



**US Army Corps
of Engineers®**
Omaha District

Papillion Creek Watershed

Streambed Degradation Study

Section 22: Planning Assistance to States

Final Report



U.S. Army Corps of Engineers, Omaha District

In Partnership with

Papio-Missouri River Natural Resources District,

City of Omaha,

Papillion Creek Watershed Partnership

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EXECUTIVE SUMMARY

Papio-Missouri River Natural Resources District and City of Omaha officials, in conjunction with the Papillion Creek Watershed Partnership (PCWP) members, have identified the need for comprehensive assessment of degradation issues occurring along the Papillion Creek and its tributaries throughout the watershed. The U.S. Army Corps of Engineers, Omaha District (USACE), conducted a Section 22 Planning Assistance to States study to address these issues with the following goals:

- Assess the level of stream degradation that has occurred since the streams were originally classified by USACE and the U.S. Geological Survey in the 1990s.
- Develop a comprehensive strategy document that identifies level of stream degradation, which assets are at greatest risk (e.g., bridges, utilities, residential and commercial development, and ecosystem), and identifies priority construction projects.

Extensive alteration within the Papillion Creek Basin has been occurring since the early 1900s. To reduce the risk of flooding in Omaha, drainage districts were formed between 1910 and 1928, and significant channelization of the Big Papillion Creek and its contributing tributaries began. Additionally, the Nebraska Department of Roads and Irrigation has historical accounts that indicate the majority of Papillion Creek, Big Papillion Creek, and West Papillion Creek were straightened between 1910 and 1913 (Rus et al., 2003). The continued expansion of commercial and residential properties in the watershed has altered the hydrology and sediment transport characteristics, resulting in increased runoff peaks and accelerated erosion of riverbeds and banks throughout the Papillion Creek watershed.

Members of the PCWP were surveyed to create a list of specific areas where channel degradation and bank erosion were causing impacts. These impacts ranged from creek banks eroding into residential property, exposure of utility lines (sewer, gas, electric, potable water, etc.), to flooding caused by loss of channel capacity and increased peak flows. Extensive site visits were completed to most of the high priority sites across the entire watershed. For this study, three sub-watersheds (Cole Creek, West Papillion Creek, South Papillion Creek) were selected for more detailed analysis and recommendations. Within these reaches, detailed designs were developed for the case study sites (Site A – Cole Creek, Blondo to Western Ave., Site B – West Papillion Creek at 132nd Street, and Site C – South Papillion Creek). This analysis could be expanded to all sub-watersheds by either USACE or the PCWP in the future, or when updated survey data is available.

A solutions matrix and design concepts to help mitigate ongoing channel and bank degradation are provided for each of these watersheds using new and existing surveys, hydraulic modeling, and the USACE-developed FluvialGeomorph Geographic Information System-based tools. The solutions are intended to be implemented in a “Systems Approach” that includes multiple structures as a force multiplier over the benefits of a single structure.

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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
CEM	Channel Evolution Model
CFS	Cubic Feet per Second
CHL	Coastal and Hydraulics Lab – Engineer Research and Development Center
CMP	Corrugated Metal Pipe
CMS	Cubic Meters per Second
CSA	Channel Stability Analysis
Corps	United States Army Corps of Engineers
ER	Entrenchment Ratio
EWN	Engineering with Nature
FEMA	Federal Emergency Management Agency
FG	Fluvial Geomorph Software Package
GCS	Grade Control Structure

GMA	Geomorphic Metric Analysis
HEC-RAS	USACE Hydrologic Engineering Center – River Analysis System software
I-80	Interstate 80
LB	Left Bank
LiDAR	Light Detection and Ranging
LPSTP	Longitudinal Peaked Stone Toe Protection
GRR	General Reevaluation Report
NDEE	Nebraska Department of Environment and Energy
NeSCAP	Nebraska Stream Condition Assessment Procedure
NGPC	Nebraska Game and Parks Commission
NRD	Natural Resources District
NWO	Northwestern Division, Omaha District, United States Army Corps of Engineers
NWP	Nationwide Permit Program
OHWM	Ordinary High-water Mark
P-MRNRD	Papio-Missouri Natural Resources District
PAS	Planning Assistance to States Study Authority
PCN	Preconstruction Notification
PCWP	Papillion Creek Watershed Partnership
PGP	Programmatic General Permit
RB	Right Bank
RGP	Regional General Permit
S	Water Surface Slope
SI	Sinuosity Index
SID	Sanitary and Improvement District
SP	Stream Power
SS	Shear Stress
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USP	Unit Stream Power (also referred to as W_i)
W/D	Width-to-Depth Ratio
WASCOB	Water and Sediment Control Basin
W_i	Unit Stream Power (also referred to as USP)

WOTUS Waters of the US

WRDA Water Resources Development Act

1 INTRODUCTION

1.1 PURPOSE

Papio-Missouri River Natural Resources District (P-MRNRD) and City of Omaha officials, in conjunction with the Papillion Creek Watershed Partnership (PCWP) members, have identified the need for comprehensive assessment of degradation issues occurring along the Papillion Creek and its tributaries throughout the watershed. PCWP member agencies include the cities of Omaha, Bellevue, Papillion, La Vista, Gretna, and Ralston, Sarpy County, Boys Town, and the P-MRNRD. The P-MRNRD submitted a Letter of Request dated February 10, 2017, to the U.S. Army Corps of Engineers, Omaha District (Corps or USACE) to conduct a Section 22 Planning Assistance to States (PAS) study to address these issues with the following goals:

- Assess the level of stream degradation that has occurred since the streams were originally classified by USACE and the U.S. Geological Survey (USGS) in the 1990s.
- Develop a comprehensive strategy document that identifies levels of stream degradation, which assets are at greatest risk (e.g., bridges, utilities, residential and commercial development, and ecosystem), and identifies priority construction projects.

While this PAS study will not in itself lead to construction of a project, it will offer the P-MRNRD and the Cooperating Agencies (City of Omaha and PCWP) the opportunity to work closely with the Corps on a technical assessment of degradation issues, trends, and the development of a comprehensive strategy allowing for the prioritization of construction projects that will benefit communities within the watershed.

1.2 STUDY PROCESS

The Corps uses a defined six-step process for conducting comprehensive planning studies. The process is iterative, with steps repeated as necessary to formulate efficient, effective, complete, and acceptable plans. The six steps in the Corps planning process are as follows:

- Step 1 – Identifying Problems and Opportunities
- Step 2 – Inventorying and Forecasting Conditions
- Step 3 – Formulating Alternative Plans
- Step 4 – Evaluating Alternative Plans
- Step 5 – Comparing Alternative Plans
- Step 6 – Selecting/Recommending a Plan

Section 22 studies are flexible, and in this case, the study process involved two phases. Phase 1 consisted of preliminary tasks establishing the existing conditions in the Papillion Creek Watershed. In this context, site visits were conducted, existing data was consolidated, and a data gap analysis was performed. Also during this phase, a problem statement, objectives, and the purpose/outcome of the study, listed as the goals above, were established. A follow-on charette was conducted with the larger Papillion Creek Watershed Partnership Community, which provided for further discussion and consensus of moving from Phase 1 to Phase 2 of the study. Phase 2 commenced with the signing of an amended agreement and contributing funds receipt.

Problem Statement:

- Runoff patterns/stream alterations are resulting in systemic stream degradation, causing instability and risking damage to adjacent public and private property and infrastructures, and impacts on the environment throughout the Papillion Creek Watershed.

Study Objectives:

- Conduct Basin Assessment to determine status of the watershed.
- Identification and categorization of sites according to type, risk, and issue.
- Evaluate the current state and trends of degradation and channel change in select watersheds.
- Provide the FluvialGeomorph (FG) ArcGIS (Esri's Geographic Information System program) tool and files from the analysis for future use by the sponsors. *
- Identify local solutions with watershed/regional benefits.
- Create a Solutions Matrix that connects three specific areas of concern to application of solutions throughout the watershed. *
- Develop a list of projects with a determined priority identification.
- Develop conceptual preliminary site design for three sites.
- Evaluate the regulatory and environmental considerations of the proposed designs.

**These objectives were modified during the study to take advantage of new analysis tools developed by USACE since scoping.*

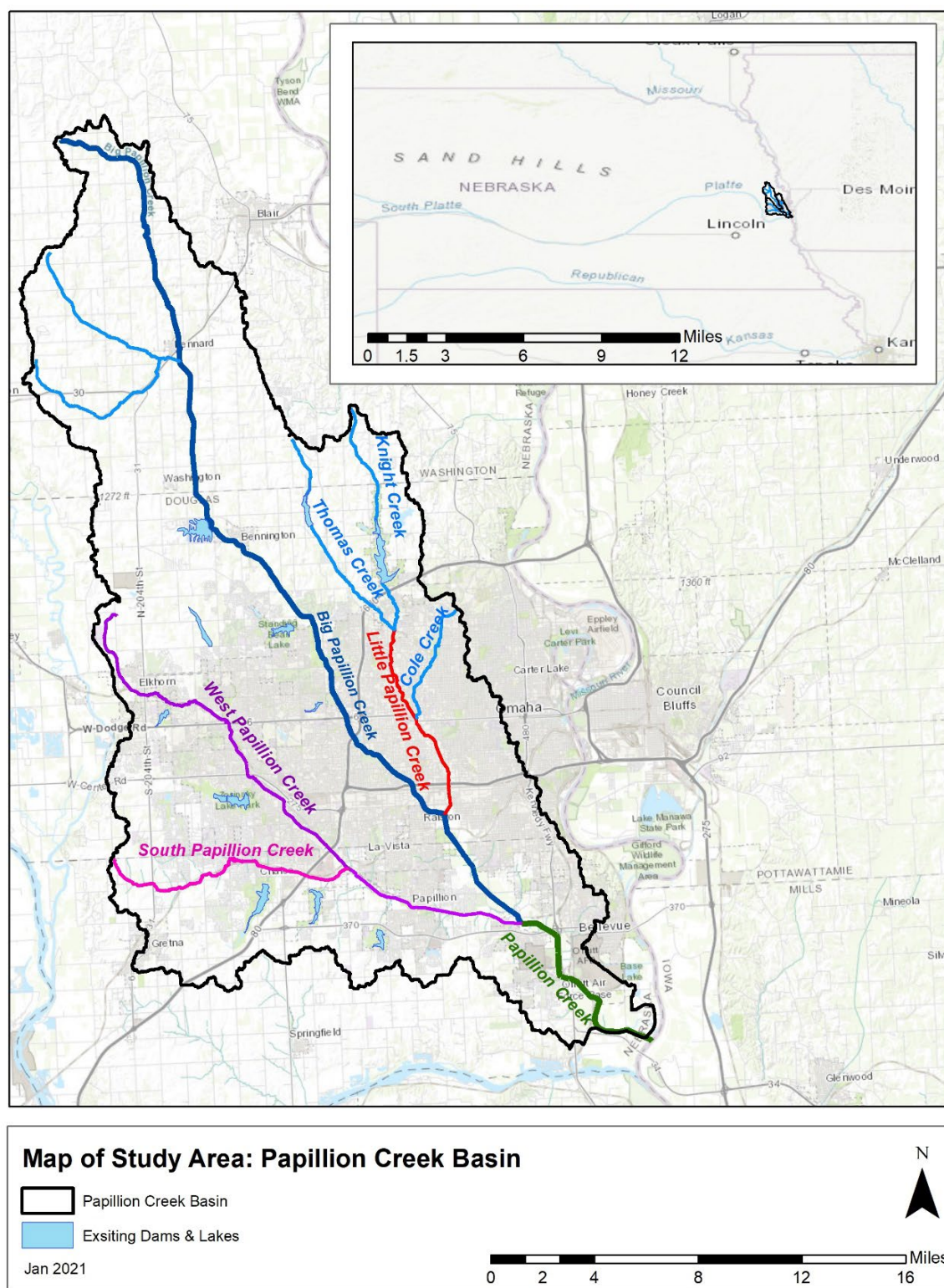
2 DESCRIPTION OF STUDY AREA

2.1 BASIN LOCATION AND OVERVIEW

The study area is the majority of the Papillion Creek Watershed, which covers approximately 402 square miles of drainage area extending from northern Washington County southward through Douglas and Sarpy Counties, and ultimately discharges to the Missouri River south of Bellevue, Nebraska. The area of the watershed in Washington County was not included in this study. The study area includes the Omaha metropolitan area and surrounding communities which continue to experience rapid urbanization. There are three primary creeks that form the Papillion Creek system – Little Papillion Creek, Big Papillion Creek, and West Branch Papillion Creek.

The Papillion Creek basin is about 41 miles long, has a maximum width of about 17 miles, and drains an area of approximately 402 square miles (Figure 2-1). The Omaha metropolitan area is near the center of the basin, of which about 40 percent is urbanized (Omaha/Douglas County & Sarpy County, 2021). The Omaha area lies on a loess-mantled upland till surface dissected by deep major stream valleys and smaller tributaries. The climate of the area is continental sub-humid with about 30 inches of average annual rainfall, which is normally adequate for dry land farming. The stream channels are well entrenched with moderately to steeply sloping banks. The area has a deficiency of land- and water-based recreation in relation to population.

Extensive alteration within the Papillion Creek Basin had been occurring since the early 1900s. To reduce the risk of flooding in Omaha, drainage districts were formed between 1910 and 1928, and significant channelization of the Big Papillion Creek and its contributing tributaries began. Additionally, the Nebraska Department of Roads and Irrigation has historical accounts that indicate the majority of Papillion Creek, Big Papillion Creek, and West Papillion Creek were straightened between 1910 and 1913 (Rus et al., 2003).

**Figure 2-1: Papillion Creek Basin***Source: USACE, 2021*

2.2 OTHER STUDIES AND LITERATURE

The Papillion Creek and Tributaries Lakes, Nebraska – General Reevaluation Report's (USACE, 2021) Appendix A - Hydrology, Section 5, provides an extensive history of flooding within the Papillion Creek basin. While bed degradation continually occurs outside of flooding events, the high flow velocities associated with flooding events has a significant impact on bed and bank erosion. Development of the watershed has, and will continue to change the peak, duration, and volume of floods in the basin.

On July 23, 1946, Congress initiated interest in determining the need for flood control within the Papillion Creek basin and on November 30, 1949, the first survey was authorized for Big Papillion Creek and its tributaries. Since the early 1960s, the Papillion Creek basin has been extensively studied. The existing project was authorized by specific legislation, as documented in reports of Congress, and was implemented through a series of design memorandums, and operations and maintenance (O&M) manuals. Following the partial implementation of the original project, various reevaluation reports and studies associated with the project, or the basin have been published. The following summary of reports was compiled in USACE, 2021. The key takeaway from this list is that, outside of some work done in the broad “watershed” studies, very little evaluation has been done on channel degradation and resulting impacts to the watershed.

- **Apr. 1961: Survey Report on Flood Control Papillion Creek & Tributaries**
Initial investigation into recommending a project along Little Papillion Creek.
- **Feb. 1967: Review Report Papillion Creek & Tributaries**
Comprehensive multi-volume report as a result of the devastating June 1964 flood. Report recommends construction of 21 dams and reservoirs at a cost of \$26.8 million, at a benefit to cost ratio (BCR) of 2.0.
- **Nov. 1967: Papillion, Big Papillion Creek, West Papillion Creek, Omaha Metro, NE**
First of three volumes looking at floodplain information for the Omaha Metro in the Papillion Creek watershed.
- **Apr. 1968: Little Papillion Creek, South Branch, Omaha Metro, NE**
Second of three volumes looking at floodplain information for the Omaha Metro in the Papillion Creek watershed.
- **May 1969: Thomas Creek, Cole Creek, Hell Creek, Big Papillion Creeks**
Third of three volumes looking at floodplain information for the Omaha Metro in the Papillion Creek watershed.
- **Aug. 1971: Papillion Creek & Tributaries**
Similar to the February 1967 report, except Site 17 was dropped due to not being cost effective (Note - Site 17, Candlewood Lake, was built by a private developer).
- **Sep. 1975: Papillion Creek Plan Evaluation**
Details changes to previously authorized project.

- **Mar. 1985: Reevaluation Report & Final Supplement to Final Environmental Impact Statement (EIS)**
Comprehensive reevaluation report that recommended a combination of structural and nonstructural measures within the basin.
- **Jan. 1992: *Union Pacific Railroad Bridge at Papillion Creek Model Study***
Results of physical model study on concrete flume; integral part of Big Papillion Creek channel improvement project.
- **Dec. 1997: *HEC-1 Model of West Papillion Creek Omaha, NE***
Report prepared by HDR for USACE as part of a Section 22 study.
- **Nov. 1999: *West Papillion Creek Section 22***
Section 22 report prepared for P-MRNRD that incorporates USACE hydraulics and HDR hydrology from 1997.
- **Sep. 2004: *Multi-Reservoir Analysis, Papillion Creek Watershed***
Report by HDR prepared for the P-MRNRD to assess the feasibility of several dam sites.
- **Sep. 2007: *West Papillion Creek Section 22***
Hydrology portion of Phase II Section 22 report.
- **Apr. 2009: *Papillion Creek Watershed Management Plan***
Report by HDR prepared for the P-MRNRD and the PCWP to develop a watershed management plan for the basin.
- **Aug. 2011: *Papillion Creek Watershed Nebraska Hydrologic Analysis***
Report by USACE to update previous floodplain mapping for watershed to reflect current land use conditions, development, and stream characteristics. Includes a 2008-2010 modeling effort.
- **Mar. 2014: *Papillion Creek Watershed Management Plan, 2014 Update***
Report by HDR prepared for the P-MRNRD and the PCWP to update the 2009 Plan.
- **Oct. 2014: *Hydrologic Engineering Branch Technical Report, Lower Papillion Creek***
Unsteady flow hydraulic routing analyses for Douglas and Sarpy counties, Nebraska.
- **Mar. 2015: *Papillion Creek Watershed, Douglas and Sarpy Counties, NE***
Development of hydraulic models necessary to determine water surface profiles and inundations for selected flood frequencies for the Papillion Creek Watershed in Douglas and Sarpy counties, Nebraska, and incorporated areas.

2.3 CLIMATE CHANGE CONSIDERATIONS

USACE published guidance for incorporating climate change impacts to inland hydrology in civil works studies, designs, and projects in Engineering and Construction Bulletin (ECB) 2018-14.

There is the potential that project conditions could be impacted by climate change sometime in the future. This risk is possible but not very likely. Observed streamflow data collected in the vicinity of the project area does not yet exhibit evidence of a shift towards higher stream flows. Peer reviewed journal articles indicate that the frequency of large events is likely increasing but offers little consensus with regards to trends in projected, climate-changed hydrology. Note that modeled climate change hydrology has considerable uncertainty as it is affected by other variables like precipitation and temperature which carry their own uncertainty.

Nonetheless, there is some evidence within projected streamflow records, albeit lacking consensus, that peak flows may be trending upward. Additionally, the area encompassing Papillion Creek is highly developed, resulting in a considerable population in the 0.2-percent Annual Exceedance Probability (AEP) floodplain. Thus, if flood risk were to increase in the future there would be considerable consequences. For the detailed climate change analysis, see *Papillion Creek and Tributaries Lakes, Nebraska – General Reevaluation Report* (USACE, 2021).

An updated ECB 2018-14 analysis of the lower Missouri River was completed in Spring 2023, and is available to view here: https://www.nwk.usace.army.mil/Portals/29/App_J%20-%20Missouri_QualitativeCCreport.pdf.

3 IDENTIFICATION OF AREAS OF CONCERN

3.1 SURVEY OF PAPILLION CREEK WATERSHED PARTNERSHIP MEMBERS

Members of the PCWP were surveyed to create a list of specific areas where channel degradation and bank erosion were causing impacts. These impacts ranged from creek banks eroding into residential property, exposure of utility lines (sewer, gas, electric, potable water, etc.), to flooding caused by loss of channel capacity and increased peak flows.

