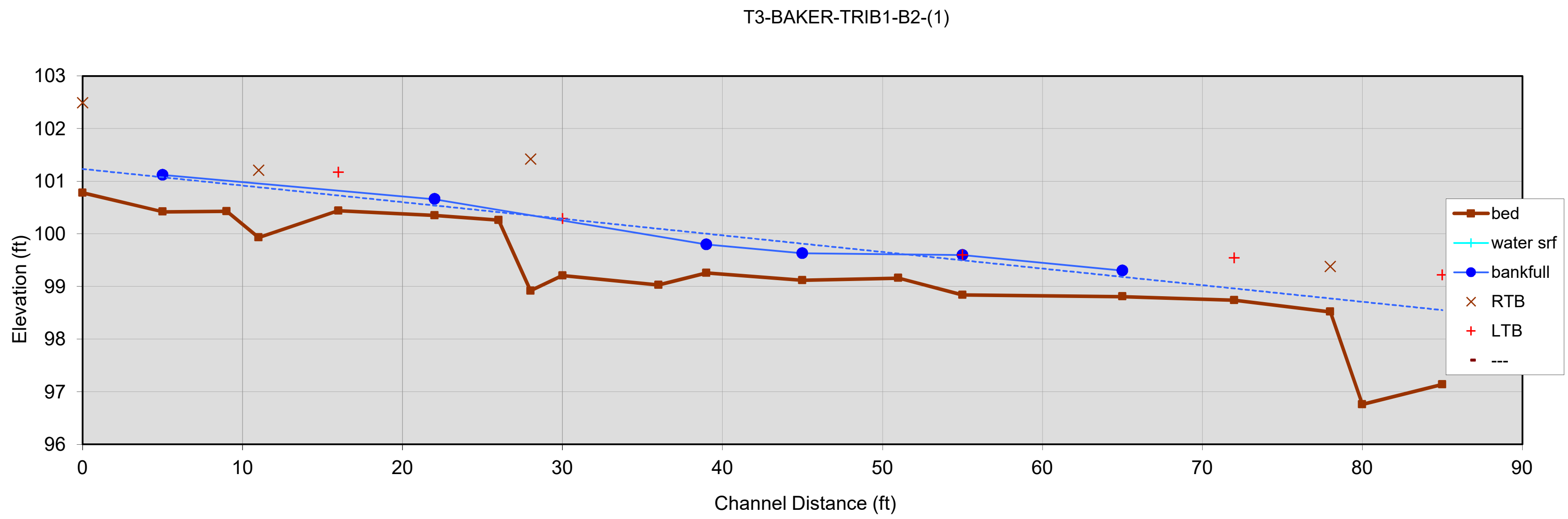
Reference Reach

Stream:	T3-BAKER-TRIB1-B2-(1)
Watershed:	North Sulfur River
Location:	LRH Mitigation Area
Latitude:	33.4748
Longitude:	-95.8939
County:	Fannin
Date:	May 10, 2018
Observers:	Tweedy, Starr, Voight
Channel Type:	Eb
Drainage Area (sq.mi)	0.0032

Profile Summary

	typical	min	max
bankfull width (ft)	2.4		
pool-pool spacing (ft)	---	---	---
riffle length (ft)	---	---	---
pool length (ft)	---	---	---
run length (ft)	---	---	---
glide length (ft)	---	---	---
channel slope (%)	3		
riffle slope (%)	---	---	---
pool slope (%)	---	---	---
run slope (%)	---	---	---
glide slope (%)	---	---	---
measured valley slope (%)	---		
valley slope from sinuosity (%)	3.4		
Riffle Length Ratio	---	---	---
Pool Length Ratio	---	---	---
Run Length Ratio	---	---	---
Glide Length Ratio	---	---	---
Riffle Slope Ratio	---	---	---
Pool Slope Ratio	---	---	---
Run Slope Ratio	---	---	---
Glide Slope Ratio	---	---	---
Pool Spacing Ratio	---	---	---

Longitudinal Slope Profile



	slope (%)	slope ratio	length (ft)	length ratio	pool-pool spacing (ft)	p-p ratio
reach	3	---	85.0 (35.4 channel widt	---	---	---
riffle	---	---	---	---	---	---
pool	---	---	---	---	---	---
	---	---	---	---	---	---
	---	---	---	---	---	---

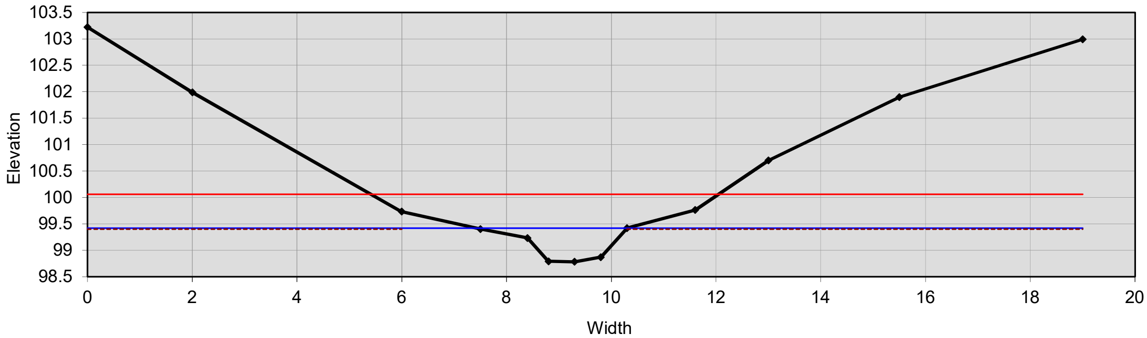
notes	cross section ID	bed feature	station	station	Benchmark Elevation 100 / Turning Points BS	HI	FS	FS bed	water	FS bankfull	user defined FS RTB	FS LTB	FS	azimuth AZ	ELEV bed	ELEV water srf	ELEV bankfull	ELEV RTB	ELEV LTB	ELEV ---
back sight to benchmark					6.54	106.54														
			0			106.54		5.76							100.78					
			0			106.54					4.05							102.49		
			5			106.54		6.12							100.42					
			5			106.54				5.42							101.12			
TREE ROOTS			9			106.54		6.11							100.43					
			11			106.54		6.61							99.93					
			11			106.54					5.33							101.21		
			16			106.54		6.1							100.44					
			16			106.54						5.37							101.17	
			22			106.54		6.19							100.35					
			22			106.54				5.88							100.66			
TREE ROOTS/DEBRIS JAM			26			106.54		6.28							100.26					
			28			106.54		7.62							98.92					
			28			106.54					5.12							101.42		
			30			106.54		7.33							99.21					
			30			106.54						6.25							100.29	
SCOUR TREE TRUNK			36			106.54		7.51							99.03					
			36			106.54														
			39			106.54		7.28							99.26					
			39			106.54				6.74							99.8			
			45			106.54		7.42							99.12					
			45			106.54				6.91							99.63			
			51			106.54		7.38							99.16					
			55			106.54		7.7							98.84					
			55			106.54				6.94							99.6			
			55			106.54						6.94							99.6	
			65			106.54		7.73							98.81					
			65			106.54				7.24							99.3			
			72			106.54		7.8							98.74					
			72			106.54						7							99.54	
DEBRIS JAM			78			106.54		8.02							98.52					
			78			106.54					7.16							99.38		
			80			106.54		9.78							96.76					
			85			106.54		9.4							97.14					
			85			106.54						7.32							99.22	

Reference Reach				hints
Stream:	T3-BAKER-TRIB1-B2-(1)			
Watershed:	North Sulfur River			
Location:	LRH Mitigation Area			
Latitude:	33.4748			
Longitude:	-95.8939			
County:	Fannin			
Date:	May 10, 2018			
Observers:	Tweedy, Starr, Voight			
Channel type:	Eb			
Drainage area (sq.km)	0.0032			

Dimension		bankfull channel		
		typical	min	max
floodplain:	width flood prone area (ft)	6.2	5.8	6.6
	low bank height (ft)	0.6	0.6	0.7
riffle - run	x-area bankfull (sq.ft)	1.0	1.0	1.0
	width bankfull (ft)	2.4	2.0	2.9
	mean depth (ft)	0.42	0.4	0.5
	max depth (ft)	0.7	0.6	0.7
	hydraulic radius (ft)	0.3		
pool:	x-area pool (sq.ft)	1.7	1.7	1.7
	width pool (ft)	2.7	2.7	2.7
	max depth pool (ft)	0.9	0.9	0.9
	hydraulic radius (ft)	0.5		
dimensionless ratios:		typical	min	max
	width depth ratio	5.8	3.9	8.3
	entrenchment ratio	2.6	2.4	2.8
	bank height ratio	0.9	0.9	1.0
	riffle max depth ratio	1.7	1.4	1.7
	pool area ratio	1.7	1.7	1.7
	pool width ratio	1.1	1.1	1.1
	pool max depth ratio	2.2	2.2	2.2

hydraulics:	bankfull channel		
discharge rate (cfs)		---	
channel slope (%)	3		
	riffle-run & (range)		pool
velocity (ft/s)	---	---	---
Froude number	---	---	---
shear stress (lbs/sq.ft)			
shear velocity (ft/s)			
stream power (lb/s)	---	(-------)	
unit stream power (lb/s/ft)	---	---	
relative roughness	---	(-------)	
friction factor u/u*	---	---	
threshold grain size (t*=0.06) (mm)			
Shield's parameter	---		