Not every area of concern made the list of priorities. Ongoing maintenance and repairs are made by municipalities, Sanitary & Improvement Districts (SIDs), Natural Resource Districts (NRDs), and other agencies. Ideally, as solutions to local areas are developed, they will have regional benefits.

3.2 SITE VISITS – APPENDIX A SITE VISIT REPORT

Once an initial list was developed, the USACE and sponsor team visited sites on three different occasions from fall 2018 to summer 2019. A detailed summary of those site visits is provided in Appendix A.

3.3 TABLE OF SITES – APPENDIX B (INITIAL 2018; UPDATED 2021)

Throughout the study several sites underwent repairs or had channel and bank stabilization practices implemented and were removed from the list. At the same time, continuing degradation resulted in new areas being identified. A list of this type is dynamic; changes in the watershed and hydrology will continue to influence the location and extent of impacts. As such, the FG results, which can show trends that may result in problem areas in the future, are a vital planning tool in the watershed. Appendix B includes the active list of concern areas identified by the PCWP in fall 2021.

4 FLUVIALGEOMORPH GIS ANALYSIS

4.1 THE FLUVIALGEOMORPH TOOLBOX

FluvialGeomorph is a GIS-based toolbox designed to calculate metrics associated with river and creek channel morphology. Using multiple terrains, usually generated from Light Detection and Ranging (LiDAR) data, changes can be plotted and mapped to help identify current and future areas of change in the watershed. This chapter summarizes the toolbox and provides detailed analysis on three creeks in the Papillion Creek Watershed.

4.1.1 CHANNEL EVOLUTION MODEL

The six-stage Channel Evolution Model (CEM), developed by Simon and Hupp (Simon & Hupp, 1986), in Figure 4-1 is used to provide qualitative discussion on the condition of the channel reaches. There have been wide-scale changes in land-use in the Papillion Creek watershed and they are continuing today. The changes include stream channelization, agricultural and urban development, public infrastructure encroachments in the form of bridges, roadways, utilities. The changes impact soil infiltration and runoff rates changing the characteristic delivery of sediment and hydrologic discharge regimes throughout the watershed. The changes lead to a process of channel bed incision followed by widening and floodplain re-development.

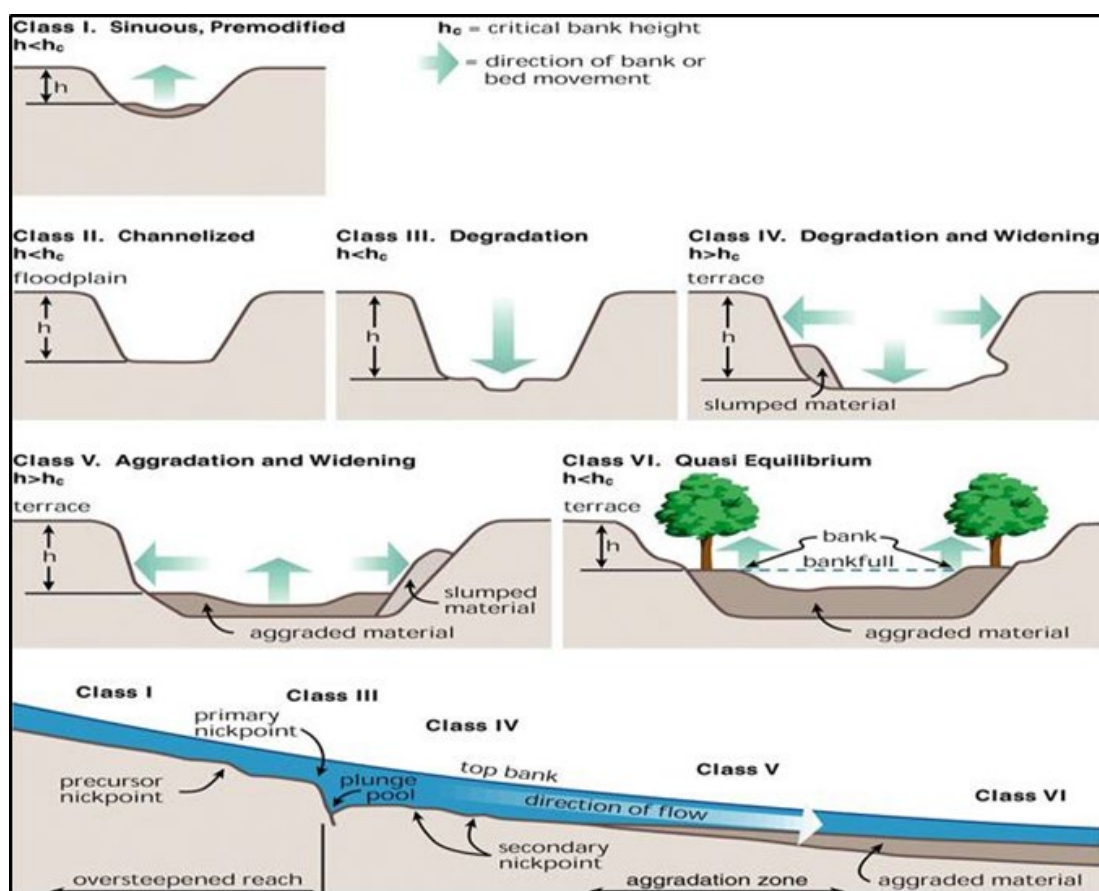


Figure 4-1: Cross-section 113 Illustrating the 6-Stage Channel Evolution Model

Source: Simon & Hupp, 1986

4.1.2 APPROACH TO WATERSHED ASSESSMENTS USING FLUVIALGEOMORPH:

The FG watershed assessment approach was developed to provide a relatively rapid method for evaluating stream channel stability based on existing LiDAR high-resolution terrain data. There are five categories identified in completing typical geomorphic studies outlined for the FG toolkit analysis.

FG-Level 1 defines the Channel Stability Analysis (CSA) for stream channel reaches or watersheds. The rapid assessment analyzes the longitudinal water surface slope profiles and cross-sectional analysis. This provides a reconnaissance level of detail to identify potential areas of concern based on simple slope and cross-sectional area comparative analysis. The CSA provides a basis for identifying potential areas of interest where channel degradation, aggradation, or widespread channel changes are observed. The first FG workflow is described in more detail by Haring and Dougherty (Haring et al., 2020) (Haring and Dougherty, 2022a).

The Level 2 workflow provides details on Geomorphic Metric Analysis (GMA) for reach and watershed assessments in Figure 4-2. The final product of the workflow is reach-level reports that map the geomorphic metrics at a stream channel reach or watershed scales. The metrics are measured from the terrain data and based on existing geomorphic principles or user-defined thresholds. The metrics are mapped by color-coded signals.

The Level 3 workflow expands upon the geomorphic metrics and adds additional analysis of planform dimensions such as meander belt width, meander wavelength, Radius of Curvature to Bankfull Width (R_C/BW) and others.

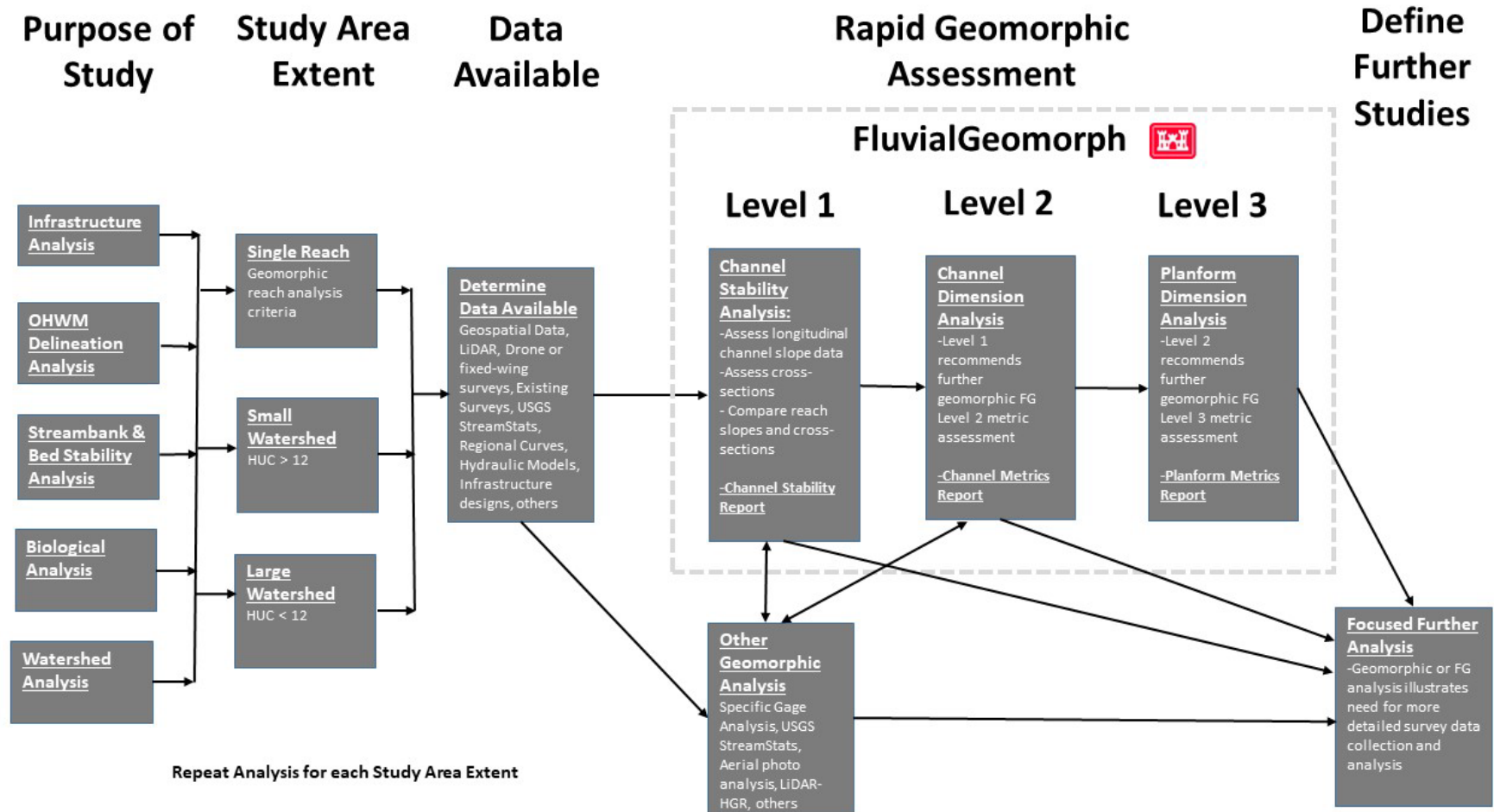


Figure 4-2: FluvialGeomorph Watershed Assessment Workflow

4.1.3 INTERPRETATION OF CSA GEOMORPHIC DATA-LEVEL 1

The cross-sections for all the reaches were generally spaced at 50 feet apart. The individual, lateral cross-section stationing across the channel cross-sections were spaced at one-foot increments. The longitudinal water surface profiles were plotted using approximately three-foot spacing. The Level 1 CSA uses a combination of cross-sections and the longitudinal profile to assess channel stability reach trends.

4.1.4 INTERPRETATION OF CDA GEOMORPHIC DATA-LEVEL 2

Identifying bankfull channel-forming discharge frequency, or recurrence interval (RI), is critical to determine the expected rate of change in stream channel geomorphology. Based on the early work from Leopold et al., on average, the 1.5-year recurrence interval discharge was found to shape and form channel morphology from a natural, process-based relationship (Leopold et al., 1964). This is based on the premise that form and process relationships, under the correct circumstances, can be effectively employed to define the parameters for natural alluvial channel systems. Crowder and Knapp reported bankfull discharge recurrence intervals ranging from one-to-1.23 years for Illinois streams (Crowder & Knapp 2005). Rosgen defines the recurrence intervals for North American streams in the range of 1.1-to-1.8 years. Rosgen also reported that streams in high precipitation zones that have high percent impervious areas from urban development, the corresponding recurrence intervals of bankfull discharge (using annual maximum flood frequency analysis) are closely grouped between the 1.05 and 1.2-year recurrence interval discharge. For low precipitation areas, the recurrence intervals are generally considered to range from 1.5 and 1.8-years (Rosgen, 2008). The USACE manual on channel stability recommends using a two-year recurrence interval for channel-forming discharge and engineering analysis (USACE, 1994).

FG analysis was completed by identifying geomorphic indicators within the channel. For example, the cross-section in Figure 4-3 provides a relatively good geomorphic signal indicating the channel-forming discharge where there is access to an adjacent floodplain, in this case, on both sides of the channel.

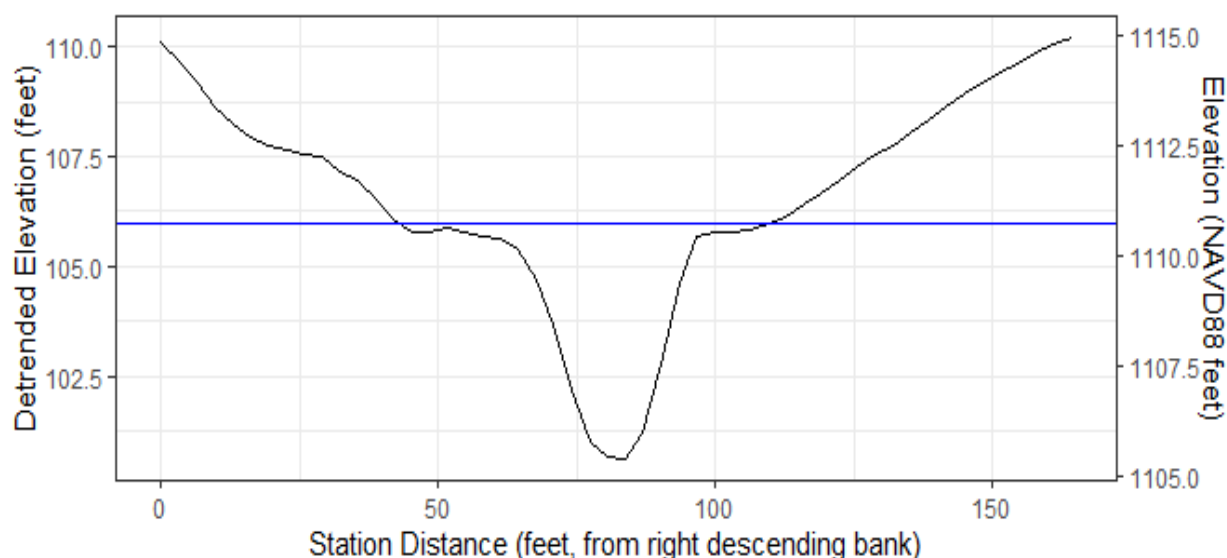


Figure 4-3: Example Bankfull Estimate Channel Cross-section for Cole Creek

The two-year recurrence interval was used for geomorphic interpretation and to calculate stream power.

The generalized stream channel metrics are described in Table 4-1 and are based on bankfull channel dimensions to include width, mean depth, cross-sectional area, discharge, water surface slope, width-to-depth ratios, entrenchment ratios, sinuosity, radius of curvature, stream power, and shear stress.

Table 4-1: FluvialGeomorph Metrics

Channel Stability (Level 1) Analysis Metrics	
Width, Mean Depth, Cross-sectional Area	Hydraulic geometry relationships required for regional curve development: dimensions of bankfull width (ft) and mean depth (ft), cross-sectional area, and discharge (cubic feet per second (cfs)) to drainage area (square miles).
Slope	Slope is directly measured from the elevation surface that is generated from LiDAR derived water surface. Slope is a measure of the elevation difference between two cross-sections.
Channel (Level 2) and Planform (Level 3) Dimension Analysis Metrics	
Width to Depth Ratio	Shape of the channel based at bankfull width (ft) and mean depth (ft) at bankfull discharge.
Entrenchment Ratio	Depicts relative access to the active floodplain. Typically, for channel stability at two-times the maximum bankfull depth (flood prone width), the water surface should be at least 2.5-times the water surface width at bankfull depth. Incised or degraded channel reaches will continue to laterally erode and build floodplains until the entrenchment ratio reaches 2.5.
Sinuosity Index	Sinuosity is the ratio of stream length to valley length. It can also be described as the ratio of valley slope to channel slope for defined reaches. Less than 1.2 likely means a channelized reach and combined with the W/D less than 10 may indicate incised channel reaches.
Stream Power (S x Q)	Stream Power is the (S) slope x (Q) discharge Variable in riffle and pool and other channel environments $Q_s Q_{50} \sim SQ$; Lanes-Balance of Dynamic River Forces.
Shear Stress	Shear stress is a measure of force per unit area. Shear stress is the shearing force divided by the area over which it interacts. Shields (1936) developed a relation between the shear stress required to initiate particle movement which was expanded upon by Lane (1955), Leopold, Wolman, and Miller (1964), and Rosgen and Silvey (2007).
Radius of Curvature (R_c)/ Bankfull Width (BW) (Level 3)	The ratio value of R_c to bankfull width (BW) is commonly used as a diagnostic test for channel planform stability. The ranges that can occur in nature are highly variable but in general if the R_c /BW ratio is less than 1.2 (<1.2), then the outside bend-channel banks will likely be eroding very aggressively as the channel bend progresses erosion in a down-valley direction.

Width to Depth (W/D):

The W/D provides insight into cross-sectional shape and relationship between channel shape (width/depth) and sediment transport capability. It is typically measured from a bankfull perspective, but in this case bankfull is not defined and considered to be between the two-to-10-year model defined discharges.

In a typical alluvial system, high W/D (20-40) represents a wide channel that has issues with sediment transport. The channel is over-widened, and the stream power (energy of the flow) is spread out, so sediment is deposited. These are areas that have massive point bars, shifting channels, and other unstable channel features developing. If the W/D is between 10 and 20, there typically is an appropriate balance between discharge and sediment transport and the channel is relatively stable. When W/D are lower (<10) then typically there are issues with channel degradation associated with lower sinuosity.

If the W/D increases when increasing the discharge, then the channel access to the floodplain is spreading out even more and dissipating energy across a wider expanse. If the W/D decreases, then the depth is increasing more than the width and the access to larger floodplain areas is restricted.

Entrenchment Ratio (ER):

The ER is an indicator of access to a floodplain based on the discharge chosen for analysis. The ratio is typically applied with known bankfull discharge and measured as the channel width at two-times maximum bankfull depth (flood-prone width). For this study, geomorphic bankfull indicators were used from the LiDAR cross-sections to approximate the bankfull condition. Bankfull analysis was completed at the riffle cross-over locations so the depth loss is lowest in these locations; however, this is a constraint to using this method as there is no way to determine the exact depth encountered at these locations, which affects the final ratios. Field validation should be completed as necessary. In general, ratios of one-1.4 represent entrenched streams, 1.41-2.2 represent moderately entrenched streams, and ratios greater than 2.2 indicate rivers only slightly entrenched in a well-developed floodplain (Rosgen 1994).

Water Surface Slope (S):

Slope is a measure of the elevation difference between two cross-sections. Channel slope has direct impacts on the capacity to transfer water and sediment through the reach. If local channel slopes change, then discharge and sediment transport capacities change to balance the differences as described in Lane's balance relationship (Lane 1955). There are other influences on local channel slopes such as public infrastructure, vegetation, or lack thereof, debris in the channel, bedload and bank material composition, cohesive sediments on channel margins, revetments, grade control structures, etc.

Sinuosity Index (SI):

The SI is a measure of the winding and wiggleness of a stream channel and is defined as the channel (thalweg) distance divided by the valley distance for that particular stream length. Sinuosity is highly dependent on channel boundary conditions with influences from bedrock control-channel confinement, cohesive materials, non-cohesive materials, infrastructure, vegetation, and others. The SI tends to increase in a downstream direction as lower channel gradients and decreasing sediment sizes are encountered. Typically, the SI is measured for a channel distance of at least 20 to 30 bankfull widths. An SI of 1.0 is a straight channel. An SI of

less than 1.2 is considered low sinuosity, 1.2-1.5 moderate, and greater than 1.5 high (Rosgen 1994).

Shear Stress (SS):

Shear stress is a measure of force per unit area (lbs/ft²) it is the shearing force divided by the area over which it interacts. Shields (1936) developed a relation between the shear stress required to initiate particle movement which was expanded upon by Lane (1955), Leopold, Wolman, and Miller (1964), and Rosgen and Silvey (2007). The shear stress values to determine the grain size of material in motion for this study were derived from Rosgen and Silvey (2007).

Stream Power (SP):

Stream power is a useful index in describing erosion capacity of streams, development of channel profile and pattern, and sediment transport. There are many different derivations for stream power for geomorphic analysis with true values less important than the actual influence on shaping the channel and sediments. The unit stream power (w_i or USP) is based on the amount of work done per unit of time per length of stream. The density of water and acceleration due to gravity are constant while discharge, slope, and stream width are adjustable to make calculations.

Unit Stream Power (w_i or USP):

Unit stream power can be used to compare known discharges and relative slope. For the FG unit stream power outputs, slope changes throughout the reaches and discharges change based on Hydrologic Engineering Center – River Analysis System (HEC-RAS) modeled outputs. The unit stream power provides a method for directly determining if the per-unit width of cross-sectional stream power increases or decreases based on changes to the cross-sectional width.

4.2 COLE CREEK FG ANALYSIS

4.2.1 INTRODUCTION

Cole Creek is a small urban watershed in the north central Omaha metropolitan area (Figure 4-4). The Creek is approximately seven square-miles and is fully urbanized with limited greenspace. Typical characteristics of urbanized watersheds include degradation due to lower sediment supply to the channel from runoff control reservoirs, channelization and encroachments to drainage ways, increased channel slopes, reduced access to natural floodplains, and increased runoff rates from non-porous pavement and other urban structures. Figure 4-5 illustrates an example hydrograph and the change over time due to increased urbanization. Changes to the hydrograph impact the channel network by changing thresholds established between the balance of sediment mobilization and transport to channel slope and discharge.

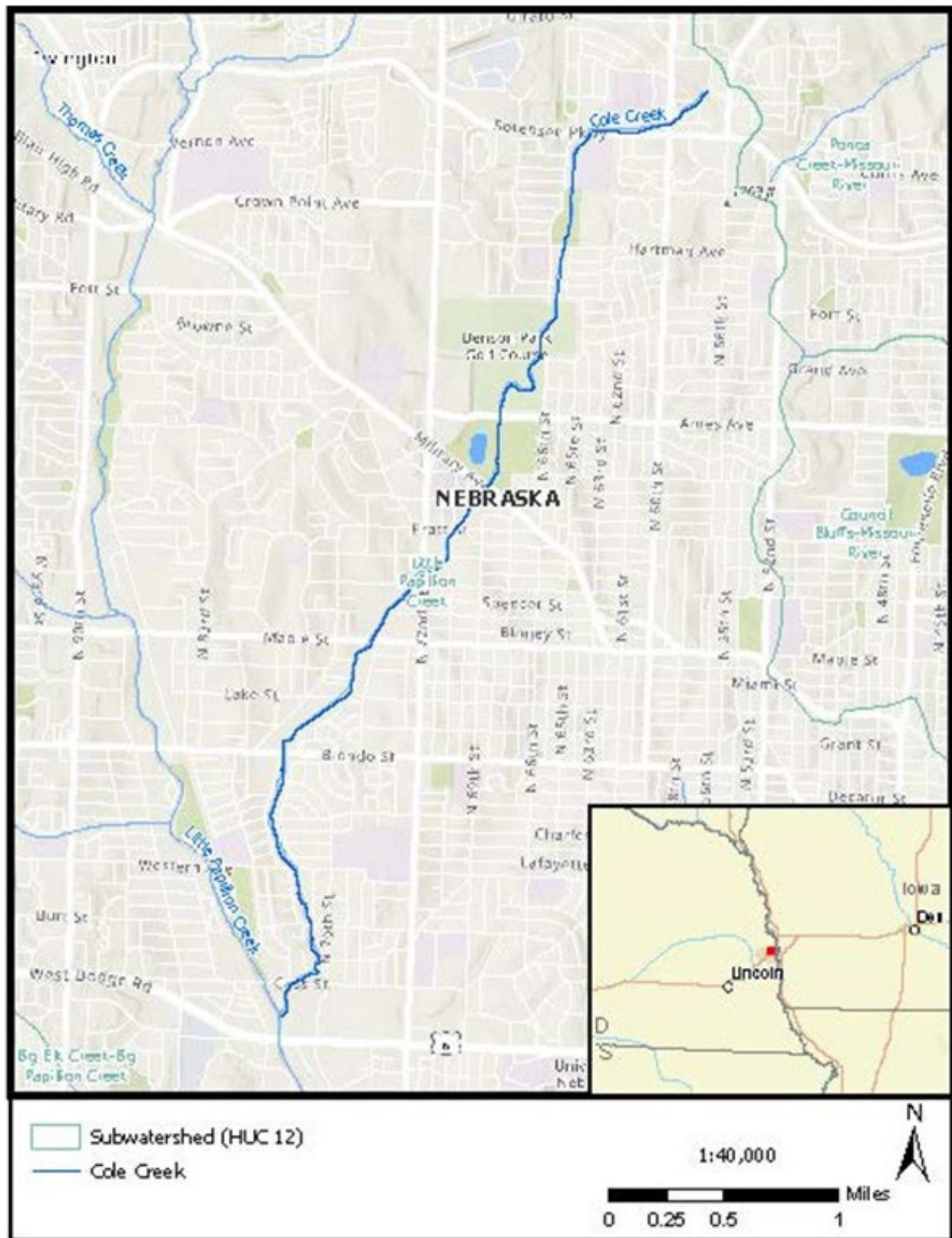


Figure 4-4: Cole Creek Watershed, Omaha, NE

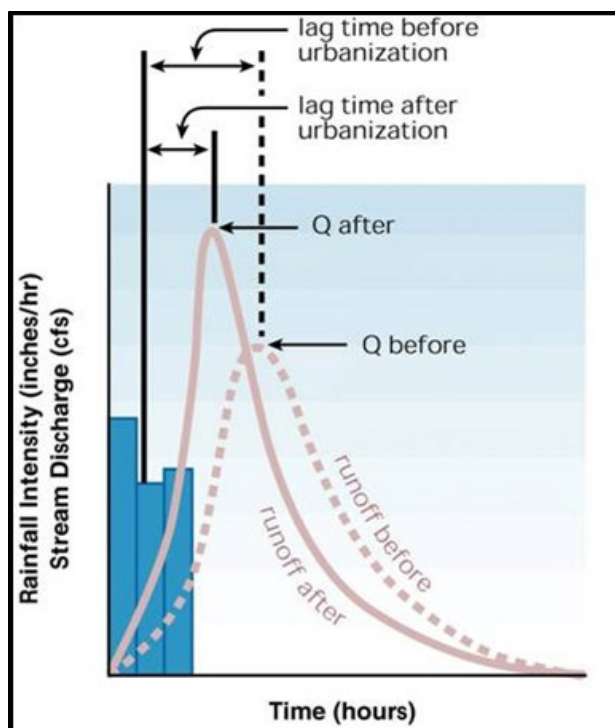


Figure 4-5: Example Urban Hydrograph

Source: USDA, 1996

As one or more of these components change then the channel stability balance is disturbed, and the system adjusts accordingly (Lane, 1955). For Cole Creek, the watershed has been manipulated and changed mostly fifty-plus years ago but there are some areas that have seen changes in the past 20 years that have required the channel to adjust even more. Overall, Cole Creek has a lot of revetment-type materials within the channel, somewhat helping with channel stability in some cases, but causing negative impacts in others.

For example, during the site visit in April 2019, the channel section in Figure 4-6 illustrates a large quantity of broken concrete and rubble that is typical in many areas within Cole Creek. The concrete rubble mostly lines the center of the channel and does not provide bank protection. This type of protection is not consistent but does provide limited benefits for channel stabilization; however, the concrete rubble also lines the center of the channel and directs flow into the channel banks that are already eroding. In many cases, the streambanks are vertical and very susceptible to extreme slumping and mass bank failure.



Figure 4-6: Cole Creek Channel and Bankline Showing Riprap Rubble

Note: Location between Seaward Street and Hillside Drive

The Cole Creek study area is composed of 5 Reaches (Figure 4-7):

- Reach 1 – Big Papillion Creek to Blondo Street Bridge
- Reach 2 – Blondo Street Bridge to North 72nd Bridge
- Reach 3 – North 72nd Bridge to Ames Avenue Bridge
- Reach 4 – Ames Avenue Bridge to Parkview Lane
- Reach 5 – Parkview Lane to Sorensen Parkway

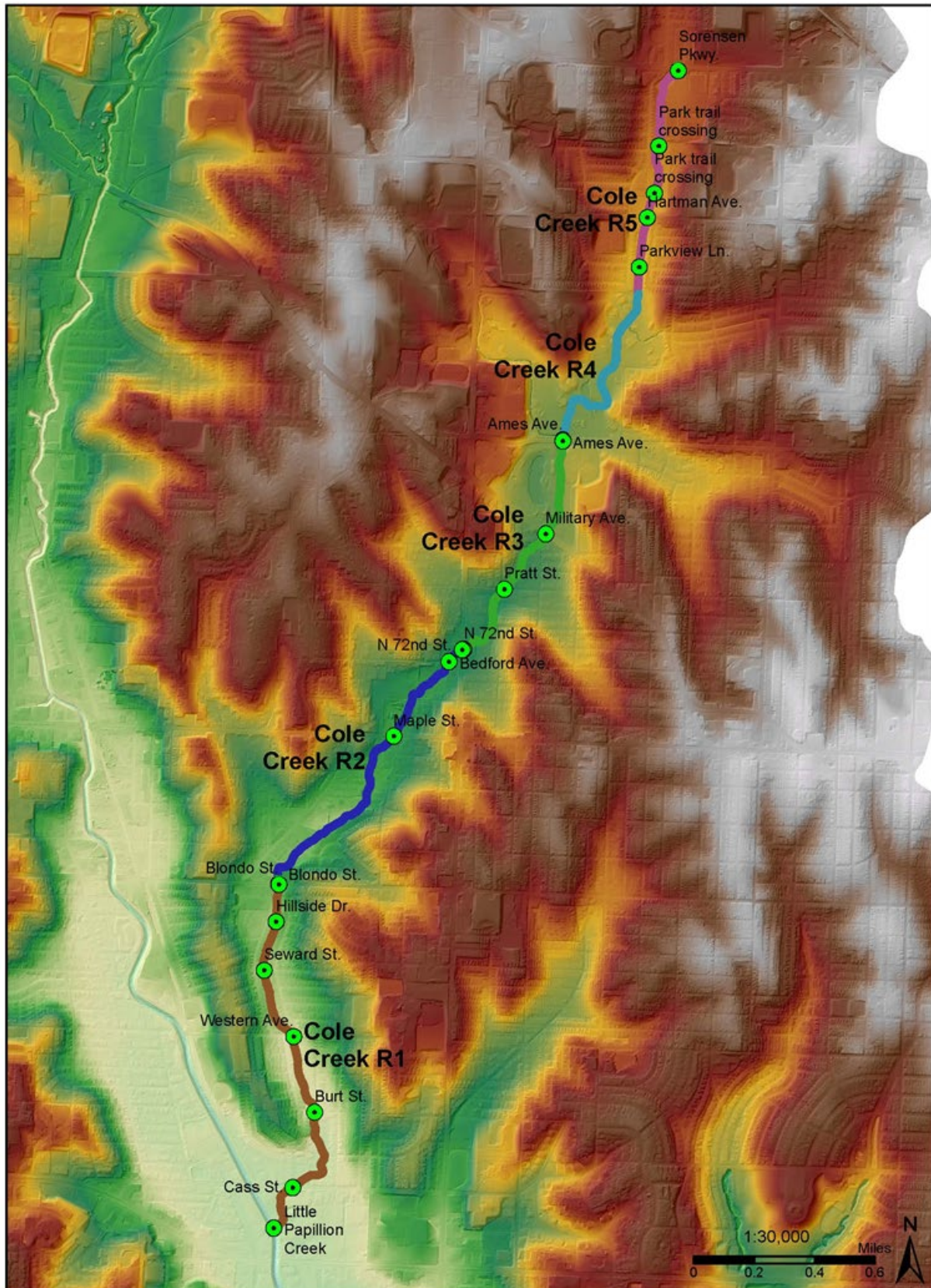


Figure 4-7: Cole Creek Study Reaches (1-5)

The Cole Creek FG assessments were completed for Rapid Geomorphic Assessment (RGA) Level 1-CSA (Reaches 1-5) and Level 2-CSA (Reach 4).

To allow for analysis of the metrics in Table 4-1, the following data sources were used.

LiDAR Data and Resolution:

The study used three different LiDAR datasets to complete the FG analysis, from 2004, 2010, and 2016. Details for each set of LiDAR is described in the following paragraphs.

The 2004 LiDAR data was collected by Horizons, Inc., on January 4 and 6, 2004, for the Metropolitan Area Planning Agency (MAPA). The elevation point data was converted into a geodatabase feature and then into a shapefile for input into the LASTools, shp2las tool. Once converted into a LASer (LAS) data file the Ground classification tool in Esri's ArcPro was run to classify the bare earth points. The bare earth points were used to create a one-foot resolution raster. The lack of classified water points and the density of one point per every two meters created challenges with the 2004 LiDAR data.

The 2010 LiDAR data was collected by Merrick & Co. between April 2010 and April 2011 to produce a one-meter Digital Elevation Model (DEM) and two-foot interval contour lines for the Nebraska-Iowa Regional Orthoimagery Consortium (NIROC), the Natural Resources Conservation Service (NRCS) Eastern Nebraska and Prairie Creek. The Cole Creek area was collected between November 9, 2010, and April 9, 2011. The vertical accuracy was 0.36 meters at the 95 percent confidence level and a positional accuracy of 0.185 meters root mean square error (RMSE). Horizontal Datum is North American Datum of 1983. Vertical Datum is North American Vertical Datum of 1988. The LAS dataset was filtered for ground points and converted into a one-foot resolution DEM which is used as the basis for analyzing the Cole Creek channel.

The 2016 LiDAR data was collected by Woolpert, Inc. for the NE Eastern Nebraska UA LiDAR 2016 B16 from December 8, 2017, to February 3, 2017. The LAS tiles were classified with ground and water points with a density of 0.7 points per meter.

Analysis Assumptions and Limitations:

FG is not a model, so stating and understanding the limitations of this and other geomorphic and hydraulic data is of utmost importance. Assumptions include:

- The 2004 and 2016 elevation data are compared when the flowline points are calibrated. The higher density 2016 data is used as the baseline when the flowline points tool is run for the 2004 data. Due to the lower density and lack of water points for the 2004 data, cross-sections are drawn to optimize the available data. The 2004 cross-sections are then copied and expanded to match the 2016 flowline, allowing for a comparison of the same portion of the stream from both data sets.
- The LiDAR data used in the analysis does not penetrate the water surface so true channel depth is not measured. The geomorphic metrics are based on the depth captured between the water surface and the bankfull indicators.
- Based on assessing the LiDAR, the three collects were taken during a similar water surface level event as many of the cross-section flow line points are nearly identical. It also appears that there are portions of the LiDAR data sets that may have very minor depth loss due to low water conditions during the collects.

- For Level 2 analysis in distinguishing bankfull channel conditions, riffle cross-over locations were identified to measure bankfull indicators that are essential in identifying channel forming discharge as it shapes an active floodplain and provides a bankfull geomorphic signal.
- The resulting geomorphic metrics reported in this document are based on the FG process of detrending DEM elevations. For this study, geomorphic channel signals were identified within study reaches to identify and establish relative bankfull channel measurements. Detrending is then used to normalize the floodplain and channel slope to project the bankfull elevation through the reach. This provides a method for projecting the bankfull channel measurement to each cross-section chosen for analysis. The cross-sections are then used to calculate the bankfull channel metrics throughout the reach.
- The interpretation of the LiDAR data needs to be completed in an objective, consistent manner. Depending on the year of collection there are differing levels of accuracy that can be expected and should be considered when assessing and making recommendations from interpreting the data.
- Mean depth was used instead of hydraulic radius to calculate shear stress.
- The LiDAR water surface slope trends are only representing the range of points that the LiDAR collected. Vegetation with lack of coverage can have major impacts on the assessment abilities of using LiDAR. When assessing the slope trends or cross-sections, aerial photos should be reviewed to determine level of potential vegetation interference.
- Because the LiDAR water surface profiles do not capture water depths below the water surface, the FG W/D ratios will tend to calculate slightly higher W/D ratios. So, the FG W/D ratios are likely elevated where greater channel depths are encountered.
- The FG toolkit is meant to be used to assess stream channel conditions and provide an assessment of where system instability exists. Field site visits are required to validate the information.

The two-year discharges were used from existing HEC-RAS models (USACE Omaha District) for Cole Creek each to adjust for tributary inflows and they are:

- Reach 1 = 952 cfs - (27.0 cubic meters per second (cms))
- Reach 2 = 765 cfs - (21.7 cms)
- Reach 3 = 599 cfs - (15.8 cms)
- Reach 4 = 509 cfs - (14.4 cms)
- Reach 5 = 345 cfs - (9.8 cms)

4.2.2 INTERPRETATION OF GEOMORPHIC DATA

Level 1 FG Analysis:

While the development and creation of LiDAR high-resolution terrain data is a typically common, straightforward procedure, automation and interpretation of resulting terrains can be more challenging; reliable interpretation requires both insight and appropriate judgement-based decision-making on the part of the investigator. FG provides the automated assessment platform and toolkit (Haring and Dougherty, 2022a-2022b) to provide step-by-step instructions through the process of transforming LiDAR data into fluvial geomorphic assessments. These assessments can be used by fluvial geomorphologists and water resource professionals to assess stream conditions and identify problems and opportunities. By organizing several complex datasets into standard reports, the FG toolbox concisely presents volumes of data to aid analysis.

The cross-sections for all the reaches were 50 feet apart. The individual cross-section points were spaced at one-foot increments along the cross-section. The longitudinal water surface profiles were plotted using approximately three-foot spacing. The Level 1 CSA uses a combination of cross-sections and the longitudinal profile to assess channel stability.

FG Level 2 CSA Analysis:

CSA analyzes bankfull channel conditions based on LiDAR-derived DEMs to compare against empirically based data to assess channel stability. The final products of the CSA are reach-level reports that plot and map the metrics at a stream-channel-reach scale. The metrics are compared based on standard, existing or user-defined thresholds. The metrics are mapped by color-coded signals. Reach 4 was identified as a candidate to benefit from the additional analysis that can be provided through FG Level 2. The summary of the FG Level 2 analysis appears after the FG Level 1 analysis for all reaches of Cole Creek.

4.2.2.1 REACH 1: LITTLE PAPILLION CREEK TO BLONDO STREET BRIDGE

The Reach 1 site map is illustrated in Figure 4-8 and the water surface profiles from 2004, 2010, and 2016 are plotted in Figure 4-9. Overall, the channel in this reach is relatively straight, with some minor meandering within the highly incised channel with twenty-foot-plus bank heights.