Cross Section



Bankfull Dimensions	
1.0	x-section area (ft.sq.)
2.9	width (ft)
0.4	mean depth (ft)
0.6	max depth (ft)
3.4	wetted parimeter (ft)
0.3	hyd radi (ft)
8.3	width-depth ratio

Flood Dimensions	
6.6	W flood prone area (ft)
2.3	entrenchment ratio
0.6	low bank height (ft)
1.0	low bank height ratio

Materials	
---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow	
---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance	
---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power	
3	channel slope (%)
	shear stress (lb/sq.ft.)
	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID		
instrument height	104.7	---
longitudinal station	63.5	---

Bankfull Stage

FS		---
elevation	99.42	99.23

Low Bank Height

FS		---
elevation	99.4	

Flood Prone Area

width fpa	6.6	6.6

Channel Slope

percent slope	3	3

Flow Resistance

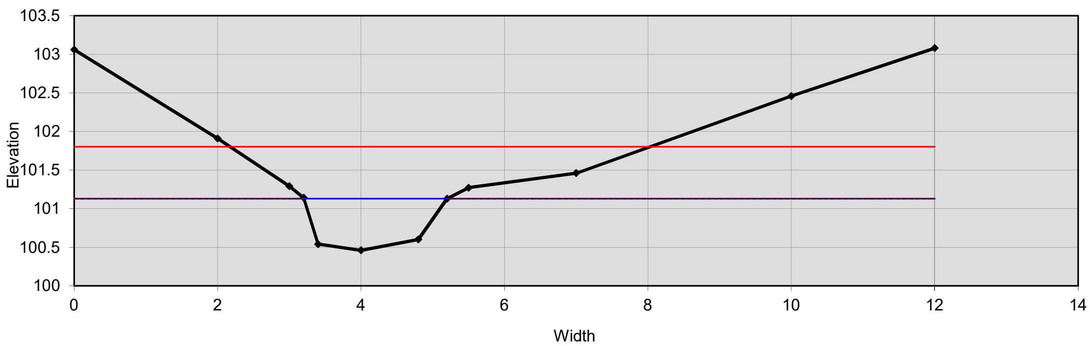
Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes
0		104.7	1.48	103.22		LPIN
2		104.7	2.71	101.99		GS
6		104.7	4.97	99.73		GS
7.5		104.7	5.3	99.4		BACK OF BENCH
8.4		104.7	5.47	99.23		FRONT OF BENCH
8.8		104.7	5.91	98.79		LEFT CHANNEL
9.3		104.7	5.92	98.78		TW
9.8		104.7	5.83	98.87		CHANNEL
10.3		104.7	5.28	99.42		TOB/BF
11.6		104.7	4.94	99.76		BACK OF BENCH
13		104.7	4	100.7		GS
15.5		104.7	2.8	101.9		GS
19		104.7	1.71	102.99		RPIN

Cross Section 2

0 + 5 T3-BAKER-TRIB1-B2-(1), Riffle



Bankfull Dimensions	
1.0	x-section area (ft.sq.)
2.0	width (ft)
0.5	mean depth (ft)
0.7	max depth (ft)
2.7	wetted parimeter (ft)
0.4	hyd radi (ft)
3.9	width-depth ratio

Flood Dimensions	
5.8	W flood prone area (ft)
2.9	entrenchment ratio
0.7	low bank height (ft)
1.0	low bank height ratio

Materials	
---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow	
---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance	
---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power	
3	channel slope (%)
	shear stress (lb/sq.ft.)
	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID	2	
instrument height	107.56	---
longitudinal station	5	---

Bankfull Stage

FS		---
elevation	101.13	101.08

Low Bank Height

FS		---
elevation	101.13	

Flood Prone Area

width fpa	5.8	5.8

Channel Slope

percent slope	3	3

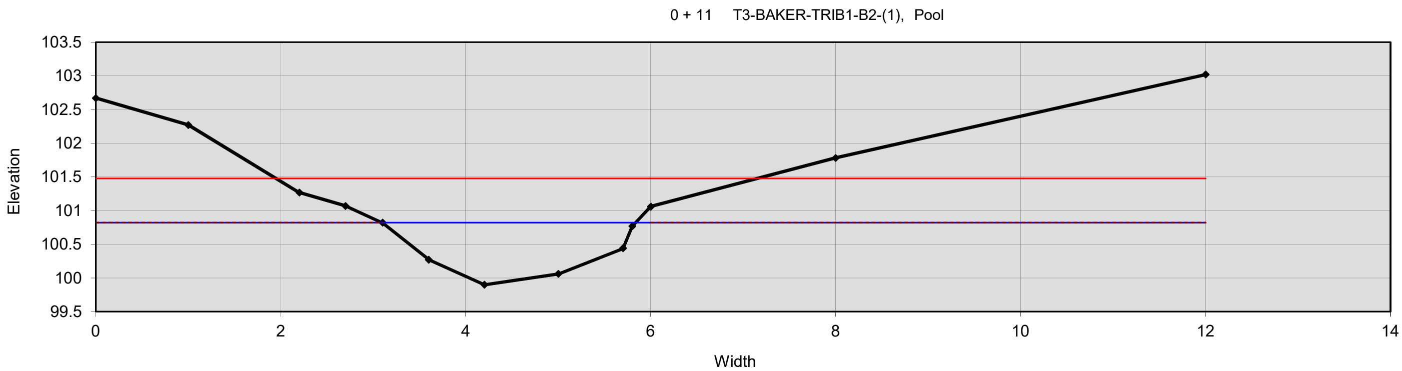
Flow Resistance

Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes
0		107.56	4.5	103.06		GS
2		107.56	5.65	101.91		GS
3		107.56	6.27	101.29		BF
3.2		107.56	6.42	101.14		CS
3.4		107.56	7.02	100.54		SLP BRK
4		107.56	7.1	100.46		TW
4.8		107.56	6.96	100.6		CS
5.2		107.56	6.43	101.13		SLP BRK
5.5		107.56	6.29	101.27		SLP BRK
7		107.56	6.1	101.46		GS
10		107.56	5.1	102.46		GS
12		107.56	4.48	103.08		GS

Cross Section 3



Bankfull Dimensions

1.7	x-section area (ft.sq.)
2.7	width (ft)
0.6	mean depth (ft)
0.9	max depth (ft)
3.5	wetted parimeter (ft)
0.5	hyd radi (ft)
4.5	width-depth ratio

Flood Dimensions

5.2	W flood prone area (ft)
1.9	entrenchment ratio
0.9	low bank height (ft)
1.0	low bank height ratio

Materials

---	D50 (mm)
---	D84 (mm)
	threshold grain size (mm):

Bankfull Flow

---	velocity (ft/s)
---	discharge rate (cfs)
---	Froude number

Flow Resistance

---	Manning's roughness
---	D'Arcy-Weisbach fric.
---	resistance factor u/u*
---	relative roughness

Forces & Power

3	channel slope (%)
	shear stress (lb/sq.ft.)
	shear velocity (ft/s)
---	unit strm power (lb/ft/s)

Cross Section

reference ID	3	
instrument height	107.56	---
longitudinal station	11	---

Bankfull Stage

FS		---
elevation	100.82	100.89

Low Bank Height

FS		---
elevation	100.82	

Flood Prone Area

width fpa	5.2	5.2

Channel Slope

percent slope	3	3

Flow Resistance

Manning's "n"		---
D'Arcy - Weisbach "f"		---

Note:

Distance (ft)	BS (ft)	HI (ft)	FS (ft)	Elevation (ft)	Omit Bkf	Notes	dist	elev	to find d max	100.82 bkf	w	a
0		107.56	4.89	102.67		GS	0	102.67	102.67	100.8		
1		107.56	5.29	102.27		GS	1	102.27	102.27	100.8	0.0	0.0
2.2		107.56	6.29	101.27		GS	2.2	101.27	101.27	100.8	0.0	0.0
2.7		107.56	6.49	101.07		SLP BRK	2.7	101.07	101.07	100.8	0.0	0.0
3.1		107.56	6.74	100.82		SLP BRK	3.1	100.82	100.82	100.8	0.0	0.0
3.6		107.56	7.29	100.27		CS	3.6	100.27	100.27	100.8	0.5	0.1
4.2		107.56	7.66	99.9		TW	4.2	99.9	99.9	100.8	0.6	0.4
5		107.56	7.5	100.06		CS	5	100.06	100.06	100.8	0.8	0.7
5.7		107.56	7.12	100.44		CS	5.7	100.44	100.44	100.8	0.7	0.4
5.8		107.56	6.79	100.77		SCOUR	5.8	100.77	100.77	100.8	0.1	0.0
6		107.56	6.5	101.06		SLP BRK	6	101.06	101.06	100.8	0.0	0.0
8		107.56	5.78	101.78		GS	8	101.78	101.78	100.8	0.0	0.0
12		107.56	4.54	103.02		GS	12	103.02	103.02	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0
							#N/A	#N/A	1107.56	100.8	0.0	0.0

Meander Pattern - Channel Plan Form

This Worksheet

1) This sheet will graph the distance and azimuth entered in the profile worksheet.

2) Fill in the values below using the graphed pattern, aerial photos, topo maps, etc.