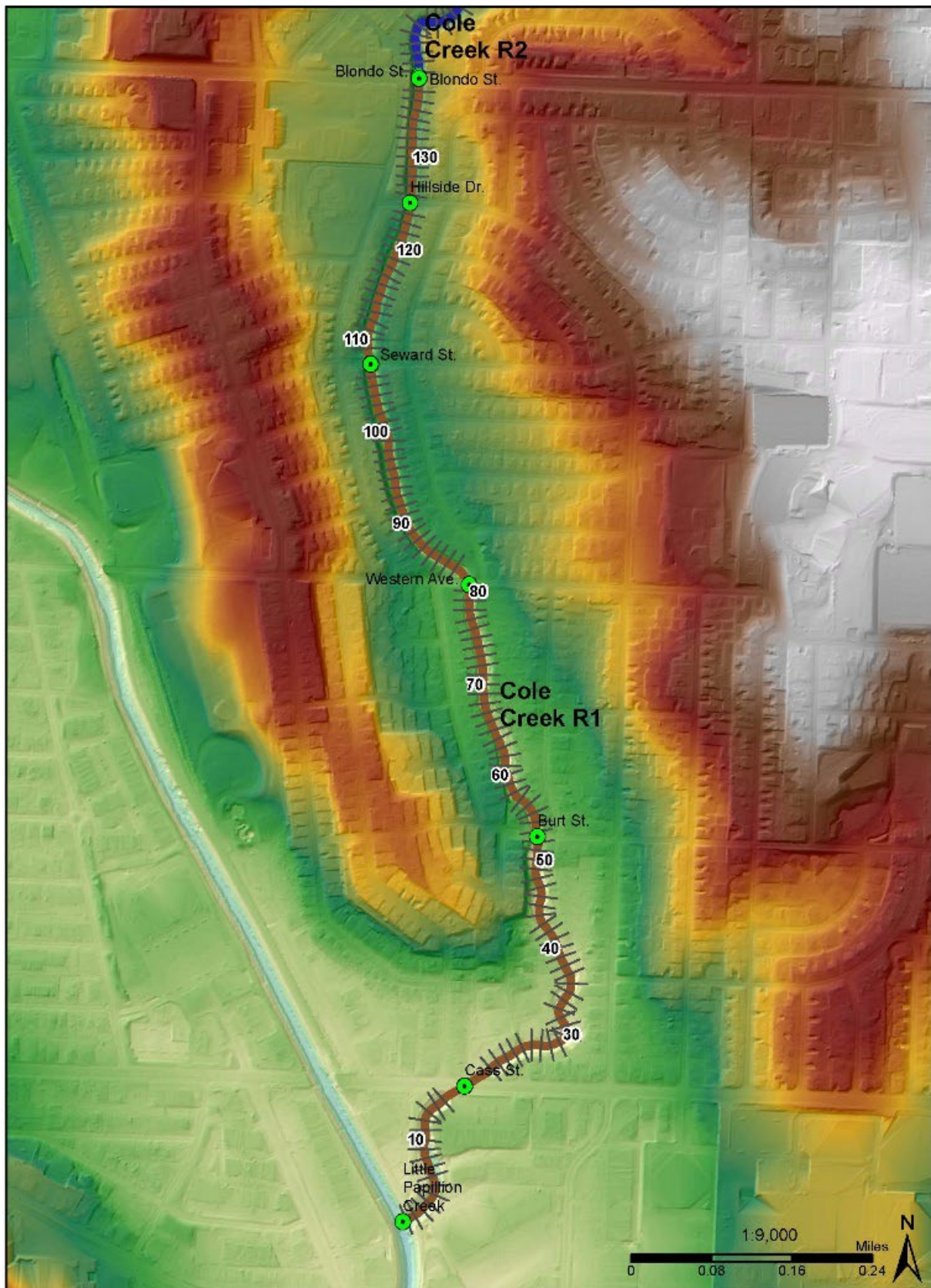


Figure 4-8: Cole Creek Reach 1 – Cross-section Location Map

The lower section of the reach has relatively close matching profile (Figure 4-9) and cross-sections (Figures 4-10 and 4-11) showing little or no changes between the 2004 to 2016 data. The profile within this reach is relatively consistent except for the channel section upstream of Western Avenue.

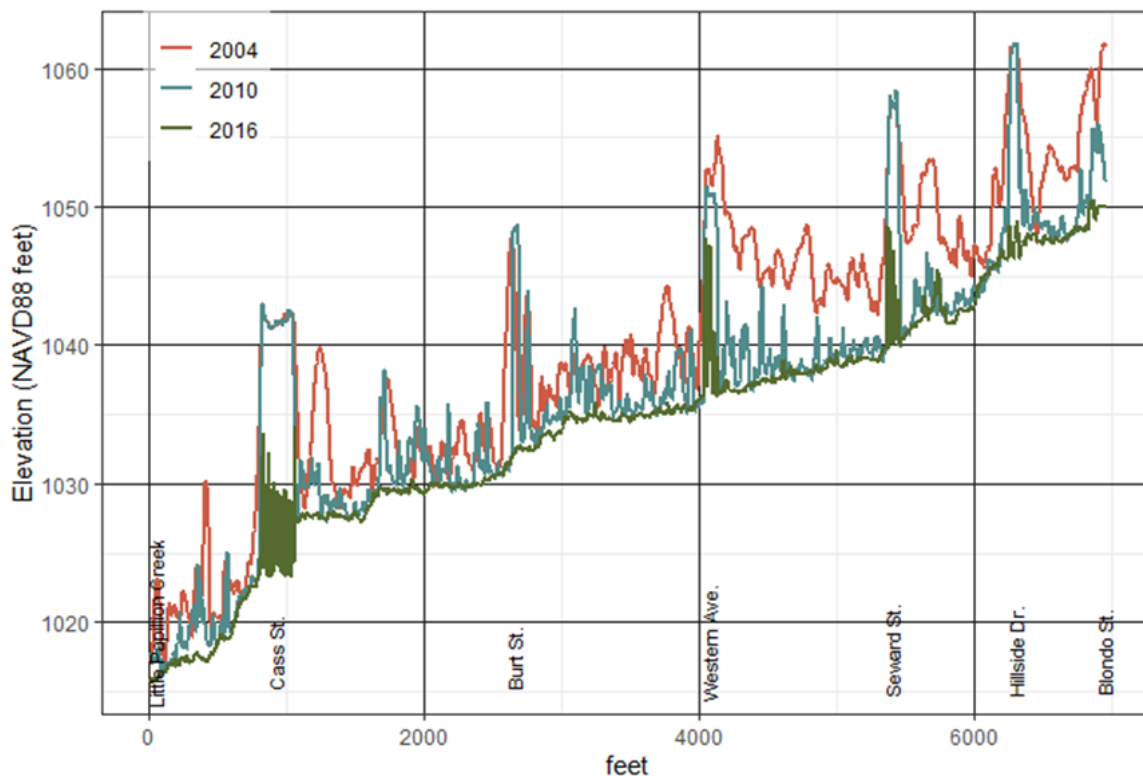


Figure 4-9: FG Level 1, Reach 1 – LiDAR Water Surface Profiles

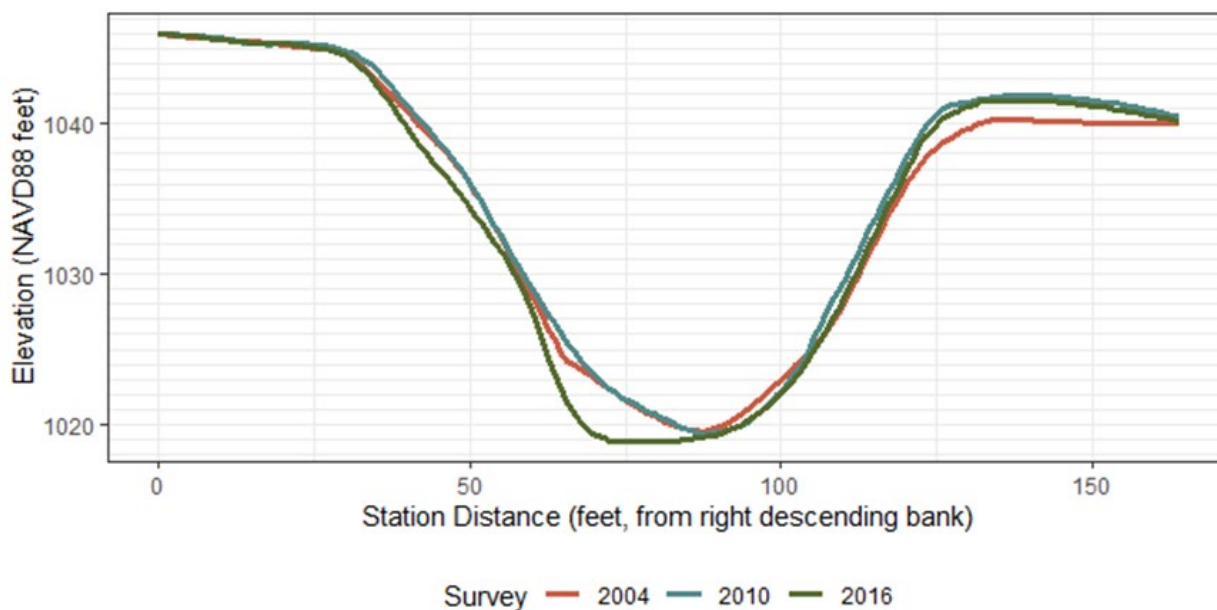


Figure 4-10: Cross-section 11 Illustrating Good Match Between LiDAR Data Sets

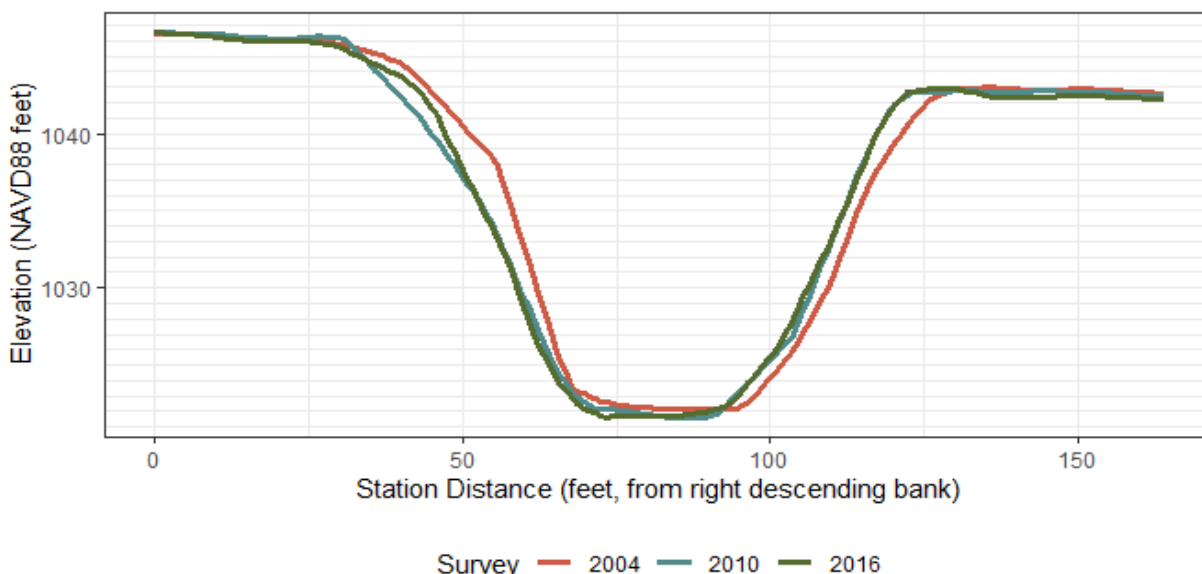


Figure 4-11: Cross-section 14 Illustrating Good Match Between LiDAR Data Sets

The Western Avenue culvert was replaced prior to the LiDAR data collection in 2004 and there are possible bed changes (lower by degradation; Figure 4-12 is associated with that change upstream of the crossing). There was also a change to the Seward Street crossing between 2004 and 2010 (Figure 4-13). Further investigation into the causes of local bed and bank erosion issues is warranted. The culvert inverts and sizing designs should be reviewed to determine what channel changes may have occurred as a result of the culverts being replaced.

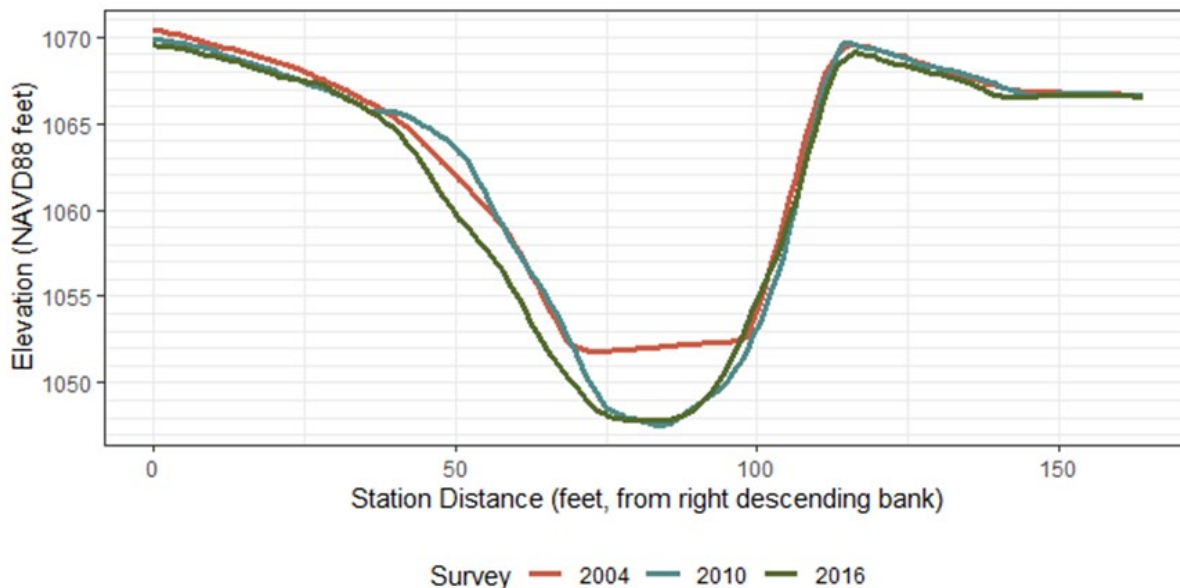


Figure 4-12: Cross-section 84 Illustrating Bed Changes Between 2004 and 2016

Associated with the bed degradation, there is also lateral bank erosion which is expected in incised channels (Figure 4-13). The channel has eroded the bed approximately two-to-three feet (Figure 4-12) and eroded laterally eight-to-ten feet (Figure 4-13) in two locations.

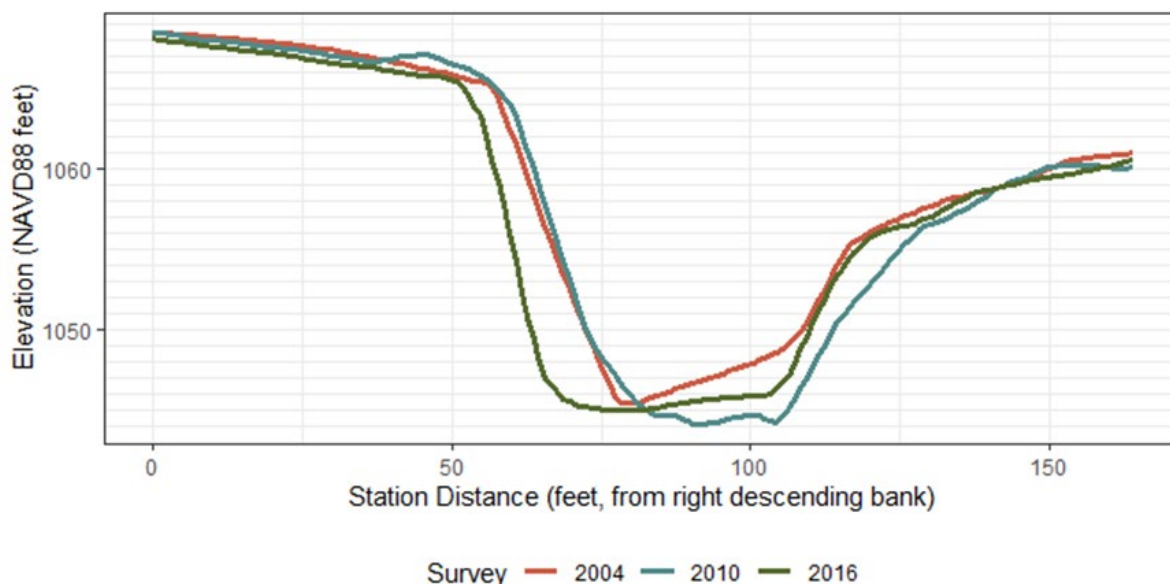


Figure 4-13: Cross-section 113 Illustrating Left Bank Lateral Erosion

Reach 1 Summary:

- The reach is trending between a CEM Stage IV and V. There is some degradation that has occurred and there is active local channel erosion.
- There have been culvert changes in the upper reach (between LiDAR collection dates) and the channel bed and banks may still be adjusting to the changes.
- The culvert changes are upstream of the Western Avenue culvert channel degradation; some lateral erosion may require bank stabilization to assist the channel in recovery (see bed and bank stabilization alternatives).
- The LiDAR water surface slopes are plotted in Figure 4-14. The slope trends show a decrease in channel slope from 0.0045 to 0.0041 ft/ft. The slopes are largely being controlled by the road culverts and concrete rubble in the channel bottom.
- Based on the FG Level 1 analysis, the lower section of Reach 1 appears to have a stable bed with local channel erosion downstream of the Western Avenue culvert. Upstream of the culvert there appears to be channel degradation and some lateral bank erosion. The section above Western Avenue should be further investigated to field-validate the information from this report.

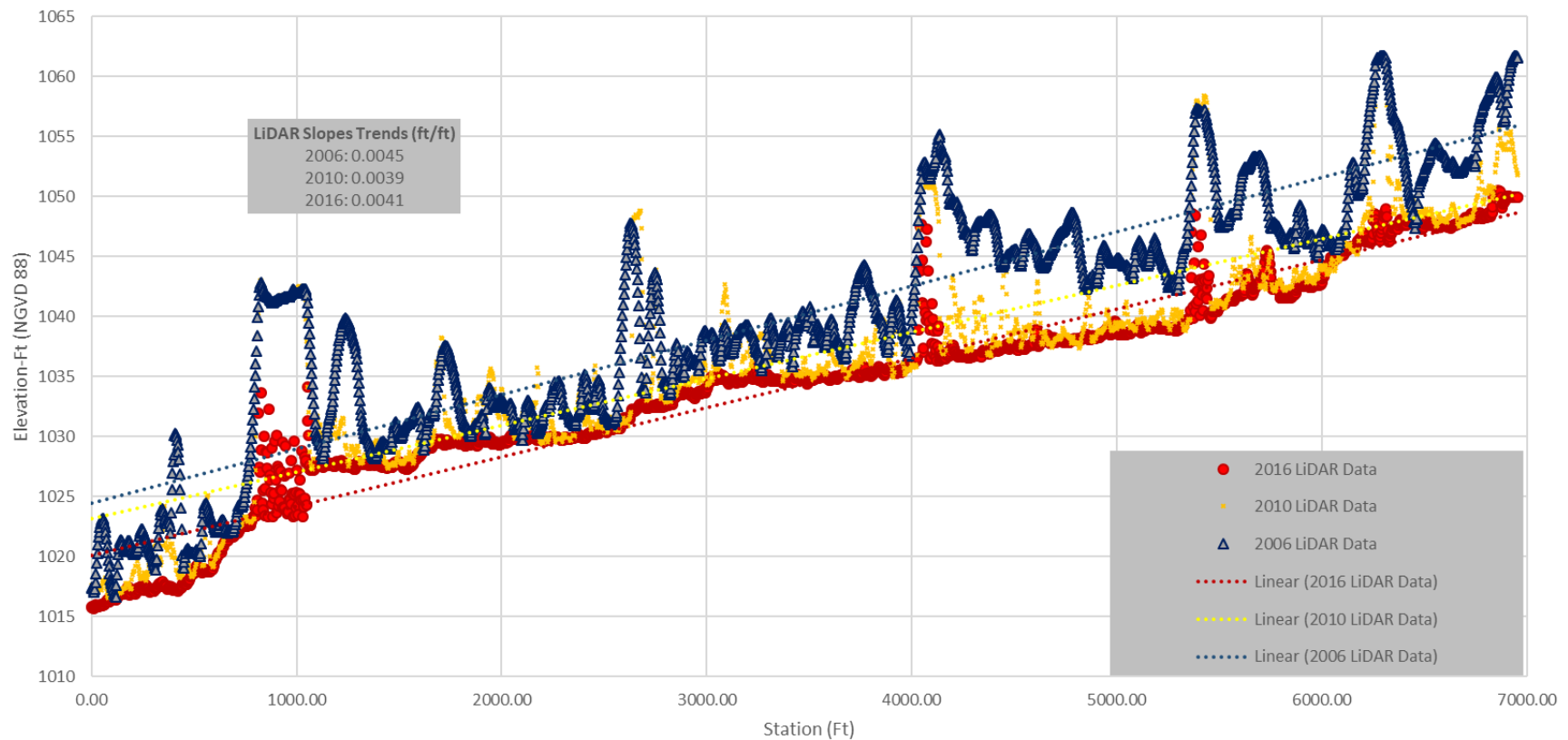


Figure 4-14: Reach 1 – LiDAR Slope Trends

Note: The LiDAR labeled 2004 and/or 2006 throughout this report refer to the same dataset, and thus are used interchangeably. The LiDAR collects were completed in 2004 and 2006 and were combined for that dataset.

4.2.2.2 REACH 2: BLONDO STREET BRIDGE TO NORTH 72ND STREET

Reach 2 is illustrated in Figure 4-15 and the LiDAR water surface profiles are plotted in Figure 4-16. Similar to Reach 1, this reach is relatively straight with minor meandering but is less incised, with bank heights ranging from 12 to 15 feet in the downstream section transitioning to eight-to-10 feet in the middle parts of the reach back to 10-to-15 feet in the upstream section.

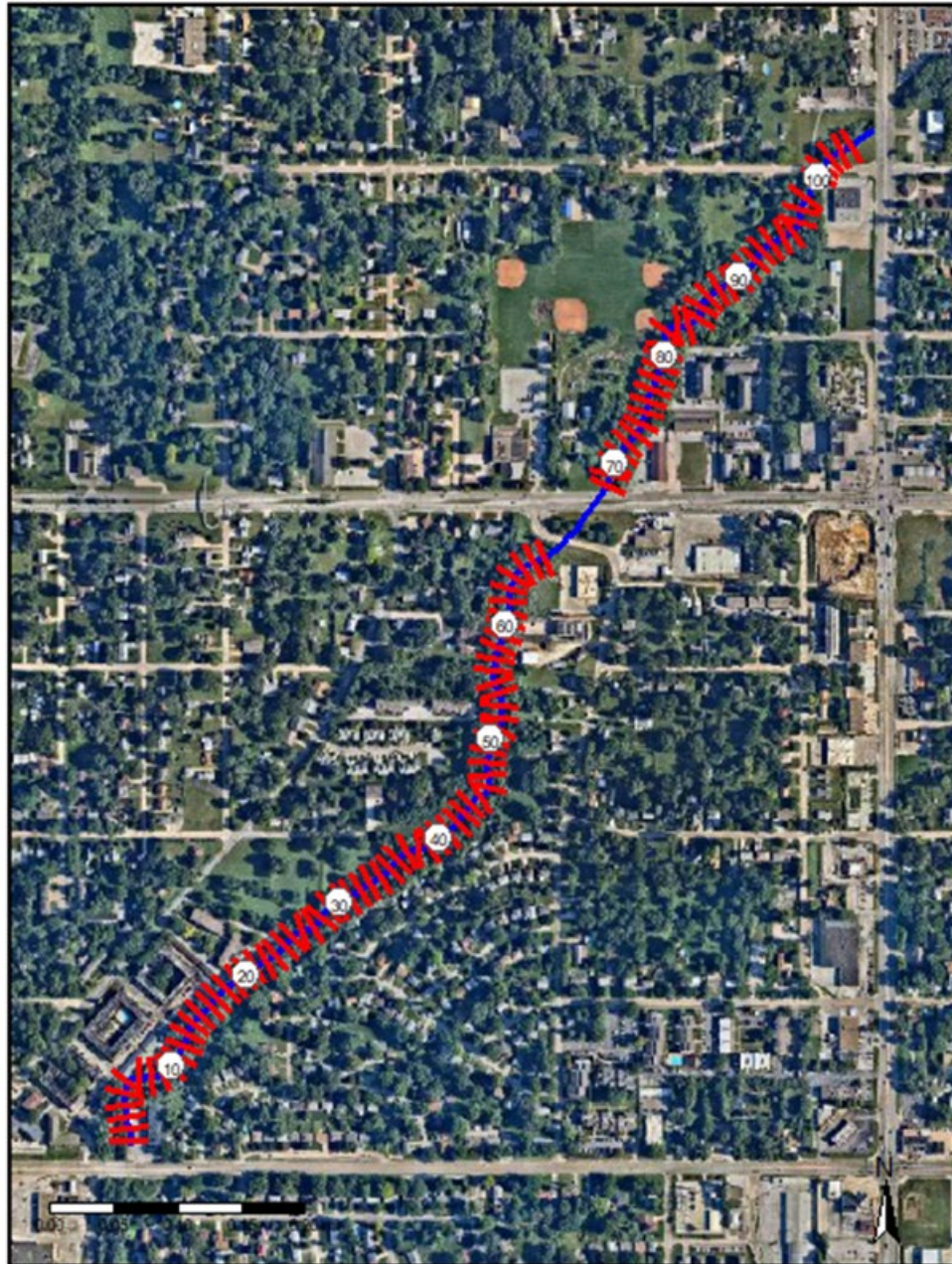


Figure 4-15: Cole Creek Reach 2 – Cross-section Location Map

The water surface profiles show a trend of channel degradation in the downstream section of the reach (cross-sections 1-26) from Blondo Street to approximately station 1800. The bed lowering was likely caused by the culvert changes downstream in the upper section of Reach 1. The middle section of Reach 2 (cross-sections 27-57) approximately station 1800 to the Maple Street culvert is not as incised. This sub-reach has much lower bank heights, eight to 10 feet, with some access to active floodplains. Figure 4-17 illustrates potential channel degradation as the channel appears to deepen and widen at this cross-section location. Figure 4-18 shows channel migration with no associated degradation.

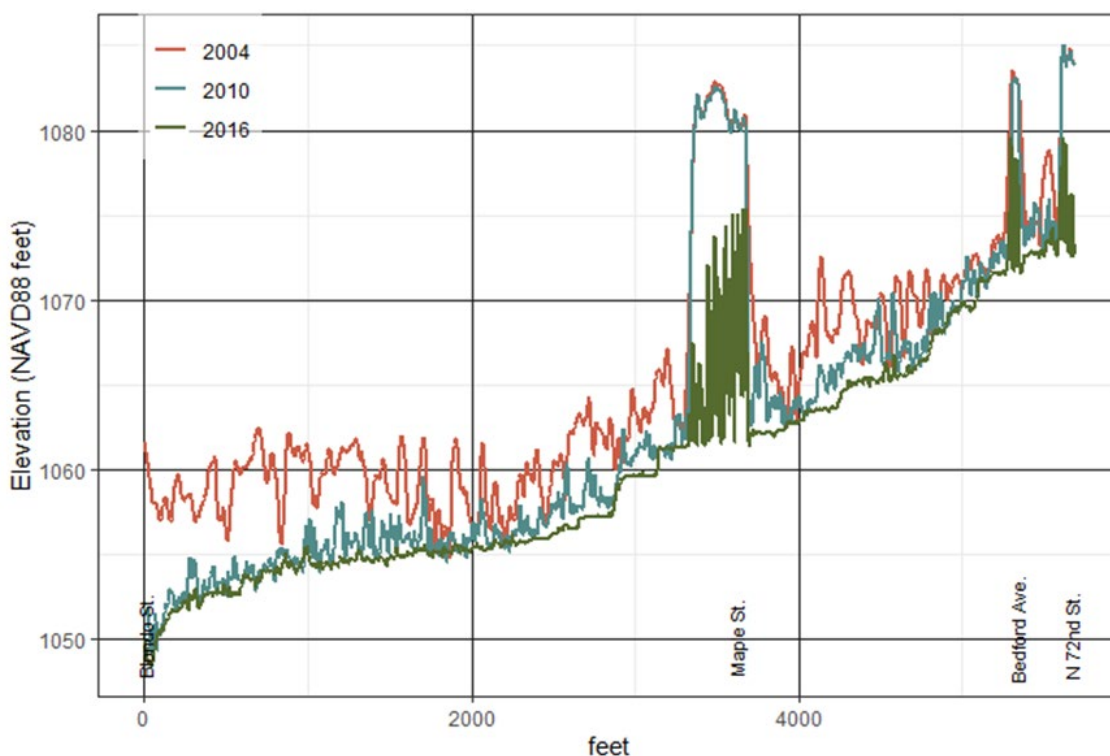


Figure 4-16: FG Level 1, Reach 2 – LiDAR Water Surface Profiles

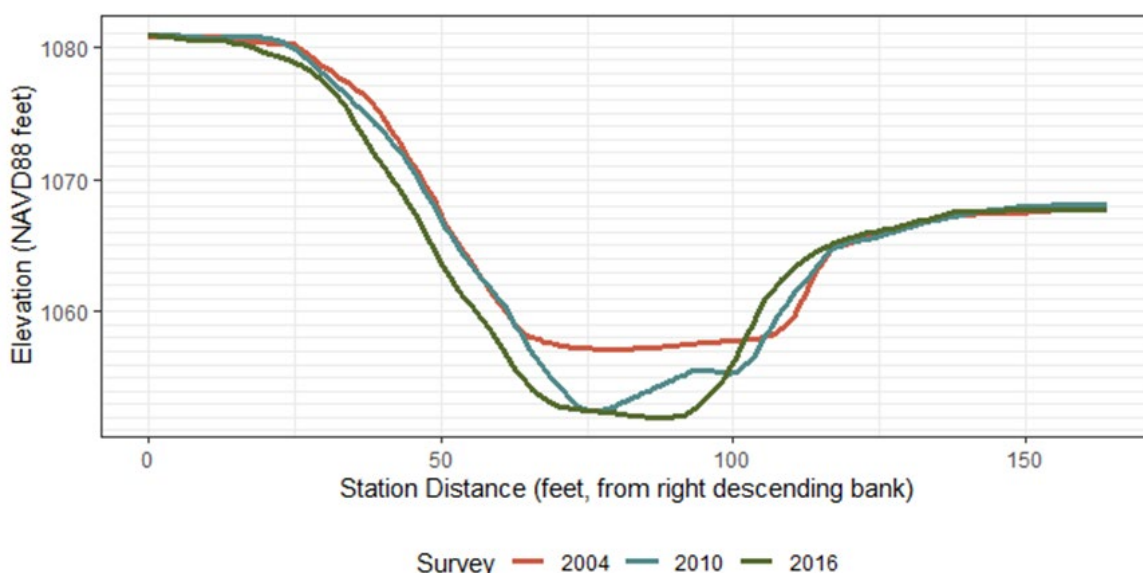


Figure 4-17: Reach 2 – Cross-section 7 Depicting Potential Channel Degradation

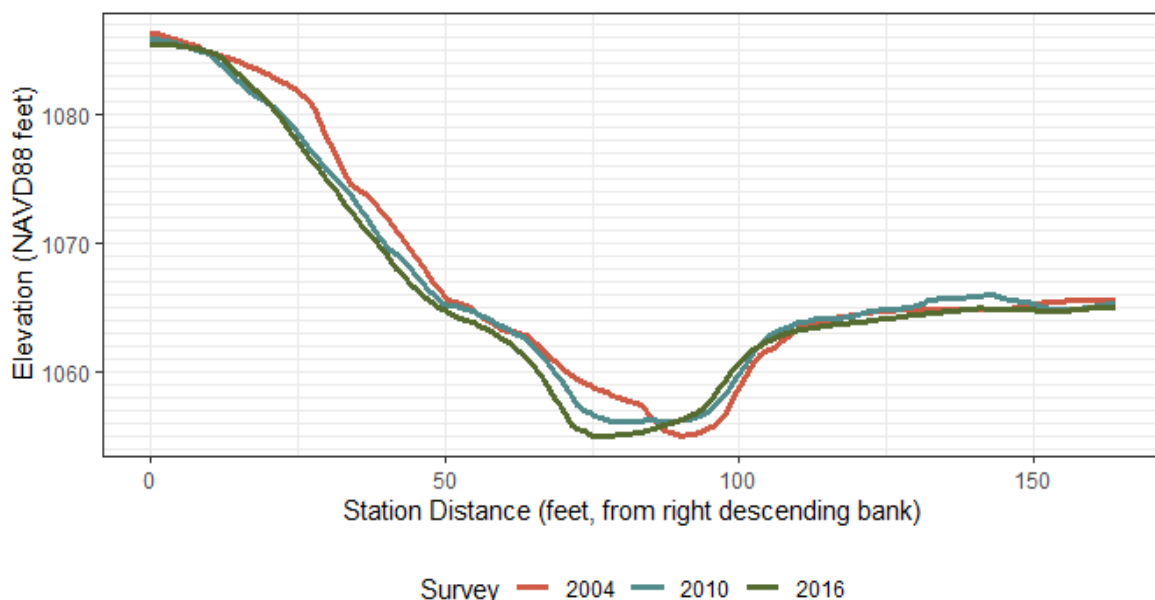


Figure 4-18: Reach 2 – Cross-section 38 Illustrating Channel Migration

The channel bed upstream of the Maple Street culvert is relatively stable with some bank erosion (right) in the range of 10 to 15 feet (Figure 4-19). The bank erosion appears local as many of the cross-sections appear to match well, showing some minor bed and bank erosion (Figure 4-20).

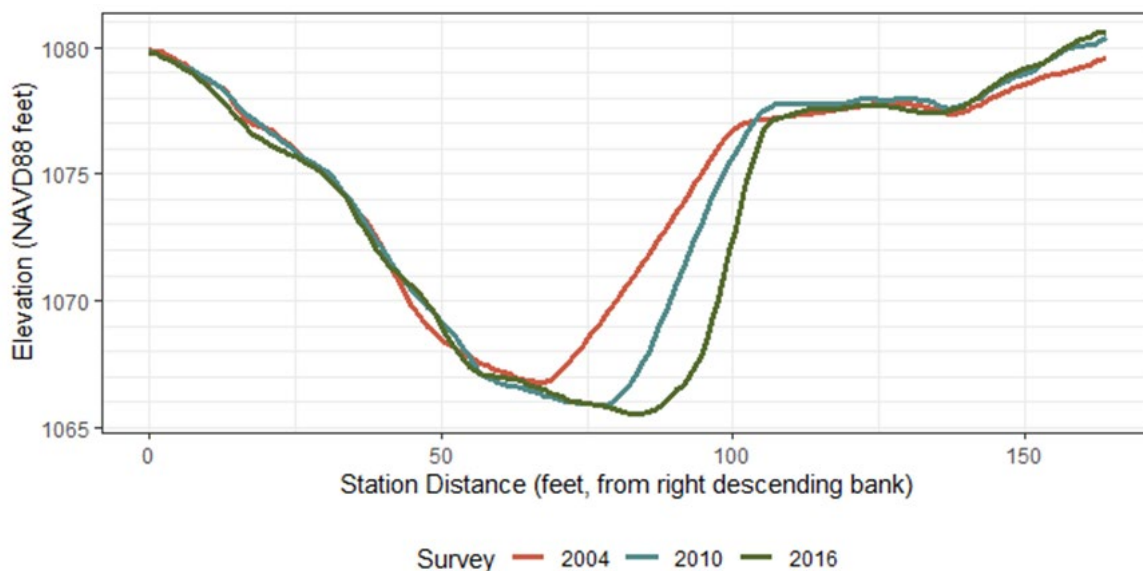


Figure 4-19: Reach 2 – Cross-section 86 Illustrating Lateral Right Bank Erosion

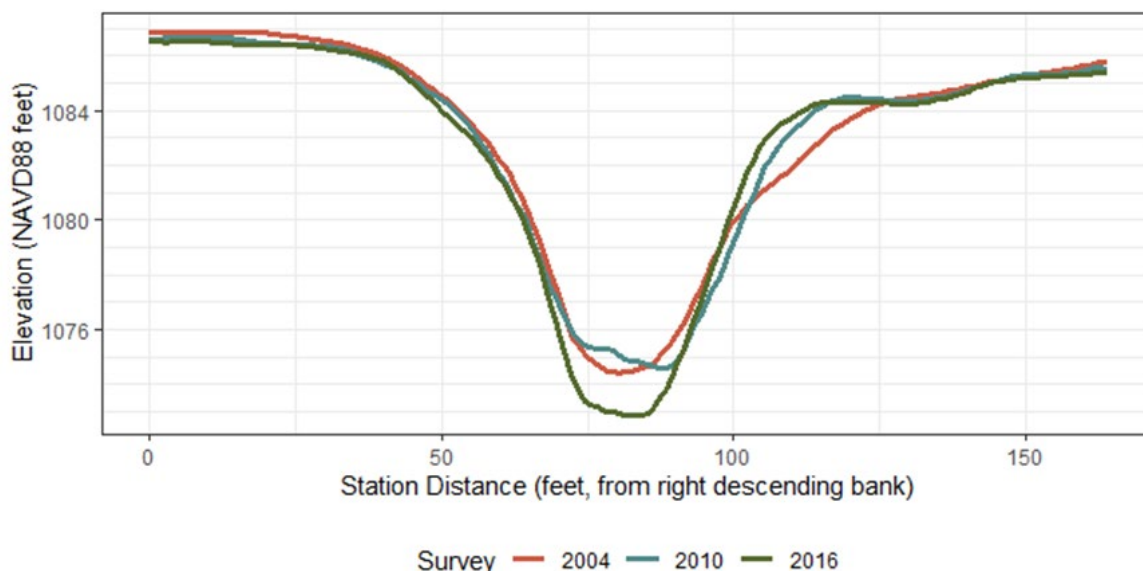
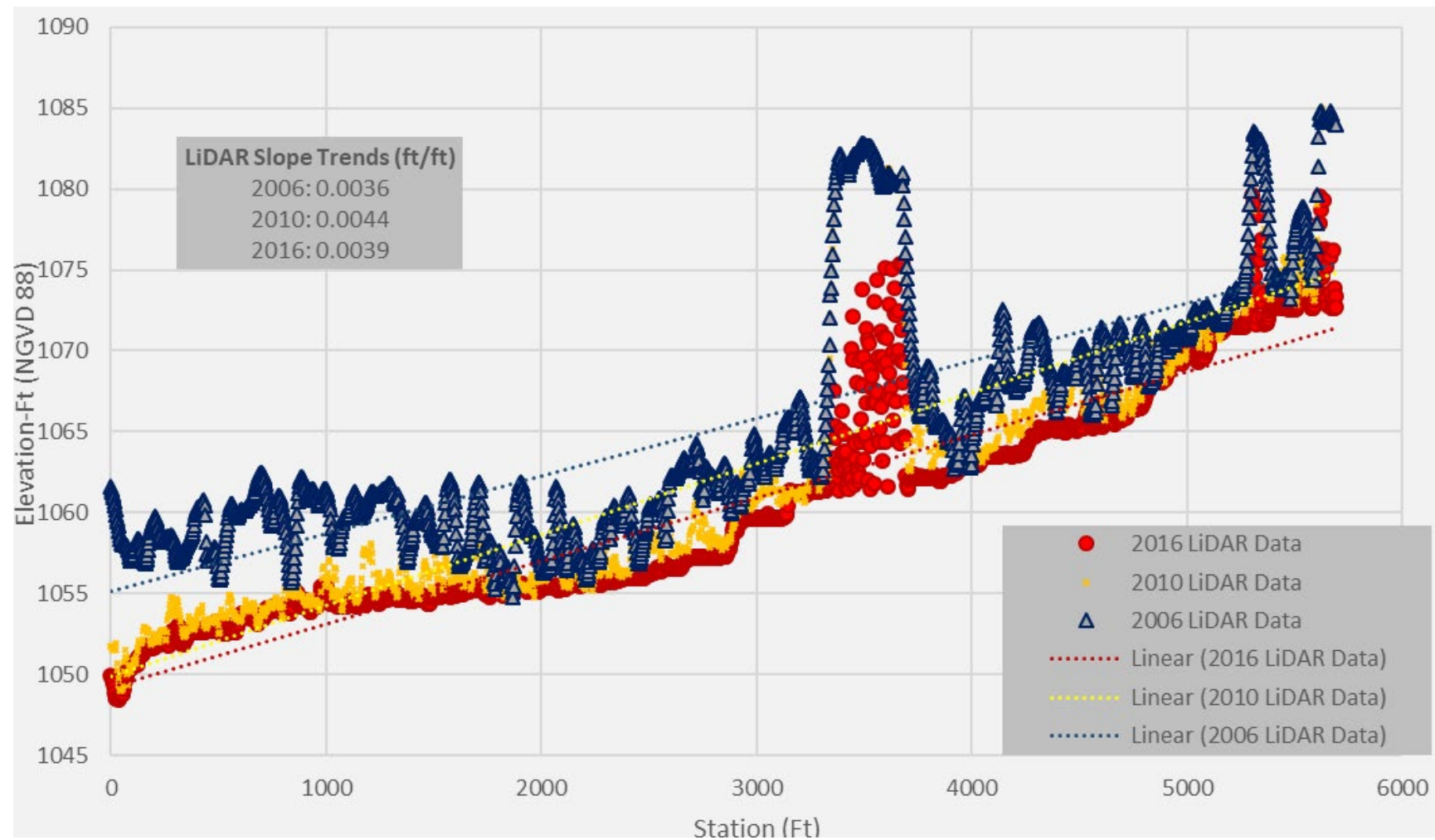