3) Before printing the graph, its width or height may need adjusting. "Square" the graph by clicking and dragging.

4) more info

Meander Length

		min	max
meander length (ft)	24.5	24	25

Meander Width

		min	max
belt width (ft)	5.3	5	5.5
amplitude (ft)			

Bends

		min	max
radius (ft)	2.6	2.5	2.7
arc angle (degrees)	56	42	70

Sinuosity

stream length (ft)	89
valley length (ft)	79

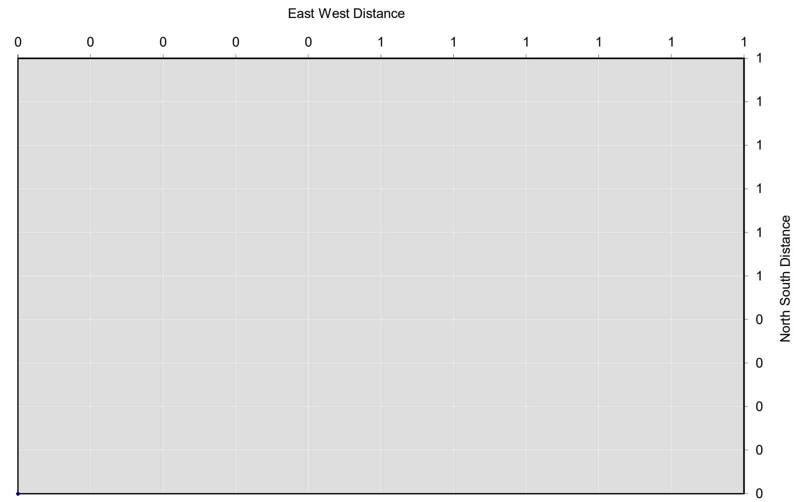
Graph Format

Z scale: 10

show banks

show centerline

T3-BAKER-TRIB1-B2-(1) North Sulfur River LRH Mitigation Area



Dimensions (ft)		Ratios	
Bankfull Width:	2.4	Sinuosity:	1.13
Meander Length:	24.5 (24 - 25)	Meander Length Ratio:	10.2 (10 - 10.4)
Belt Width:	5.3 (5 - 5.5)	Meander Width Ratio:	2.2 (2.1 - 2.3)
Radius of Curvature:	2.6 (2.5 - 2.7)	Radius / BkF Width:	1.1 (1 - 1.1)

Reference Reach

Stream:	T3-BAKER-TRIB1-B2-(1)
Watershed:	North Sulfur River
Location:	LRH Mitigation Area
Latitude:	33.4748
Longitude:	-95.8939
County:	Fannin
Date:	May 10, 2018
Observers:	Tweedy, Starr, Voight
Channel Type:	Eb
Drainage Area (sq.mi):	0.0032

Pattern

	typical	min	max
bankfull width (ft)	2.40		
meander length (ft)	24.5	24.0	25.0
belt width (ft)	5.3	5.0	5.5
amplitude (ft)	---	---	---
radius (ft)	2.6	2.5	2.7
arc angle (degrees)	56.0	42.0	70.0
stream length (ft)	89.0		
valley length (ft)	79.0		
Sinuosity	1.1		
Meander Length Ratio	10.2	10.0	10.4
Meander Width Ratio	2.2	2.1	2.3
Radius Ratio	1.1	1.0	1.1

Reach T3-BAKER-TRIB1-B2-(1)

Analysis of Stream Hydrology for the Restored Former North Sulphur River

Date: July 12, 2019

Prepared For: Upper Trinity Regional Water District (UTRWD)

Prepared By: Ecosystem Planning and Restoration, LLC

1. INTRODUCTION

This memorandum has been prepared to evaluate the expected hydrology of the stream mitigation work proposed for the former North Sulphur River (FNSR). The mitigation practices proposed for the FNSR are being conducted to offset impacts to waters of the US due to the construction of Lake Ralph Hall in Fannin County, Texas. Previous studies (discussed below) have evaluated the proposed work and determined that the restored FNSR channel would maintain water in the pools for prolonged periods of time, functioning as an intermittent stream with perennial pools. Since the previous studies were conducted, the mitigation designs have been further refined for the FNSR; therefore, this memorandum will provide an updated hydrologic analysis of the proposed design.

The FNSR in its current location represents the location of the North Sulphur River prior to channelization and straightening of the river that occurred in the 1920's. Channelization of the NSR resulted in the FNSR channel being cut-off from most of its historic watershed which included approximately 86 square miles. In its current condition the FNSR is supported by a drainage area of approximately 0.97 to 2.79 square miles. The mitigation designs for the FNSR and its supporting tributaries includes stabilizing the eroding channels and providing improved floodplain connection and riparian vegetation. Riparian buffers will be restored along all mitigation reaches. The design for the FNSR includes raising the stream bed so that the stream is connected to its historic floodplain and sizing the restored channel to its watershed conditions and bankfull discharge. Because of the low valley slope, most of the restored FNSR will be a sinuous channel that incorporates wood and some rock structures to promote stability, improved bed form stability, and improved aquatic habitats. Shallow riffles will be present between meander bends with deeper pools (3 to 4 feet deep) in the meander bends themselves. Near the downstream end of the restored FNSR, the valley slope will increase and a floodplain bench will be constructed for the restored FNSR channel, since the restored FNSR will have to connect to the deeper restored NSR channel at the downstream end of the project. In this steeper section, the restored channel will be less sinuous, and pools will be scoured and maintained primarily by the wood and rock structures that are proposed.

2. METHODS

Previous Studies

The expected hydrology of the restored FNSR was formerly evaluated by Dr. Robert Brandes with the results presented in a memorandum dated February 24, 2017. In the February 2017 memorandum, Dr. Brandes summarizes the methods that were used to perform the analyses, and the associated results. Based on his analyses, Dr. Brandes concluded that during a 76-year simulation period, the FNSR restored channel would have water present in its pools in all modeled years, supporting the conclusion that the restored FNSR be considered a channel with intermittent flow and perennial pools.

However, the analysis conducted by Dr. Brandes used some design assumptions that are no longer accurate, based on refined design plans for the restored FNSR. Therefore, UTRWD requested that EPR re-evaluate the analysis done by Dr. Brandis and update the models accordingly to predict the hydrologic conditions of the restored FNSR.

Methods Used for Updated Hydrologic Analysis

For the hydrologic analyses presented in this memorandum, the analyses performed by Dr. Brandes in 2017 were duplicated for the updated analyses, since these former analyses were reviewed and approved by UTRWD and regulatory agencies. The following assumptions and methods used by Dr. Brandes were also used in this updated analysis:

- The same 76-year period of rainfall (Table 2) and evaporation data used in the original study were used for the updated analyses for comparisons to be made between the original results and the updated results.
- The same spreadsheet model was used for this updated analysis, with the modifications and updates described below.
- Modeling assumed that any water stage higher than the full pool level in the stream would be immediately delivered to the NSR, which is considered a conservative approach as described in the original study.
- Pool and riffle reaches were combined into a single waterbody for analysis of each modeled stream reach.
- The model performs a mass balance calculation for each day of the simulation period to determine the end-of-day water amount in model reach pools.

However, several model inputs and assumptions were updated and modified based on updated design plans for the restored FNSR. The model parameters that were changed are:

- Drainage areas for the restored FNSR were updated based on detailed site topography and revised design stream alignments. Further, subreaches of the restored FNSR were modeled individually to account for changes in drainage area that occur along the restored stream as other restored tributaries enter the system. This approach was suggested by Dr. Brandes in his original report as a means to provide more accurate results. As seen in Figure 1, the EPR analyses were performed for each sub-reach [S2-3(a), S2-3(b), S2-3(c), and S2-3(d)] to provide a more detailed analysis for the hydrology of each design reach along the restored FNSR.

- Channel sizes were modified to reflect current design plans. In particular, the pools that Dr. Brandes modeled were considerably deeper than the current design plans (7 feet deep versus 3 to 4 feet deep, respectively). To be conservative, pool depths of approximately 3 feet (the shallower end of the design range) were used for modeling purposes.
- The number, area, and volume of pools along the reach were updated to reflect the current design plans.

3. RESULTS

The updated hydrologic analyses performed by EPR were used to determine if the conclusions from the previous Brandes study are appropriate and that the restored FNSR would be considered an intermittent channel with perennial pools. Dr. Brandes' model provided conservative results in part because of the relatively deep pools of 7 feet used in the channel geometry. Given that the design pools for the updated EPR model were much shallower at approximately 3 feet, the results provide a better visualization of what the water will do in the restored channel.

Table 1 below represents the modeled results as determined by EPR. The results are provided both in terms of storage, like the original Brandes report, as well as the predicted minimum depth of water in the pools. The results show that for the reach with the smallest drainage area of 621 acres, over the same 76-year data period, the minimum stage reached was 0.11 ac-ft, or 1.15 ft of depth in the pools, occurring during the 1956 drought year. Modeled results for the first three reaches were all relatively similar in their hydrologic properties, with the minimum depths being between 1.15 and 1.17 ft. The fourth reach [S2-3(d)] exhibits an increased minimum depth, which is to be expected as it incorporates a much larger drainage area. Channel geometry and the main spreadsheet calculations for S2-3(a) are shown in Tables 4, 5, 6, and Figure 2 below.

Table 1. Summary of EPR hydrology analysis.