Figure 4-20: Reach 2 – Cross-section 101 Depicting a Relatively Stable Bank

Reach 2 Summary:

- The reach is trending between a CEM Stage IV and V. There is some degradation that has occurred in the downstream section and there is active local channel erosion. Part of the reach has access to a floodplain (Figure 4-18).
- The downstream section of Reach 2 has channel degradation occurring, likely resulting from the culvert changes in Reach 1.
- The downstream section should be investigated further to determine if bed or bank stabilization alternatives are appropriate.
- The LiDAR water surface slopes are plotted in Figure 4-21. Different LiDAR slope trends range from 0.0036 to 0.0044 ft/ft. The water surface slopes steepened from 2004 to 2010 and is now trending back closer to the 2004 slope.
- Based on the FG Level 1 analysis, the lower section of Reach 2 has channel degradation occurring. The middle section has good access to a floodplain but has some channel migration occurring as well. The rest of the reach upstream of the Maple Street culvert is relatively stable with some bank migration occurring. The downstream section should be further investigated all the way to the Maple Street culverts to verify current channel conditions.
- If there is active channel bed degradation occurring from channel changes that occurred in the downstream Reach 1, then there is likely further migration of the instability into the middle section of this reach.

**Figure 4-21: Reach 2 – LiDAR Slope Trends**

4.2.2.3 REACH 3: NORTH 72ND STREET TO AMES AVENUE

The Reach 3 site map is shown in Figure 4-23 and the LiDAR water surface profiles are plotted in Figure 4-23. This reach has more channel meandering within the commercial and residential areas in the downstream and middle sections. The upstream reach goes through Benson Park. Reach 3 is less incised than the Reaches 1 and 2 with bank heights ranging from eight to 10 feet in the downstream section transitioning to 10-to-15 feet in the middle parts of the reach and 15 to 20 feet in the upstream section.

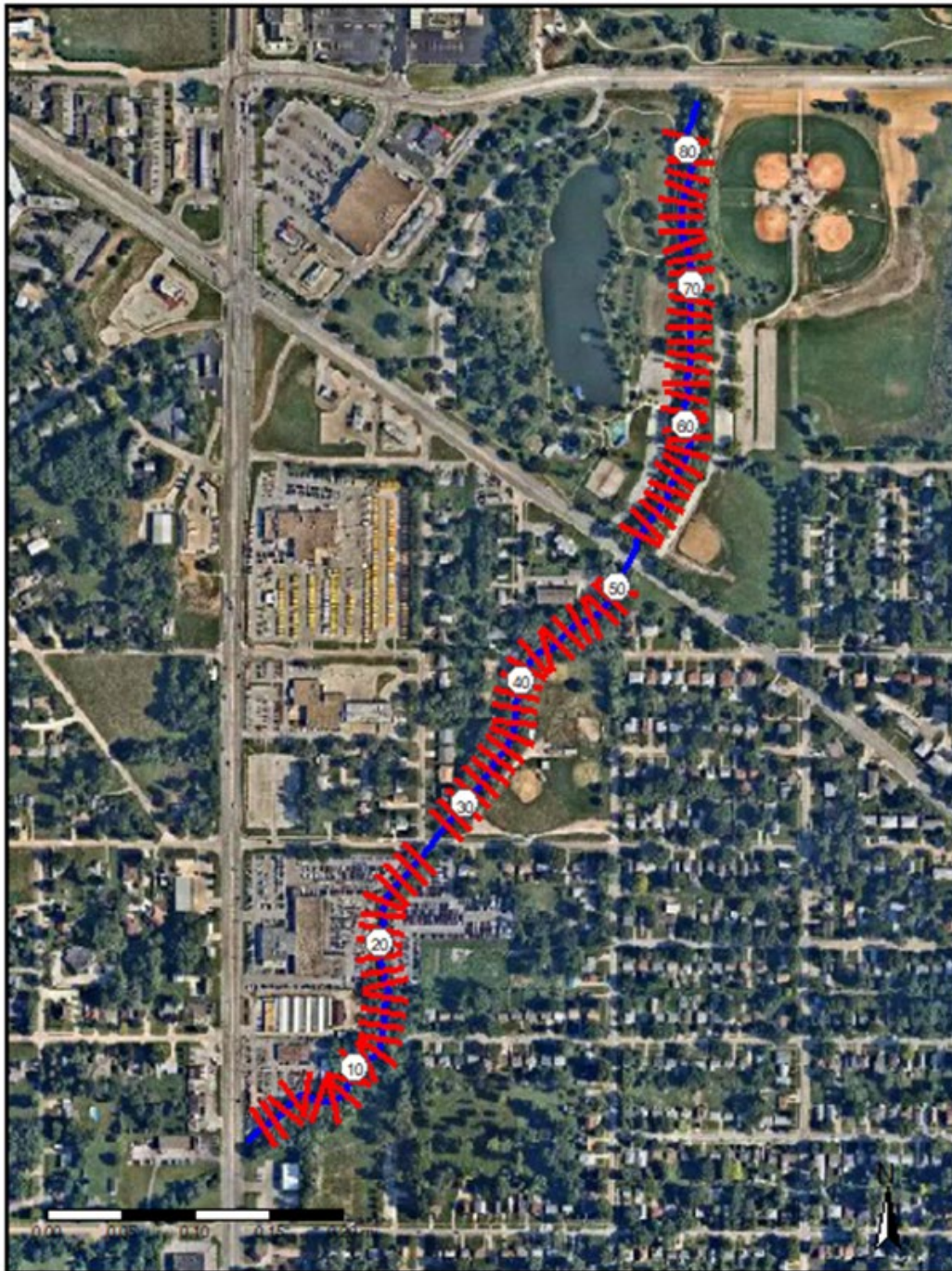


Figure 4-22: Cole Creek Reach 3 – Cross-Section Location Map

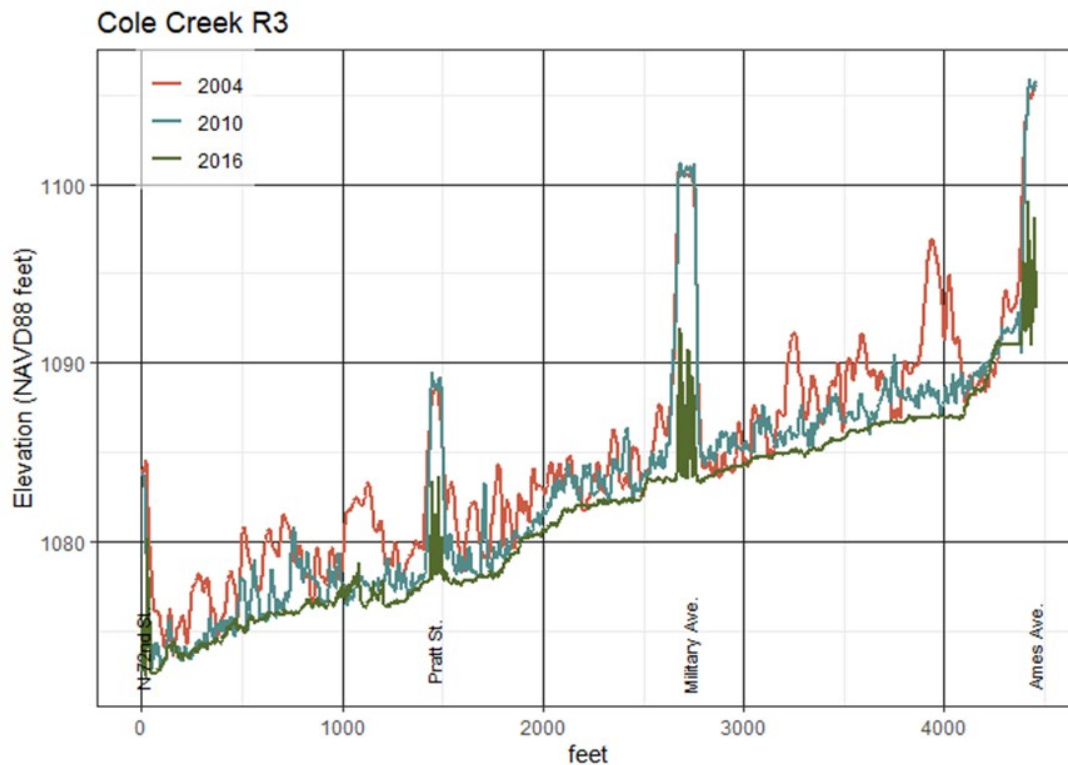


Figure 4-23: FG Level 1, Reach 3 – LiDAR Water Surface Profiles

The water surface profiles show a slight trend of channel degradation from 2004 to 2016; however, the lowest plotted points from the 2004 LiDAR do fall relatively close to the same elevations as the 2010 and 2016 counterparts, so there are likely some local channel changes occurring, but not a general trend for the reach over the 10 years between data sets. Figure 4-24 illustrates the stable channel conditions throughout this reach based on the LiDAR cross-sections.

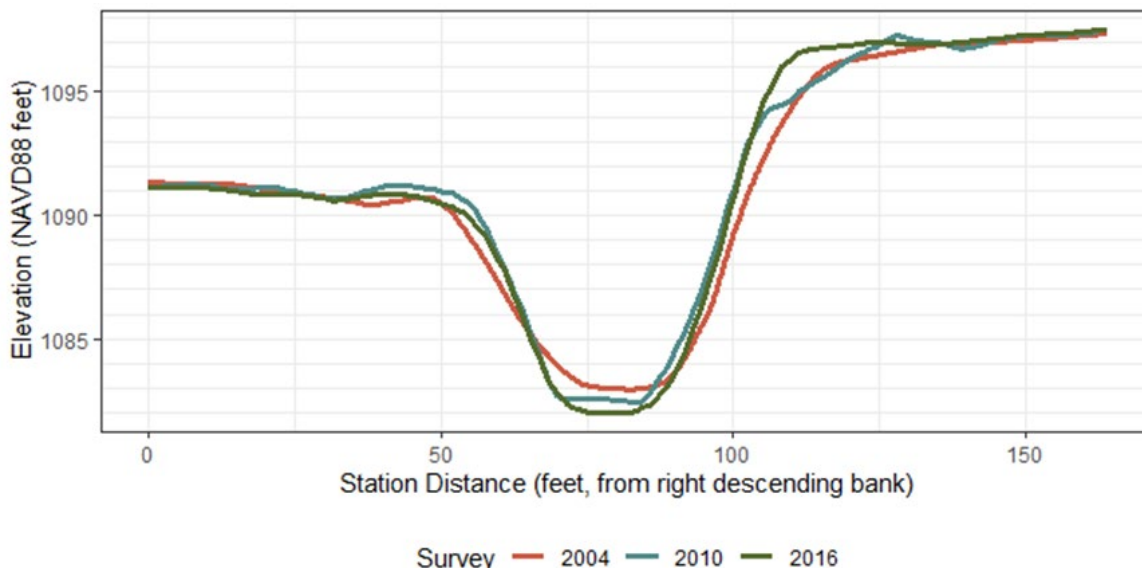


Figure 4-24: Reach 3 – Cross-section 81 Depicting a Relatively Stable Bank

Reach 3 Summary:

- Part of the reach has access to a floodplain and is likely a CEM Stage V; however, some areas still have not developed any floodplain berms (Figure 4-24) that may indicate a late CEM Stage IV.
- The channel bed in this reach is stable based on this analysis. There were no locations identified within the reach that appear to be changing relative to the analysis period between LiDAR data sets.
- The LiDAR water surface slopes are plotted in Figure 4-25. This may be the best example of a stable slope within all reaches. The slopes range from 0.0038 to 0.0041 ft/ft. and have remained constant in the past 10 years.
- Based on the FG Level 1 analysis, this reach appears to be stable from a bed and bank erosion perspective. There were no locations within the reach that appeared to be changing relative to the analysis period between LiDAR data sets.
- It would be good to field-validate this conclusion with a site visit to the three main areas within the reach. Field validation will provide information regarding determination of stable channel equilibrium slopes for project design. The sub-reaches within the reach are downstream reach-downstream of Pratt Street, middle reach between Pratt Street and Military Avenue and the upstream reach between Military Avenue and Ames Avenue.

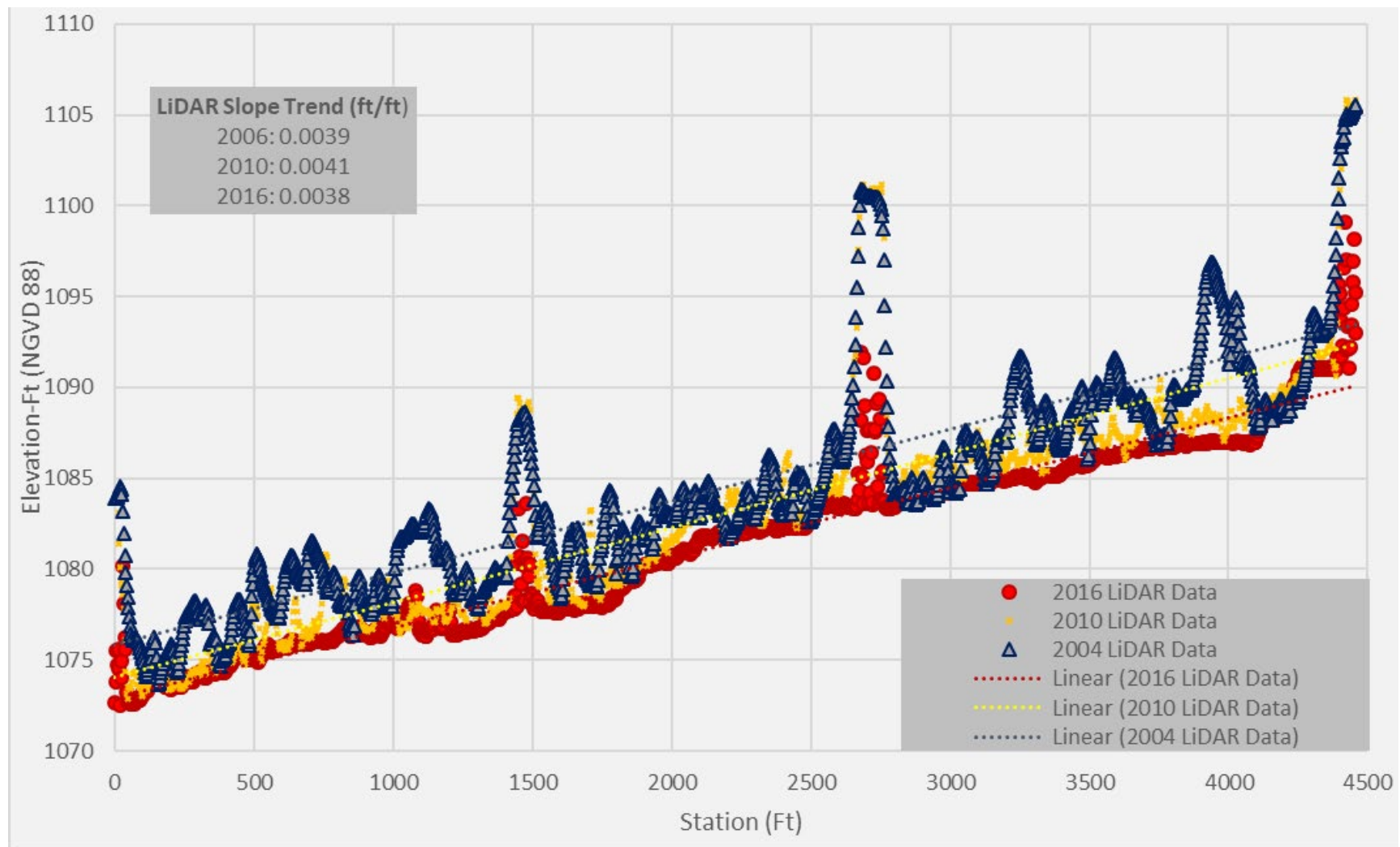


Figure 4-25: Reach 3 – LiDAR Slope Trends

4.2.2.4 REACH 4: AMES AVENUE TO OGDEN STREET

The Reach 4 site map is illustrated in Figure 4-26 and the LiDAR water surface profiles are plotted in Figure 4-27. This reach has more channel meandering than the downstream reaches and is the only non-developed section of the watershed (Benson Championship Golf Course). The downstream cross-sections range from eight to fourteen feet in height while the upstream cross-sections range from five to 10 feet.

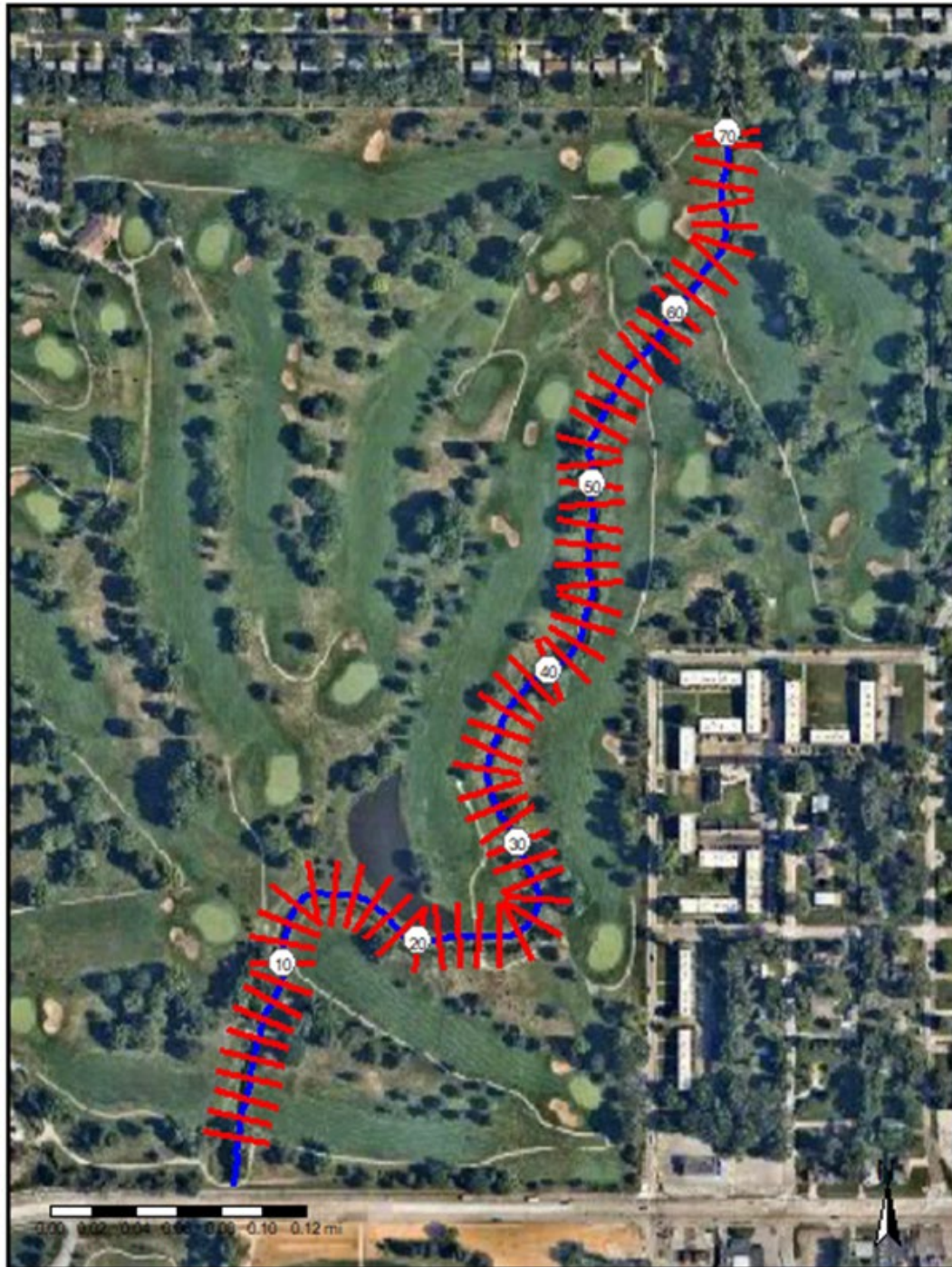


Figure 4-26: Cole Creek Reach 4 – Cross-section Location Map

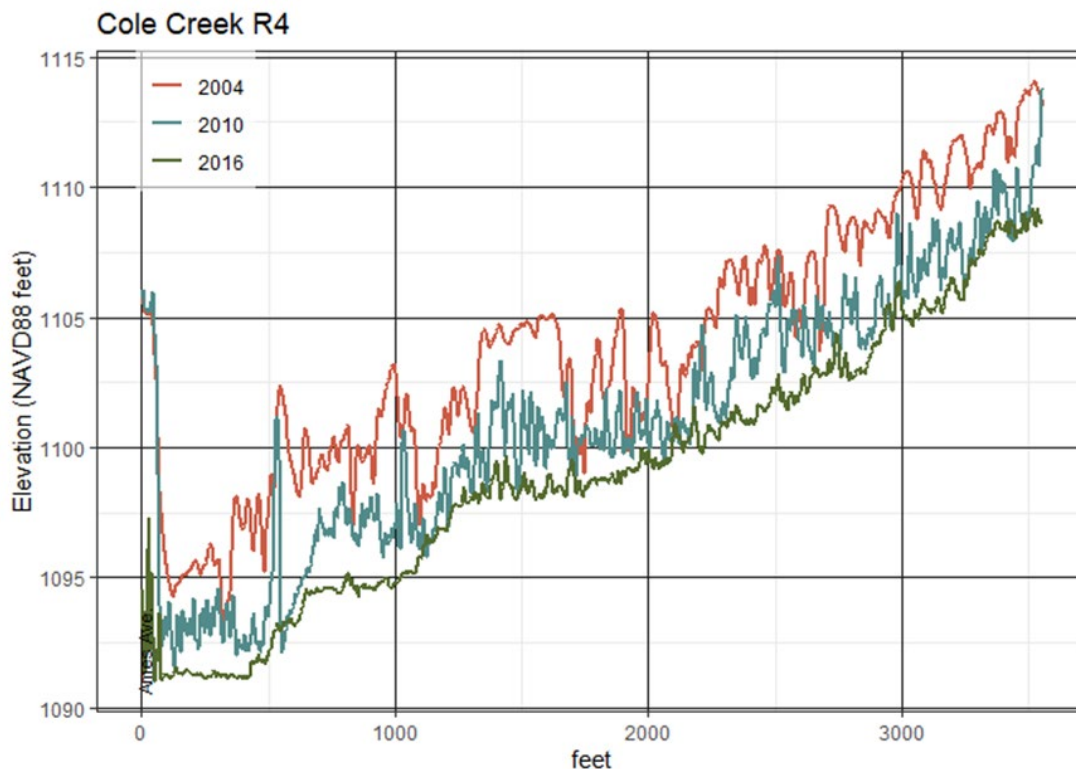


Figure 4-27: FG Level 1-Reach 4: LiDAR Water Surface Profiles

The water surface profiles indicate a trend of channel degradation ranging from approximately two to four feet. The incised channel locations are located on the downstream section of the reach as indicated by the bank heights. The channel bed lowering is more significant in the downstream section (Figure 4-28) of the reach than in the upstream section (Figure 4-29). There are larger slope breaks in the downstream section of the reach where there are riprap Grade Control Structures (GCS) (Figure 4-27). There is also local bank protection that has occurred throughout the reach.

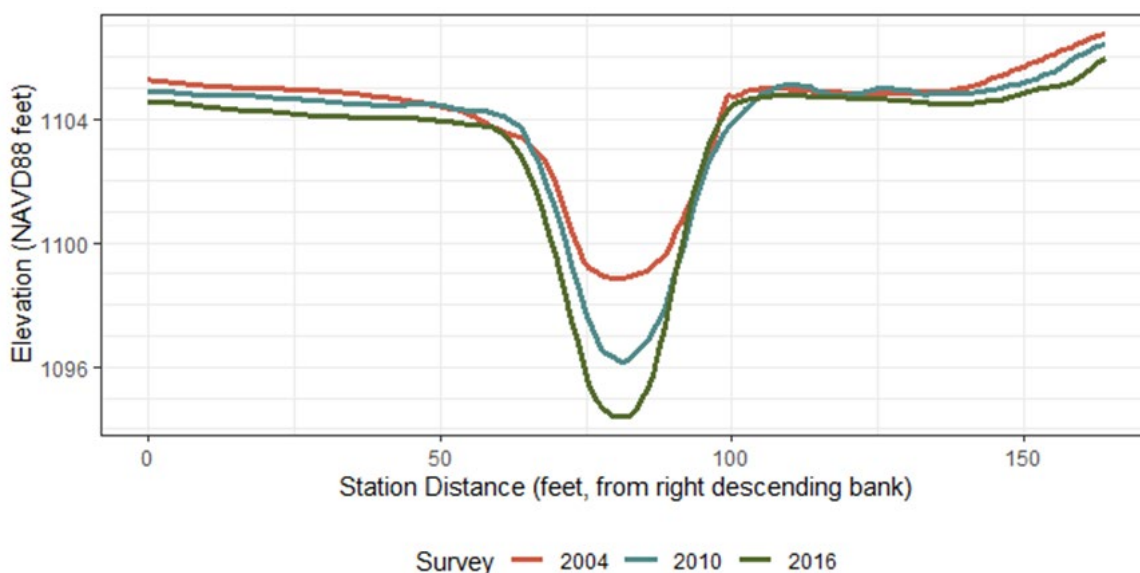


Figure 4-28: Reach 4 – Cross-section 12 Illustrating Bed Changes Between 2004 and 2016

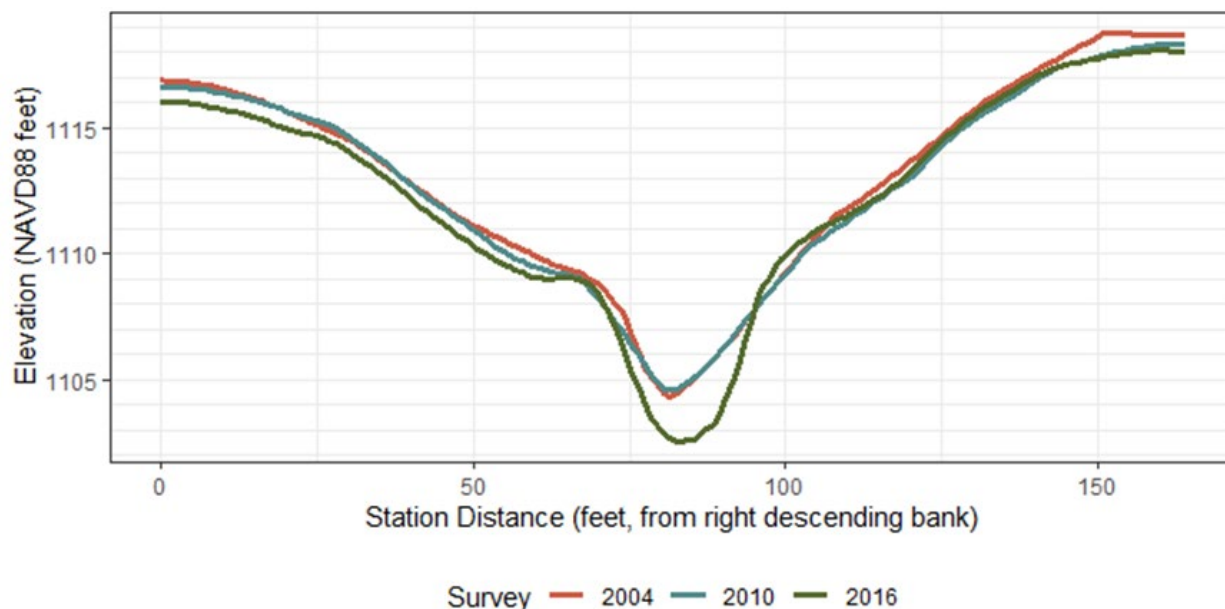


Figure 4-29: Reach 4 – Cross-section 52 Illustrating Bed Changes Between 2004 and 2016

Reach 4 Summary:

- The reach has access to a floodplain (Figure 4-29) in some locations then transitions to areas that are incised (Figure 4-30). Overall, it is hard to determine specific CEM stages for this reach as there appears to be channel bed degradation but little lateral bank erosion or channel widening. The introduction of GCSs and local bank erosion control measures has stabilized the reach. The CEM Stage likely varies from a Stage IV to a VI.
- The reach shows a trend of channel incision with very little bank erosion. There may be cohesive bank and bed materials in combination with the riprap GCSs and local bank protection that is preventing the channel from eroding.
- Figure 4-30 illustrates the LiDAR water surface slopes for Reach 4. This also may be a good example of a stable slope within all reaches. The slopes range from 0.0044 to 0.0048 ft/ft.
- From the FG analysis, this reach shows a trend of channel incision with very little bank erosion. The golf course has been proactive in treating the bed and bank erosion sites with riprap or other restoration measures so that may be the reason the reach is not in worse condition. It would be good to field-validate this conclusion with a site visit, and discuss the changes the site manager has seen over the past 10 to 15 years.

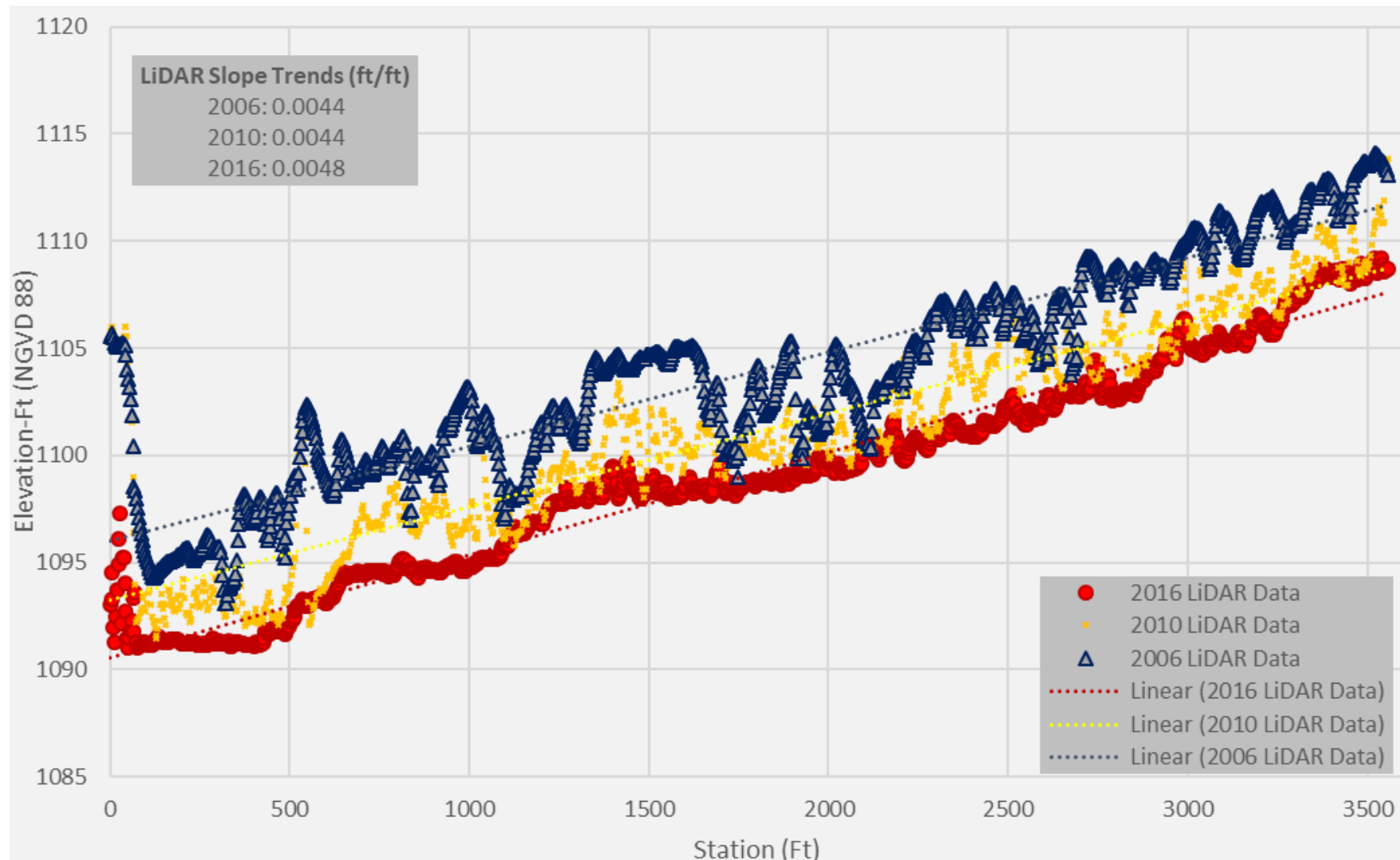


Figure 4-30: Reach 4 – LiDAR Slope Trends

4.2.2.5 REACH 5: OGDEN STREET TO SORENSEN STREET

The Reach 5 site map is illustrated in Figure 4-31 and the LiDAR water surface profiles are plotted in Figure 4-32. The reach has a straight channel pattern with evidence of recent channelization and bed and bank stabilization between Hartman Avenue and Sorensen Parkway (Orchard Park). The channelization and stabilization occurred in 2009 or early 2010 based on aerial photo investigations. The bank heights within the reach cross-sections range from five to eight feet.

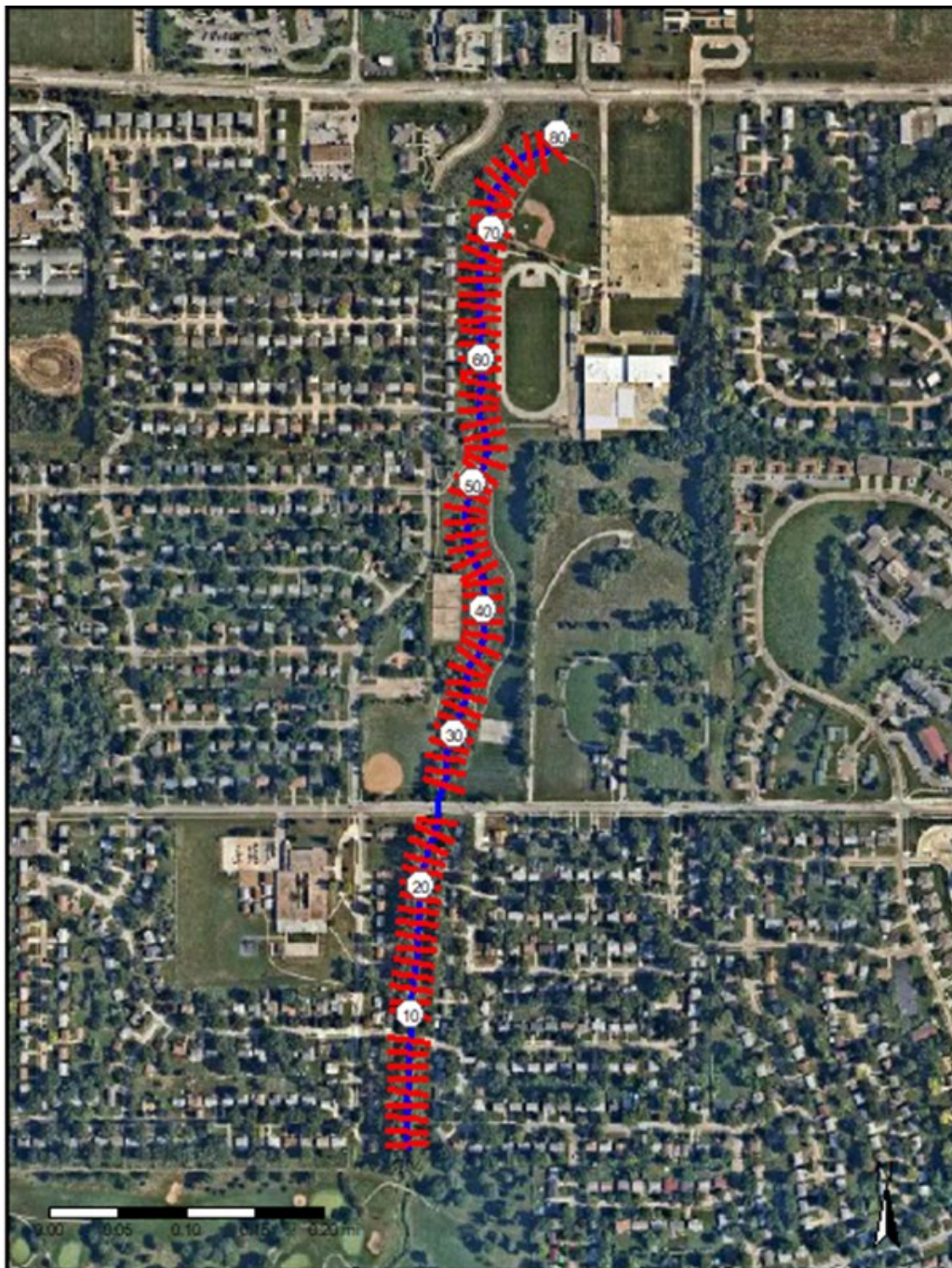


Figure 4-31: Cole Creek Reach 5 – Cross-section Location Map

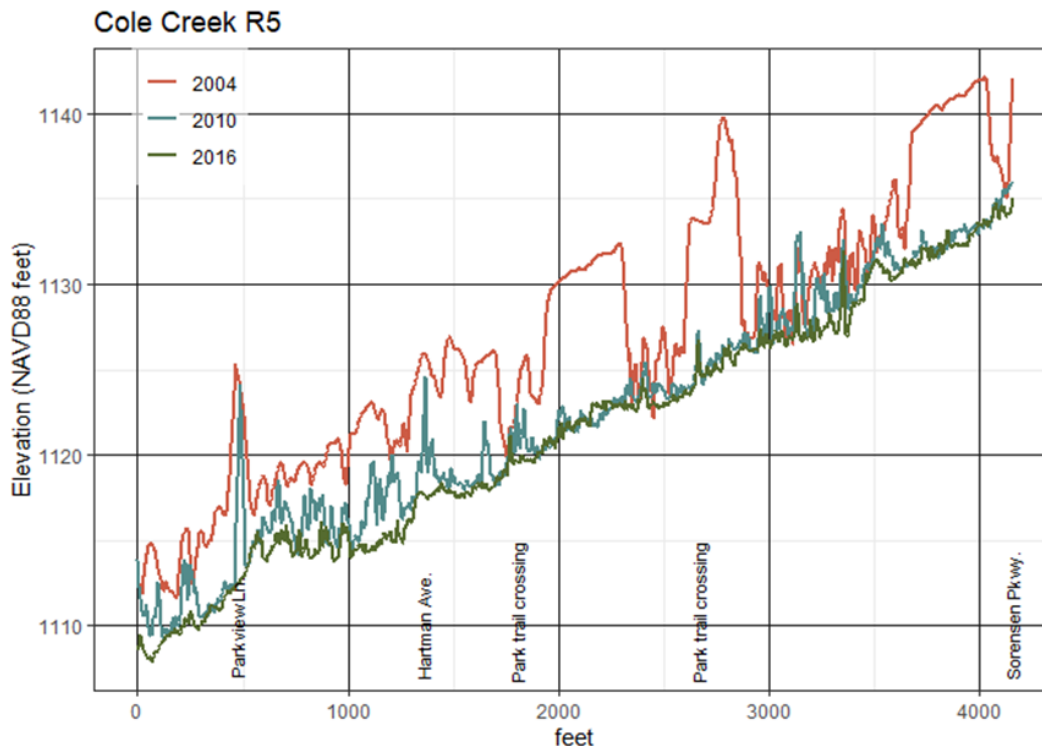


Figure 4-32: FG Level 1, Reach 5 – LiDAR Water Surface Profiles

The water surface profiles indicate a trend of channel degradation; however, as mentioned earlier, there has been an extensive amount of channelization during the LiDAR collection periods so the degradation that has been assessed from the water surface profiles is caused by data collected from outside the active channel margins.