Reach	Contributing Watersheds	Drainage Area (ac)	Reach Length (ft)	Minimum Storage (ac-ft)	Minimum Depth (ft)
S2-3(a)	1, 2	621	2234.58	0.11	1.15
S2-3(b)	1, 2, 3	710	2060.71	0.11	1.17
S2-3(c)	1, 2, 3, 4	1094	1287.66	0.06	1.15
S2-3(d)	1, 2, 3, 4, 5	1606	1882.97	0.08	1.38

The results gathered by EPR and those gathered by Dr. Brandes show similar results, both predicting that the hydrology of the restored FNSR channel will maintain water in the pools for extended durations, even during dry years. Although the results from the original model show a wetter minimum condition than EPR's results, with depths in the deeper pools at a minimum of 4.27 ft and in the shallower pools at 0.27 ft, this can be explained by the smaller pool volume being used in the updated model, and a slight decrease in the modeled drainage area. All the reaches modeled maintained water in the pools during the 1956 drought period as well, which is the same as the Brandes model showed. After analyzing the results, EPR believes the designation as an intermittent channel with perennial pools is appropriate for the restored FNSR.

Figure 1. Modeled reach designations and the contributing watersheds.

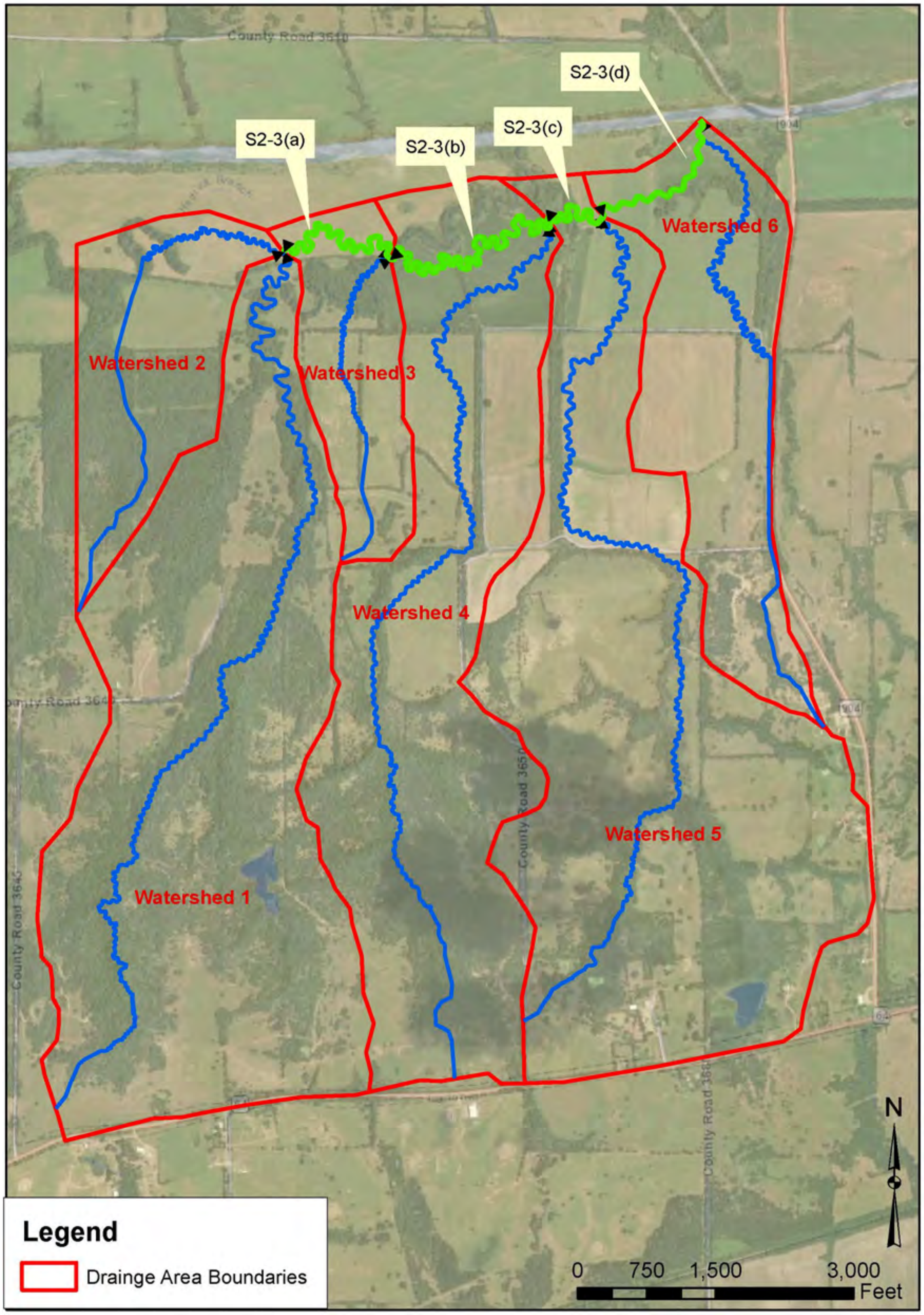


Table 2: Rainfall data used for modeling the S2-3 design reaches.

LAKE RALPH HALL REGIONAL RAINFALL DATA (INCHES)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1940	0.00	3.45	1.11	6.77	8.03	4.01	4.74	1.55	1.32	3.25	6.82	6.70	47.75
1941	0.60	3.57	2.55	7.44	3.96	12.27	6.14	1.68	1.05	8.06	0.92	2.90	51.14
1942	0.80	0.80	2.78	12.40	4.62	5.89	0.00	3.20	8.38	2.98	2.98	3.33	48.16
1943	0.21	1.81	4.78	2.61	3.59	6.59	0.17	0.00	2.65	1.19	1.01	3.13	27.74
1944	2.95	5.60	3.25	2.63	8.22	2.34	2.04	5.02	1.45	1.23	5.80	4.38	44.91
1945	2.60	8.42	7.78	1.87	3.03	8.03	4.12	2.35	8.18	6.30	1.55	0.85	55.08
1946	3.70	3.75	4.83	3.03	8.47	2.23	0.20	5.33	3.00	1.47	12.09	4.58	52.68
1947	1.40	0.50	4.42	5.31	3.43	2.80	1.24	4.91	3.85	1.93	3.53	8.48	41.80
1948	0.70	4.71	2.51	2.56	9.53	3.35	3.75	0.52	0.50	4.16	0.82	2.16	35.27
1949	11.38	5.14	2.75	6.01	2.48	6.27	4.21	5.63	2.47	6.08	0.70	3.31	56.43
1950	9.78	4.65	1.15	3.75	8.80	2.08	11.20	3.81	4.26	0.90	0.00	0.65	51.03
1951	2.81	2.28	0.55	3.25	4.19	12.92	3.17	0.42	4.01	4.87	1.20	0.71	40.38
1952	1.03	1.75	5.20	9.82	5.00	0.65	2.45	0.55	1.47	0.10	6.72	3.22	37.96
1953	1.50	1.02	4.53	8.75	2.43	0.22	6.48	3.72	2.52	2.40	3.75	3.96	41.28
1954	4.15	1.50	0.80	4.72	9.74	3.38	0.25	2.30	6.55	8.28	1.02	1.70	44.39
1955	1.65	1.45	5.25	5.50	3.10	1.45	5.50	4.38	3.70	4.55	0.60	0.82	37.95
1956	2.40	6.06	1.24	3.10	2.65	0.35	0.00	1.50	0.00	2.50	4.39	1.92	26.11
1957	1.90	2.60	7.31	11.91	16.64	6.33	0.25	0.60	6.60	3.87	10.28	2.35	70.64
1958	5.80	1.03	4.98	5.89	5.23	7.50	2.56	1.80	3.40	1.60	1.94	2.68	44.41
1959	0.40	1.55	3.10	1.26	3.60	6.86	8.15	1.70	2.75	4.45	1.30	4.82	39.94
1960	3.60	2.62	1.85	2.15	2.09	7.10	4.00	2.65	4.75	4.45	1.55	7.15	43.96
1961	1.70	2.55	7.10	0.85	2.68	4.82	3.10	2.15	3.65	1.95	4.31	3.85	38.71
1962	3.40	2.30	2.75	4.00	1.75	11.45	5.08	5.05	9.00	5.75	4.50	0.70	55.73
1963	0.80	0.55	1.65	4.60	2.30	1.51	3.45	1.10	0.95	0.05	1.80	1.47	20.23
1964	1.35	2.05	4.48	5.92	5.65	5.05	0.15	3.25	9.22	0.60	5.58	1.10	44.40
1965	2.15	5.85	1.70	1.63	6.20	3.71	0.42	1.30	5.82	1.69	4.95	1.30	36.72
1966	1.03	3.20	1.18	14.55	3.70	1.34	4.35	4.37	3.51	1.00	0.45	2.89	41.57
1967	0.38	1.47	3.74	8.95	8.29	1.30	3.95	1.80	6.88	6.05	1.30	4.13	48.24
1968	2.80	1.70	8.70	6.07	6.15	8.47	5.80	3.00	7.55	2.28	4.95	3.59	61.06
1969	4.30	3.60	5.20	2.70	17.30	3.91	0.00	1.23	4.55	4.81	0.73	5.42	53.75
1970	1.00	4.80	3.77	5.01	2.01	1.30	0.40	2.60	10.20	5.55	2.25	1.05	39.94
1971	1.30	2.25	1.10	0.20	4.35	0.84	4.82	4.17	3.48	10.50	2.75	13.68	49.44
1972	1.01	0.70	1.13	2.02	2.42	2.45	1.48	3.13	2.73	8.41	4.58	2.17	32.23
1973	2.80	2.99	5.60	4.60	2.60	5.75	3.15	1.08	13.39	5.48	3.42	1.11	51.97
1974	3.30	1.39	1.22	5.15	2.37	7.89	1.33	6.13	7.59	5.34	6.05	2.10	49.86
1975	2.63	4.16	3.44	2.69	6.74	7.81	3.65	0.87	0.20	0.06	2.24	1.80	36.29
1976	0.12	0.74	4.15	4.42	4.96	6.76	10.06	2.73	4.34	4.72	2.02	1.48	46.50
1977	3.77	2.66	6.13	3.07	1.38	2.89	0.78	2.70	1.32	0.49	2.39	1.03	28.61
1978	2.57	3.67	3.52	1.41	4.48	2.62	0.53	0.33	2.05	0.04	10.17	2.52	33.91
1979	3.47	3.90	5.34	3.41	6.83	4.54	3.73	2.04	1.40	3.09	1.21	4.10	43.06
1980	2.06	1.76	1.38	1.67	4.19	2.68	0.33	0.20	9.19	4.07	1.42	2.27	31.22
1981	1.35	2.10	4.04	4.26	7.77	7.59	0.95	0.74	0.51	15.84	2.02	0.20	47.37
1982	3.76	2.52	3.16	2.68	19.07	6.62	3.34	2.40	0.55	3.77	5.55	5.17	58.59
1983	1.12	6.63	4.46	1.49	5.55	7.05	3.46	1.87	1.06	4.12	3.38	1.05	41.24
1984	1.37	4.34	6.14	3.41	6.33	1.54	0.61	1.19	3.14	8.35	4.46	5.45	46.33
1985	1.19	3.11	5.02	5.92	5.82	3.39	2.33	0.31	2.72	7.40	5.89	1.27	44.37
1986	0.09	4.89	2.08	3.85	4.71	6.67	3.26	1.59	4.39	2.79	8.35	2.18	44.85
1987	2.06	3.85	2.65	0.13	7.36	3.52	4.45	2.03	8.46	3.93	7.02	5.85	51.31
1988	1.52	2.31	4.66	2.42	1.51	1.04	3.83	0.56	2.69	5.17	4.99	2.92	33.62
1989	2.83	5.09	4.50	0.50	10.29	9.17	6.81	2.32	2.15	1.74	0.80	0.47	46.67
1990	7.53	5.86	6.95	6.02	10.10	3.11	3.84	1.37	2.76	3.10	4.28	3.18	58.10
1991	4.14	4.59	2.63	6.44	3.67	4.33	3.31	5.13	2.45	10.47	2.45	8.51	58.12
1992	3.33	2.24	4.61	2.28	9.22	10.26	6.16	2.80	3.01	0.37	4.86	4.14	53.28
1993	1.98	5.64	4.71	5.09	2.59	3.25	0.00	0.80	3.73	10.95	3.31	4.67	46.72
1994	1.67	2.03	2.63	5.05	8.30	2.63	8.74	1.89	2.38	5.07	6.11	2.67	49.17
1995	4.15	1.28	4.03	5.32	11.31	4.12	2.59	0.69	6.62	0.51	1.42	2.83	44.87
1996	2.44	0.06	2.84	2.82	2.00	9.56	6.29	5.86	2.65	5.57	10.43	1.85	52.37
1997	1.15	8.12	4.26	9.05	3.29	3.64	1.38	3.78	0.60	6.17	2.82	8.84	53.10
1998	6.46	3.51	5.91	2.24	1.61	1.43	2.03	0.80	5.88	5.34	4.13	6.16	45.50
1999	3.32	1.15	3.37	2.11	5.64	2.37	1.90	1.41	3.94	3.25	2.73	5.50	36.69
2000	2.39	2.01	4.00	3.42	5.84	9.17	0.21	0.00	2.26	5.22	10.86	6.20	51.58
2001	3.06	11.41	4.37	2.78	5.12	3.17	0.42	6.73	4.49	5.00	1.90	7.55	56.00
2002	5.77	1.29	10.30	4.36	3.33	1.62	4.87	4.47	2.45	9.50	1.14	4.88	53.98
2003	0.00	4.23	1.56	1.30	4.37	6.02	0.40	4.29	4.53	0.58	4.88	1.33	33.49
2004	3.29	4.34	1.78	2.44	5.23	5.59	2.02	1.63	1.14	4.89	7.85	1.41	41.61
2005	7.87	2.44	2.54	2.34	2.26	0.92	3.17	0.58	1.09	1.27	0.16	0.12	24.76
2006	3.07	3.34	7.46	1.29	1.28	0.66	0.24	1.25	2.39	5.31	3.67	5.50	35.46
2007	4.08	0.71	2.51	3.95	7.57	11.79	8.56	1.22	2.00	7.05	1.48	3.38	54.30
2008	0.30	4.43	14.23	4.43	3.14	4.52	1.20	3.62	3.05	1.90	2.28	1.18	44.28
2009	2.74	1.20	5.79	7.51	8.21	1.23	5.14	3.28	2.47	15.00	3.19	3.21	58.97
2010	2.97	3.90	3.59	1.65	2.40	3.00	3.15	0.66	5.03	3.25	3.58	1.72	34.90
2011	1.29	2.49	0.32	5.85	6.75	1.19	0.89	1.17	0.87	1.78	2.28	6.56	31.44
2012	6.00	3.87	7.98	4.11	4.02	2.26	1.75	2.65	2.31	2.53	0.65	3.58	41.71
2013	2.92	2.80	1.85	2.12	5.73	4.34	4.27	0.74	4.35	4.62	3.49	2.89	40.12
2014	0.80	0.97	2.32	5.55	5.29	3.74	5.72	1.18	1.00	3.65	0.98	3.11	34.31
2015	4.39	3.87	5.99	6.02	11.54	4.25	0.99	1.68	1.56	6.90	15.17	7.83	70.19
2016	1.60	2.44	4.62	7.17	7.12	1.35	1.36	5.17	3.70	1.10	2.64	1.11	39.38
Average	2.67	3.14	3.97	4.30	5.59	4.49	3.08	2.35	3.69	4.29	3.73	3.40	44.69
Maximum	11.38	11.41	14.23	14.55	19.07	12.92	11.20	6.73	13.39	15.84	15.17	13.68	70.64
Minimum	0.00	0.06	0.32	0.13	1.28	0.22	0.00	0.00	0.00	0.04	0.00	0.12	20.23

Table 3: Modeled runoff data for design reach S2-3(a).

MONTHLY RUNOFF FOR RESTORED CHANNEL Drainage Ar. BASED HEC-HMS RAINFALL-RUNOFF ANALYSIS (AC-FT)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1940	0.0	46.7	43.1	296.3	316.9	180.3	173.4	76.5	67.8	147.2	229.3	272.5	1,850.2
1941	28.9	89.9	112.9	260.8	230.2	543.4	276.5	87.0	31.1	293.1	41.4	106.4	2,101.7
1942	45.8	23.3	129.5	402.5	197.9	297.9	0.0	132.1	341.5	138.9	90.2	146.1	1,945.9
1943	10.9	93.8	180.4	127.5	184.5	298.0	8.8	0.0	98.5	55.5	52.4	151.9	1,262.1
1944	123.4	200.1	107.3	102.6	364.4	99.5	82.4	193.9	59.6	43.0	272.2	70.5	1,718.9
1945	126.5	291.9	257.6	91.8	141.5	246.2	153.5	130.6	269.6	299.1	62.2	44.1	2,114.6
1946	168.0	160.7	245.2	157.1	306.4	96.2	11.1	270.6	150.4	78.8	281.0	112.8	2,038.3
1947	55.7	25.9	171.1	169.0	213.6	121.8	64.3	227.6	117.2	78.3	113.0	337.5	1,695.1
1948	111.5	164.1	104.5	130.1	336.0	158.1	188.7	17.1	25.9	201.7	42.5	106.8	1,587.0
1949	382.6	214.6	129.6	296.1	123.4	240.6	218.3	193.1	115.9	278.9	36.3	158.7	2,388.1
1950	319.9	228.1	64.8	171.1	443.3	89.2	494.6	178.9	213.1	33.7	0.0	33.7	2,270.4
1951	111.0	105.3	25.9	165.9	209.5	410.6	143.6	21.8	202.2	208.4	62.2	36.8	1,703.2
1952	46.7	70.0	181.5	343.2	223.0	33.7	98.5	28.5	44.1	5.2	257.7	135.8	1,467.8
1953	101.1	42.0	197.0	432.9	113.0	5.7	281.5	190.3	128.1	124.4	181.5	156.1	1,953.7
1954	186.7	77.8	41.5	190.3	328.7	164.9	23.3	119.3	178.9	203.8	52.9	88.1	1,656.1
1955	83.0	51.8	272.2	285.2	127.0	75.2	191.8	205.6	179.7	235.9	31.1	42.5	1,781.0
1956	124.4	275.3	49.3	140.0	88.1	18.1	0.0	53.1	7.5	129.6	140.5	79.8	1,106.0
1957	67.4	121.8	324.6	315.5	474.2	199.6	13.0	31.1	342.2	159.2	434.5	119.3	2,602.3
1958	202.2	53.4	171.6	219.3	100.1	306.4	98.5	93.3	176.3	83.0	91.3	104.5	1,699.9
1959	28.8	65.3	145.2	65.3	171.1	290.9	251.5	67.4	132.2	180.4	77.8	178.9	1,654.8
1960	186.7	106.0	94.6	90.7	95.4	328.2	155.6	137.4	147.8	230.7	67.4	188.0	1,828.5
1961	68.7	70.0	283.9	58.3	131.2	168.5	153.0	97.2	154.3	90.7	173.7	184.1	1,633.5
1962	155.6	88.1	103.7	127.0	88.1	484.0	233.1	248.9	264.4	280.0	191.8	25.9	2,290.7
1963	41.5	18.1	95.9	171.1	119.3	78.3	149.1	38.9	35.0	2.6	93.3	76.2	919.3
1964	55.7	102.4	216.7	148.8	285.2	254.1	7.8	115.6	340.7	31.1	224.5	57.0	1,839.6
1965	111.5	277.4	88.1	79.3	280.0	192.4	21.8	64.8	301.8	82.4	178.9	67.4	1,745.8
1966	31.1	110.2	34.0	497.8	220.4	69.5	225.5	139.2	165.7	51.9	23.3	122.9	1,691.4
1967	24.9	76.2	188.7	412.7	267.8	93.3	154.3	93.3	265.5	308.5	57.0	125.5	2,067.8
1968	124.4	88.1	248.9	324.6	197.5	270.7	228.1	147.8	308.5	118.2	210.0	139.5	2,406.4
1969	199.6	150.4	225.5	129.6	500.4	151.9	0.0	58.6	181.5	189.8	37.9	220.4	2,045.5
1970	51.9	160.7	204.8	202.7	101.6	62.2	16.6	127.0	337.0	287.8	116.7	44.1	1,713.1
1971	36.3	108.9	54.4	7.8	225.5	26.2	206.6	192.9	134.8	352.6	128.3	495.4	1,969.8
1972	52.4	36.3	53.4	73.6	125.5	88.1	71.6	114.1	108.1	353.1	164.6	112.5	1,353.3
1973	145.2	155.0	274.8	168.5	134.8	173.7	114.1	56.0	411.7	284.1	150.9	57.6	2,126.4
1974	154.0	64.8	63.3	209.0	126.8	413.0	69.0	174.2	399.8	143.9	410.9	108.9	2,337.4
1975	92.6	92.8	138.7	126.5	228.7	231.0	133.0	45.1	7.3	3.1	107.6	98.8	1,305.1
1976	6.2	38.4	186.1	145.7	218.0	276.9	438.9	141.6	152.4	207.9	58.1	76.2	1,946.5
1977	151.4	123.9	289.3	97.5	65.9	144.7	40.4	140.0	68.4	25.4	118.2	47.7	1,312.9
1978	133.3	183.8	189.0	48.7	212.1	111.5	27.5	17.1	84.5	2.1	273.3	79.6	1,362.4
1979	182.8	126.5	253.0	172.1	334.4	241.6	177.6	101.4	47.2	105.0	100.3	188.7	2,030.7
1980	64.3	50.3	49.8	71.0	132.7	139.0	17.1	10.4	288.8	211.0	73.6	117.7	1,225.7
1981	43.6	89.2	178.4	164.9	320.4	282.6	36.3	38.4	26.4	584.4	182.0	34.2	1,980.7
1982	178.9	95.9	155.0	114.6	603.0	295.5	152.4	124.4	28.0	158.1	215.2	184.8	2,306.1
1983	41.7	260.8	231.3	71.0	228.9	294.8	174.2	93.3	49.8	190.3	175.3	48.7	1,860.1
1984	57.0	164.4	318.4	164.9	284.7	79.8	23.3	61.7	150.6	276.9	213.4	181.5	1,976.5
1985	62.7	148.8	210.0	248.9	209.5	175.8	76.2	16.1	106.3	258.7	242.7	50.3	1,806.0
1986	4.7	177.3	90.2	166.2	161.0	270.1	169.0	70.5	163.3	131.7	419.5	92.8	1,916.4
1987	75.2	162.8	157.6	6.7	268.6	140.3	173.4	103.4	364.8	182.5	289.8	249.4	2,174.6
1988	59.1	73.1	238.0	125.5	78.3	32.1	186.7	29.0	119.0	200.9	215.2	102.1	1,459.1
1989	133.3	161.3	209.0	25.9	296.1	417.9	276.4	115.1	111.5	90.2	41.5	22.3	1,900.3
1990	313.7	243.2	299.7	283.1	367.1	113.6	151.9	70.5	116.1	110.4	176.8	106.3	2,352.5
1991	199.1	192.4	129.1	209.0	170.1	220.4	161.3	235.4	111.0	221.7	110.7	318.9	2,278.8
1992	154.5	94.9	204.8	115.1	426.5	492.8	215.7	160.7	138.4	19.2	193.4	127.0	2,343.1
1993	82.4	234.9	217.8	226.1	111.0	93.8	0.0	40.4	136.9	409.1	163.3	229.7	1,945.4
1994	74.7	99.6	108.4	194.4	310.6	113.6	411.2	91.8	120.3	168.5	255.1	91.3	2,039.3
1995	207.4	46.9	205.1	223.5	459.1	230.5	129.6	27.5	337.0	26.4	69.5	106.3	2,068.8
1996	97.0	3.1	125.5	121.8	103.7	331.8	200.7	261.6	118.5	258.7	470.3	75.2	2,167.9
1997	51.3	285.2	147.3	324.1	152.4	176.3	71.6	180.4	31.1	276.9	103.7	267.5	2,067.8
1998	217.5	134.3	200.4	129.1	83.5	74.1	105.3	41.5	246.8	168.5	194.2	293.7	1,888.9
1999	94.4	55.5	135.8	102.1	266.5	126.0	92.3	73.1	204.3	156.6	139.0	207.9	1,653.5
2000	123.9	99.0	204.8	133.3	221.4	343.3	93.8	0.0	117.2	198.1	466.1	300.2	2,301.1
2001	166.4	448.0	199.1	126.0	226.6	116.1	24.9	218.3	294.0	248.9	87.6	385.2	2,541.2
2002	212.6	153.5	426.7	170.6	172.7	84.0	150.9	231.8	127.0	377.0	59.1	187.4	2,353.2
2003	31.9	196.5	80.9	67.4	226.6	250.4	20.7	192.6	120.0	30.1	237.0	63.8	1,517.9
2004	119.8	203.3	92.8	123.4	268.1	243.4	87.4	75.2	51.3	177.8	289.8	63.3	1,795.6
2005	207.7	138.2	104.7	105.3	117.2	47.7	151.4	30.1	45.6	43.8	30.3	6.2	1,028.2
2006	159.2	168.5	210.0	80.9	54.4	34.2	12.4	51.3	123.9	211.6	103.7	312.1	1,522.3
2007	160.2	36.8	88.7	181.0	342.2	422.6	255.9	113.3	103.7	324.6	76.7	147.8	2,253.4
2008	15.6	143.1	556.4	224.5	155.0	215.2	62.2	167.0	125.0	83.0	118.2	61.2	1,926.3
2009	91.3	24.4	223.0	299.7	327.7	63.8	191.8	163.8	91.8	637.8	137.7	151.7	2,404.3
2010	125.0	167.0	163.3	66.4	120.3	133.5	136.6	31.9	204.0	132.7	156.6	102.1	1,539.4
2011	54.4	110.7	25.1	214.1	280.0	42.0	46.1	53.4	43.0	84.0	108.9	196.5	1,258.4
2012	178.9	177.8	285.7	188.7	201.2	117.2	67.4	108.4	69.5	117.7	33.7	146.5	1,692.7
2013	102.4	119.3	94.9	88.7	221.4	212.1	217.3	29.0	163.8	204.6	102.9	130.7	1,687.0
2014	38.4	22.8	117.7	247.3	252.5	150.9	272.7	43.6	41.0	179.9	50.8	157.1	1,574.7
2015	145.7	141.6	235.4	232.3	367.4	104.0	35.3	57.6	62.2	272.5	546.8	312.7	2,513.2
2016	81.4	113.0	134.3	273.3	304.9	32.7	69.5	249.9	191.8	57.0	134.3	44.6	1,686.7
Average	111.1	127.5	170.1	176.2	227.9	187.7	131.4	106.9	152.5	176.8	157.4	138.6	1,864.0
Maximum	382.6	448.0	556.4	497.8	603.0	543.4	494.6	270.6	411.7	637.8	546.8	495.4	2,602.3
Minimum	0.0	3.1	25.1	6.7	54.4	5.7	0.0	0.0	7.3	2.1	0.0	6.2	919.3

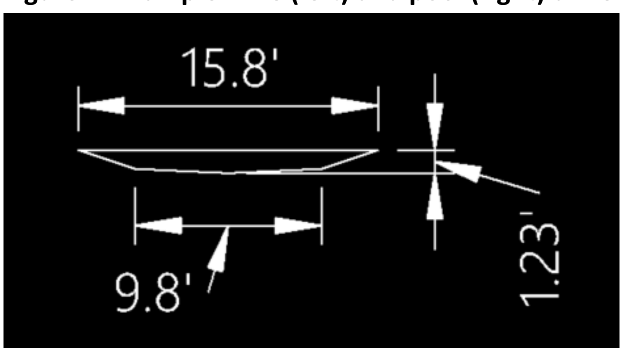
Table 4. Total feature length along the design reach S2-3(a).

Feature Length	
Riffle (ft)	**Pool (ft)**
916.99	1317.59

Table 5. Geometric data for design reach S2-3(a) based on stage.

Stage (ft)	Average End Area (sf)		Top Width (ft)		Storage (ac-ft)	Surface Area (ac)	Inc. Area (ac)
	Riffle-Riffle	Riffle-Pool	Riffle	Pool			
2.37			15.80	19.00	0.83	0.91	4.46
	5.44	5.93					
2.0			13.58	15.68	0.54	0.76	2.11
	6.04	6.38					
1.5			10.58	11.18	0.22	0.56	2.19
	2.45	3.48					
1.0			0.00	7.19	0.06	0.22	0.62
	0.00	1.42					
0.5			0.00	4.19	0.02	0.13	0.50
	0.00	0.67					
0			0.00	1.19	0.00	0.04	1.09

Figure 2. Example riffle (left) and pool (right) dimensions for design reach S2-3(a).



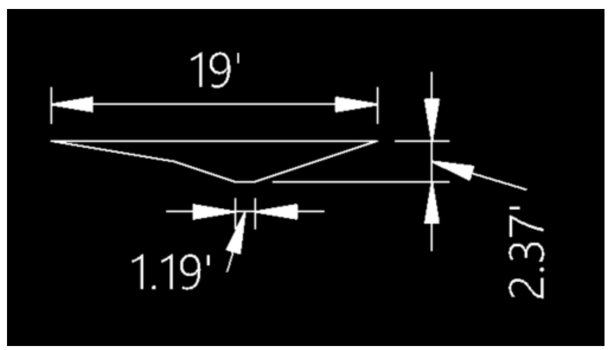


Figure 3: Stage and surface area vs storage graph for design reach S2-3(a).

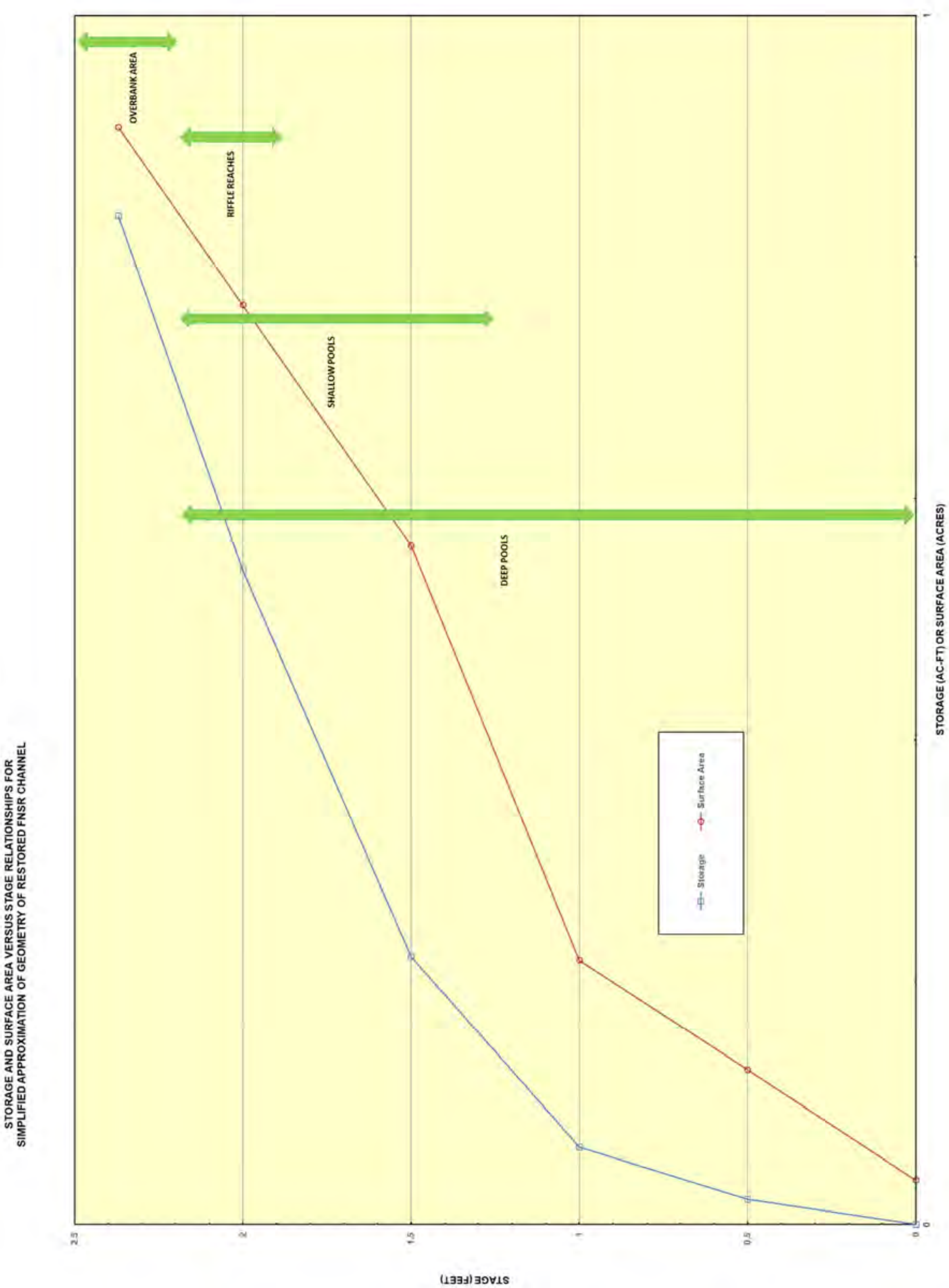


Table 6. Basin calculation spreadsheet for design reach S2-3(a).

DAILY OPERATION OF RESTORED FNSR CHANNEL - DAILY RUNOFF FROM HEC-HMS MODEL USING 1940-2016 REGIONAL RAINFALL

Drainage Area Contributing Runoff to Restored Channel: Minimum Operational	620.8	acres	1.0	Runoff Sensitivity Factor
Storage for Pumpage from Basin: Maximum Operational Storage of Restored	0	ac-ft		
Channel:	0.83	ac-ft		
Average Unit Flow for NSR at Cooper Gage 1950-2016 ac-ft/day/sq r		# zero flow days	0.00000	
Average Unit Flow for Restored Channel 1950-2016 Average 1940-2016 Storage in	5.26	ac-ft/day/sq mile ac-ft		
Restored Channel:	0.78	ac-ft on	08/14/56	
Minimum 1940-2016 Storage in Restored Channel and Date:	0.11			

(1) DAY	(2) PRECIP (INCHES)	(3) PRECIP FOR CALCS (INCHES)	(4) RUNOFF DEPTH (INCHES)	(5) RUNOFF VOLUME (AC-FT)	(6) INITIAL STORAGE (AC-FT)	(7) INITIAL SURFACE AREA (AC)	(8) MONTHLY HISTORICAL EVAP (INCHES)	(9) DAILY EVAP LOSS (AC-FT)	(10) DAILY PRECIP INFLOW (AC-FT)	(11) FINAL STORAGE (AC-FT)	(12) FINAL SURFACE AREA (AC)	(13) ANNUAL RUNOFF STORED (AC-FT)	(14) CUMUL MONTHLY PRECIP (INCHES)	(15) CUMUL MONTHLY RUNOFF (AC-FT)	(16) MONTHLY RUNOFF STORED (AC-FT)	(17) CUMUL MONTHLY EVAP LOSS (AC-FT)	(18) MON-YEAR	(19) MONTHLY PRECIP (INCHES)	(20) MONTHLY RUNOFF (AC-FT)	(21) MONTHLY RUNOFF STORED (AC-FT)	(22) END-OF-MONTH STORAGE (AC-FT)	MONTHLY EVAP LOSS (AC-FT)	(23)
1/1/1940	0.00	0.00		0.0	0.8	0.91	1.99	0.01	0.00	0.8	0.90	0.0	0.00	0	0	0.0	Jan-40	0.00	0.0	0.0	0.7	0.1	
1/2/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.90	0.0	0.00	0	0	0.0	Feb-40	3.45	46.7	0.2	0.8	0.2	
1/3/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.90	0.0	0.00	0	0	0.0	Mar-40	1.11	43.1	0.3	0.8	0.3	
1/4/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.90	0.0	0.00	0	0	0.0	Apr-40	6.77	296.3	0.2	0.8	0.3	
1/5/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.90	0.0	0.00	0	0	0.0	May-40	8.03	316.9	0.2	0.8	0.3	
1/6/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.89	0.0	0.00	0	0	0.0	Jun-40	4.01	180.3	0.2	0.8	0.4	
1/7/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.89	0.0	0.00	0	0	0.0	Jul-40	4.74	173.4	0.2	0.7	0.5	
1/8/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.89	0.0	0.00	0	0	0.0	Aug-40	1.55	76.5	0.5	0.8	0.5	
1/9/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.89	0.0	0.00	0	0	0.0	Sep-40	1.32	67.8	0.3	0.8	0.4	
1/10/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.88	0.0	0.00	0	0	0.0	Oct-40	3.25	147.2	0.3	0.8	0.3	
1/11/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.88	0.0	0.00	0	0	0.1	Nov-40	6.82	229.3	0.1	0.8	0.2	
1/12/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.88	0.0	0.00	0	0	0.1	Dec-40	6.70	272.5	0.1	0.8	0.2	
1/13/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.88	0.0	0.00	0	0	0.1	Jan-41	0.60	28.9	0.1	0.8	0.1	
1/14/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.88	0.0	0.00	0	0	0.1	Feb-41	3.57	89.9	0.1	0.8	0.2	
1/15/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.87	0.0	0.00	0	0	0.1	Mar-41	2.55	112.9	0.2	0.8	0.3	
1/16/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.87	0.0	0.00	0	0	0.1	Apr-41	7.44	260.8	0.1	0.8	0.3	
1/17/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.87	0.0	0.00	0	0	0.1	May-41	3.96	230.2	0.2	0.8	0.3	
1/18/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.8	0.87	0.0	0.00	0	0	0.1	Jun-41	12.27	543.4	0.2	0.8	0.4	
1/19/1940	0.00	0.00		0.0	0.8	0.76	1.99	0.00	0.00	0.7	0.86	0.0	0.00	0	0	0.1	Jul-41	6.14	276.5	0.3	0.7	0.5	
1/20/1940	0.00	0.00		0.0	0.7	0.76	1.99	0.00	0.00	0.7	0.86	0.0	0.00	0	0	0.1	Aug-41	1.68	87.0	0.4	0.7	0.5	
1/21/1940	0.00	0.00		0.0	0.7	0.76	1.99	0.00	0.00	0.7	0.86	0.0	0.00	0	0	0.1	Sep-41	1.05	31.1	0.3	0.8	0.4	
1/22/1940	0.00	0.00		0.0	0.7	0.76	1.99	0.00	0.00	0.7	0.86	0.0	0.00	0	0	0.1	Oct-41	8.06	293.1	0.3	0.8	0.3	
1/23/1940	0.00	0.00		0.0	0.7	0.76	1.99	0.00	0.00	0.7	0.85	0.0	0.00	0	0	0.1	Nov-41	0.92	41.4	0.1	0.8	0.2	
1/24/1940	0.00	0.00		0.0	0.7	0.76	1.99	0.00	0.00	0.7	0.85	0.0	0.00	0	0	0.1	Dec-41	2.90	106.4	0.2	0.8	0.2	
1/25/1940	0.00	0.00		0.0	0.7	0.76	1.99	0.00	0.00	0.7	0.85	0.0	0.00	0	0	0.1	Jan-42	0.80	45.8	0.1	0.8	0.1	
1/26/1940	0.00	0.00		0.0	0.7	0.76	1.99	0.00	0.00	0.7	0.85	0.0	0.00	0	0	0.1	Feb-42	0.80	23.3	0.1	0.8	0.2	
1/27/1940	0.00	0.00		0.0	0.7	0.76	1.99	0.00	0.00	0.7	0.85	0.0	0.00	0	0	0.1	Mar-42	2.78	129.5	0.2	0.8	0.3	
1/28/1940	0.00	0.00		0.0	0.7	0.76	1.99	0.00	0.00	0.7	0.84	0.0	0.00	0	0	0.1	Apr-42	12.40	402.5	0.2	0.8	0.3	
1/29/1940	0.00	0.00		0.0	0.7	0.76	1.99	0.00	0.00	0.7	0.84	0.0	0.00	0	0	0.1	May-42	4.62	197.9	0.1	0.7	0.3	
1/30/1940	0.00	0.00		0.0	0.7	0.76	1.99	0.00	0.00	0.7	0.84	0.0	0.00	0	0	0.1	Jun-42	5.89	297.9	0.3	0.8	0.4	
1/31/1940	0.00	0.00		0.0	0.7	0.76	1.99	0.00	0.00	0.7	0.84	0.0	0.00	0	0	0.1	Jul-42	0.00	0.0	0.0	0.4	0.4	
2/1/1940	0.00	0.00		0.0	0.7	0.76	2.36	0.01	0.00	0.7	0.83	0.0	0.00	0	0	0.0	Aug-42	3.20	132.1	0.7	0.8	0.5	
2/2/1940	1.05	1.05		2.4	0.7	0.76	2.36	0.01	0.07	0.8	0.91	0.1	1.05	2	0	0.0	Sep-42	8.38	341.5	0.1	0.7	0.4	
2/3/1940	0.70	0.70		2.4	0.8	0.91	2.36	0.01	0.05	0.8	0.91	0.1	1.75	5	0	0.0	Oct-42	2.98	138.9	0.3	0.8	0.3	
2/4/1940	0.00	0.00		0.0	0.8	0.91	2.36	0.01	0.00	0.8	0.90	0.1	1.75	5	0	0.0	Nov-42	2.98	90.2	0.1	0.8	0.2	
2/5/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.90	0.1	1.75	5	0	0.0	Dec-42	3.33	146.1	0.1	0.8	0.2	
2/6/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.90	0.1	1.75	5	0	0.0	Jan-43	0.21	10.9	0.0	0.7	0.2	
2/7/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.90	0.1	1.75	5	0	0.0	Feb-43	1.81	93.8	0.2	0.8	0.2	
2/8/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.89	0.1	1.75	5	0	0.0	Mar-43	4.78	180.4	0.2	0.8	0.3	
2/9/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.89	0.1	1.75	5	0	0.0	Apr-43	2.61	127.5	0.2	0.7	0.3	
2/10/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.89	0.1	1.75	5	0	0.1	May-43	3.59	184.5	0.3	0.8	0.4	
2/11/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.89	0.1	1.75	5	0	0.1	Jun-43	6.59	298.0	0.3	0.8	0.5	
2/12/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.88	0.1	1.75	5	0	0.1	Jul-43	0.17	8.8	0.4	0.7	0.6	
2/13/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.88	0.1	1.75	5	0	0.1	Aug-43	0.00	0.0	0.0	0.3	0.4	
2/14/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.88	0.1	1.75	5	0	0.1	Sep-43	2.65	98.5	0.9	0.8	0.4	
2/15/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.87	0.1	1.75	5	0	0.1	Oct-43	1.19	55.5	0.2	0.8	0.3	
2/16/1940	1.50	0.00		21.0	0.8	0.76	2.36	0.01	0.10	0.8	0.91	0.2	3.25	26	0	0.1	Nov-43	1.01	52.4	0.1	0.6	0.2	
2/17/1940	0.20	1.70		21.0	0.8	0.91	2.36	0.01	0.02	0.8	0.91	0.2	3.45	47	0	0.1	Dec-43	3.13	151.9	0.3	0.8	0.2	
2/18/1940	0.00	0.00		0.0	0.8	0.91	2.36	0.01	0.00	0.8	0.90	0.2	3.45	47	0	0.1	Jan-44	2.95	123.4	0.1	0.8	0.1	
2/19/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.90	0.2	3.45	47	0	0.1	Feb-44	5.60	200.1	0.1	0.8	0.2	
2/20/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.90	0.2	3.45	47	0	0.1	Mar-44	3.25	107.3	0.2	0.8	0.3	
2/21/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.90	0.2	3.45	47	0	0.1	Apr-44	2.63	102.6	0.3	0.8	0.3	
2/22/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.89	0.2	3.45	47	0	0.1	May-44	8.22	364.4	0.2	0.8	0.3	
2/23/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.89	0.2	3.45	47	0	0.1	Jun-44	2.34	99.5	0.3	0.8	0.4	
2/24/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.89	0.2	3.45	47	0	0.1	Jul-44	2.04	82.4	0.2	0.7	0.5	
2/25/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.89	0.2	3.45	47	0	0.1	Aug-44	5.02	193.9	0.5	0.8	0.5	
2/26/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.88	0.2	3.45	47	0	0.1	Sep-44	1.45	59.6	0.3	0.8	0.4	
2/27/1940	0.00	0.00		0.0	0.8	0.76	2.36	0.01	0.00	0.8	0.88	0.2	3.45	47	0	0.1	Oct-44	1.23	43.0	0.1	0.6	0.3	

(1) DAY
1/1/1940
1/2/1940
1/3/1940
1/4/1940
1/5/1940
1/6/1940
1/7/1940
1/8/1940
1/9/1940
1/10/1940
1/11/1940
1/12/1940
1/13/1940
1/14/1940
1/15/1940
1/16/1940
1/17/1940
1/18/1940
1/19/1940
1/20/1940
1/21/1940
1/22/1940
1/23/1940
1/24/1940
1/25/1940
1/26/1940
1/27/1940
1/28/1940
1/29/1940
1/30/1940
1/31/1940
2/1/1940
2/2/1940
2/3/1940
2/4/1940
2/5/1940
2/6/1940
2/7/1940
2/8/1940
2/9/1940
2/10/1940
2/11/1940
2/12/1940
2/13/1940
2/14/1940
2/15/1940
2/16/1940
2/17/1940
2/18/1940
2/19/1940
2/20/1940
2/21/1940
2/22/1940
2/23/1940
2/24/1940
2/25/1940
2/26/1940
2/27/1940