Figure 4-33 and 4-34 show cross-sections from the downstream section of the reach that have a relatively close match between the analysis periods. Figure 4-33 appears to show degradation from 2004; however, investigation upstream and downstream do not have a similar trend. This trend is likely from thick vegetation masking the earlier LiDAR data collected. Figures 4-35 and 4-36 illustrate examples of channelization that occurred through the middle and upstream sections of this reach.

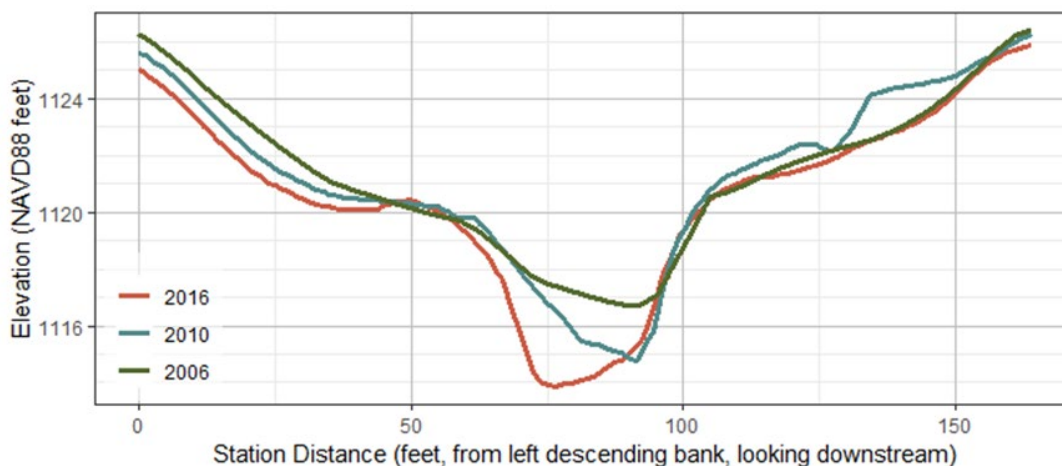


Figure 4-33: Reach 5 – Cross-section 12 Depicting a Relatively Stable Bank

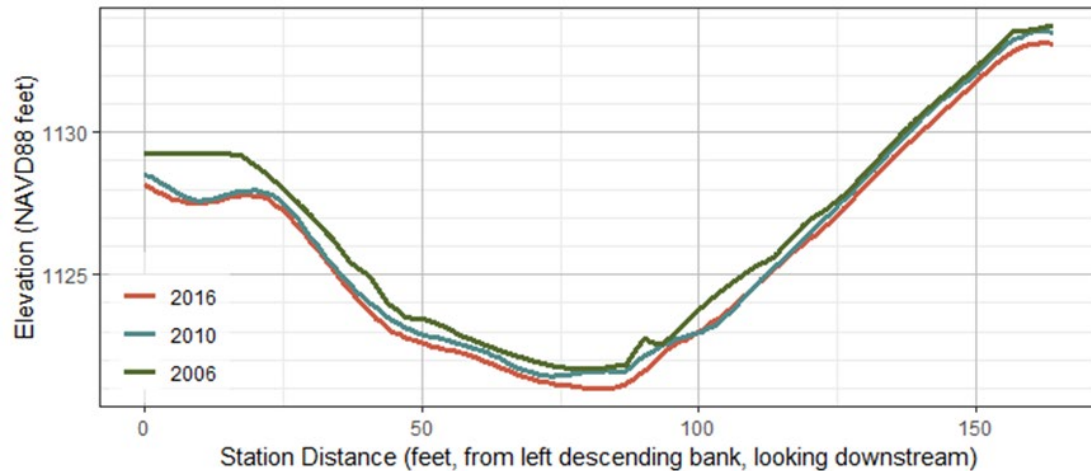


Figure 4-34: Reach 5 – Cross-section 33 Depicting a Relatively Stable Bank

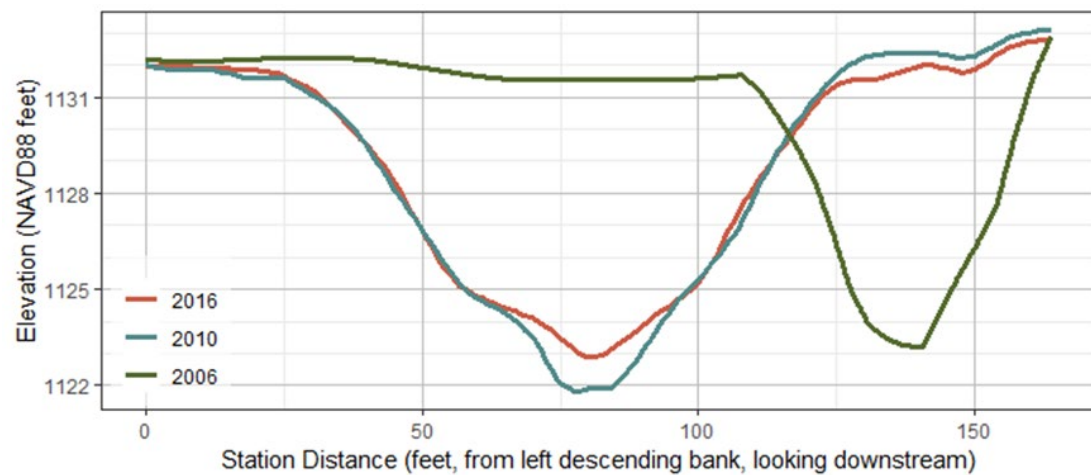


Figure 4-35: Reach 5 – Cross-section 41 Illustrating Channel Realignment

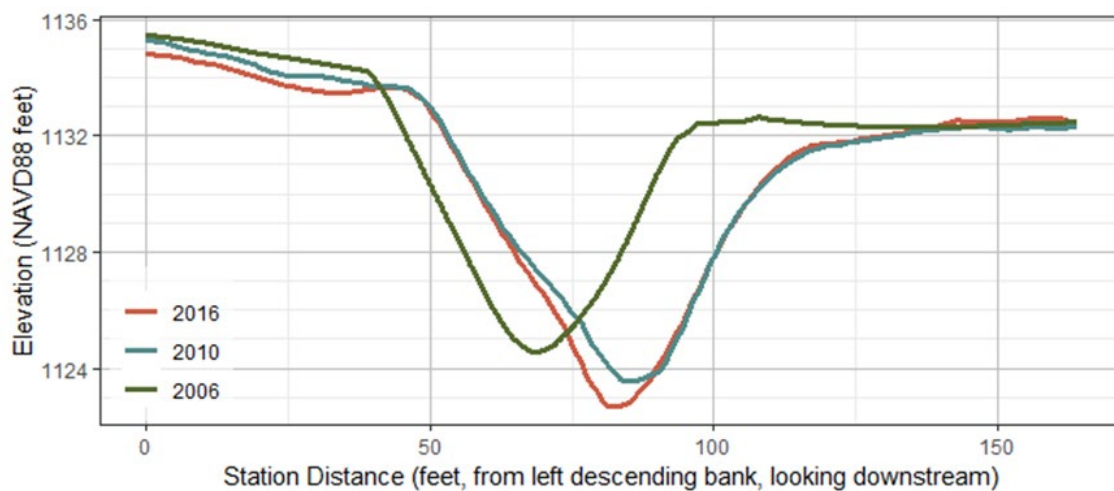


Figure 4-36: Reach 5 – Cross-section 44 Illustrating Channel Realignment

Reach 5 Summary:

- The reach went through a series of channelization and stabilization efforts from 2009 to 2010. The slope has stayed relatively constant pre-channelization to post-channelization at 0.0059 ft/ft (Figure 4-37).
- The reach would be considered as a CEM Stage VI. The channel realignment and stabilization (both bed and bank) appear to be in a stable condition.
- The bed and bank stabilization appear to have stabilized the reach (based on aerial photo investigation). It would be good to field-validate this conclusion with a site visit to the golf course and discuss the changes the site manager has seen over the past 25 years.

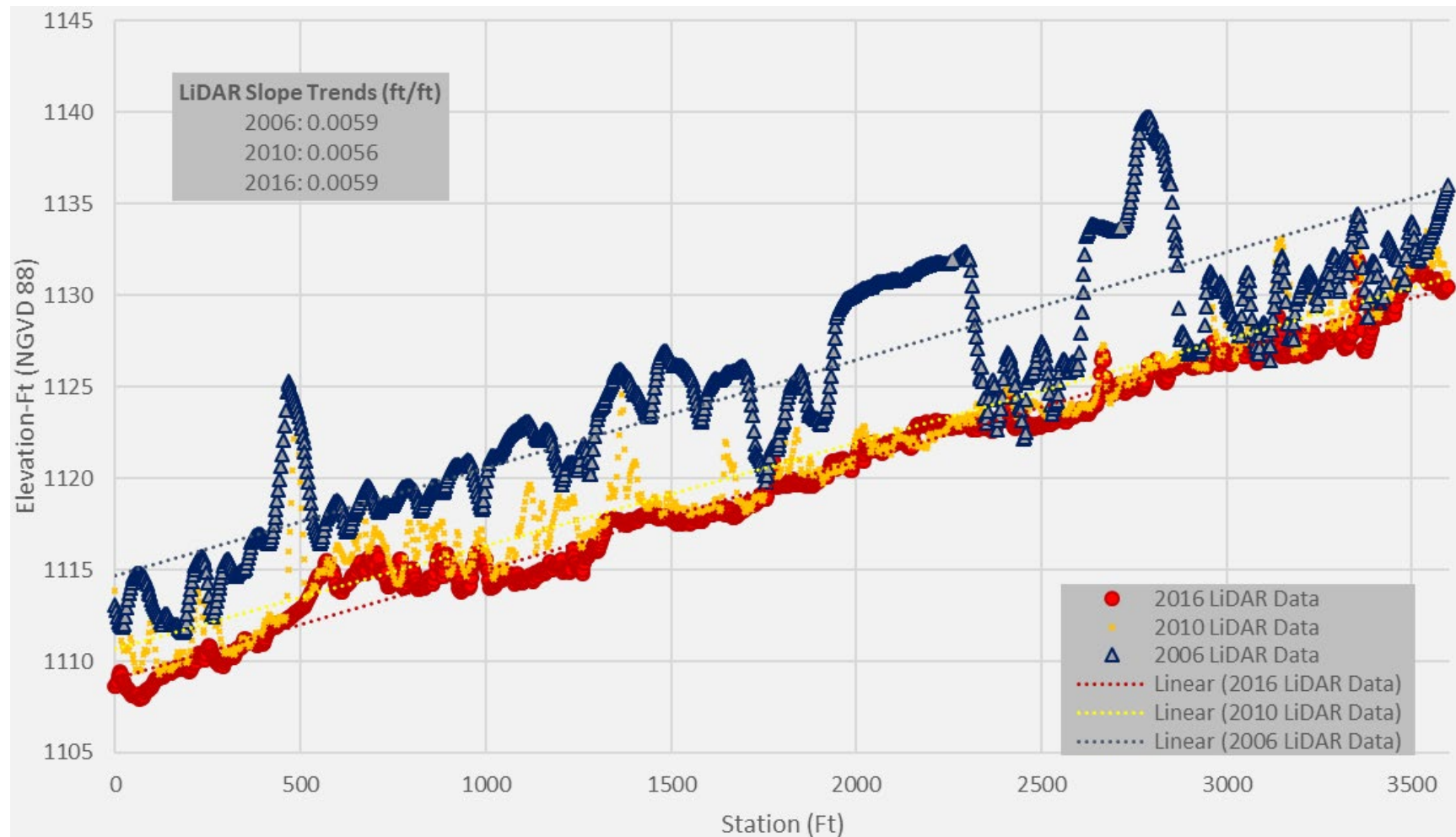


Figure 4-37: Reach 5 – LiDAR Slope Trends

4.2.3 FG LEVEL 2 ANALYSIS FOR REACH 4

Reach 4 was flagged for additional analysis since it showed the most degradational trends within the five reaches studied. The reach is maintained through the Benson Golf Course. The derived metrics for Reach 4 are shown in Figure 4-38.

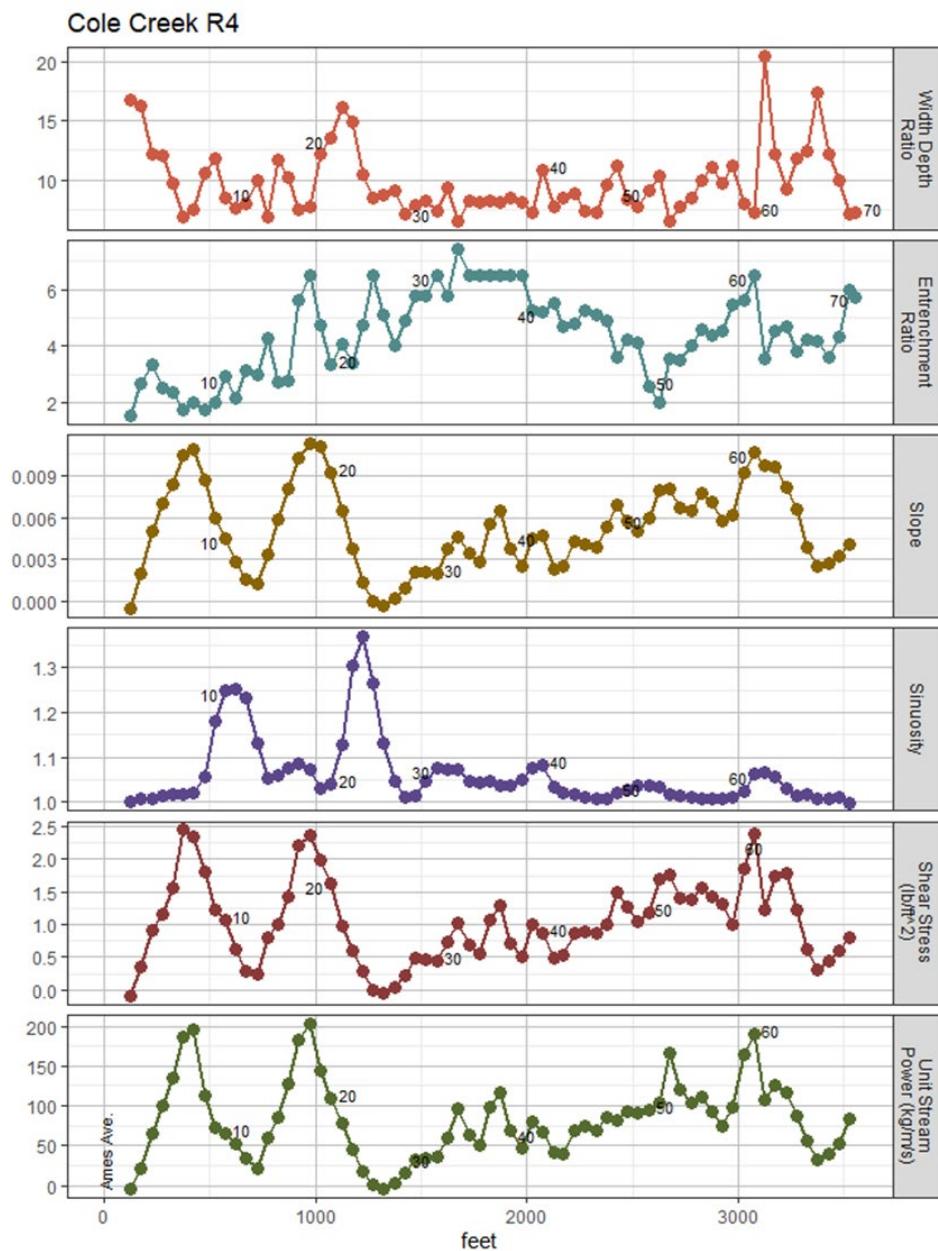


Figure 4-38: Reach 4 – FG Level 2 Metrics

Width to Depth Ratio (W/D):

The W/D ratios are mapped and shown in Figure 4-39 and 4-40. The ratios above 20 represent channel areas that are over-widened and would display (unless there is revetment) sediment bar deposition and erosion of the streambanks.

- The W/D and ER show locations where the channel is incised and has limited access to an active floodplain (Figure 4-40). Half of the W/D ratios are below 12 and demonstrate confined channel conditions.
- Upstream of the two GCSs, there are lower water surface slopes and a slightly trending increase in ER. The ERs are above the moderately-entrenched-stream classification-break of 2.2 (Rosgen, 1996), with the lower section of the reach having ERs less than 1.7. The GCSs and other revetments in the upstream section of the reach appear to have stabilized the channel with high ERs (access to a floodplain at lower flow) and lower W/Ds.
- The larger shear stress and USP occur in sections of the reach that have steeper slopes, below the GCSs or some other channel bed controls.
- The areas that likely have erosion control issues are the low sinuosity, low ERs, low W/Ds, and higher shear stress values. These are cross-section locations 2-10 and 46-53.



Figure 4-39: Reach 4 – FG Level 2 Spatial Extent of W/D Ratios

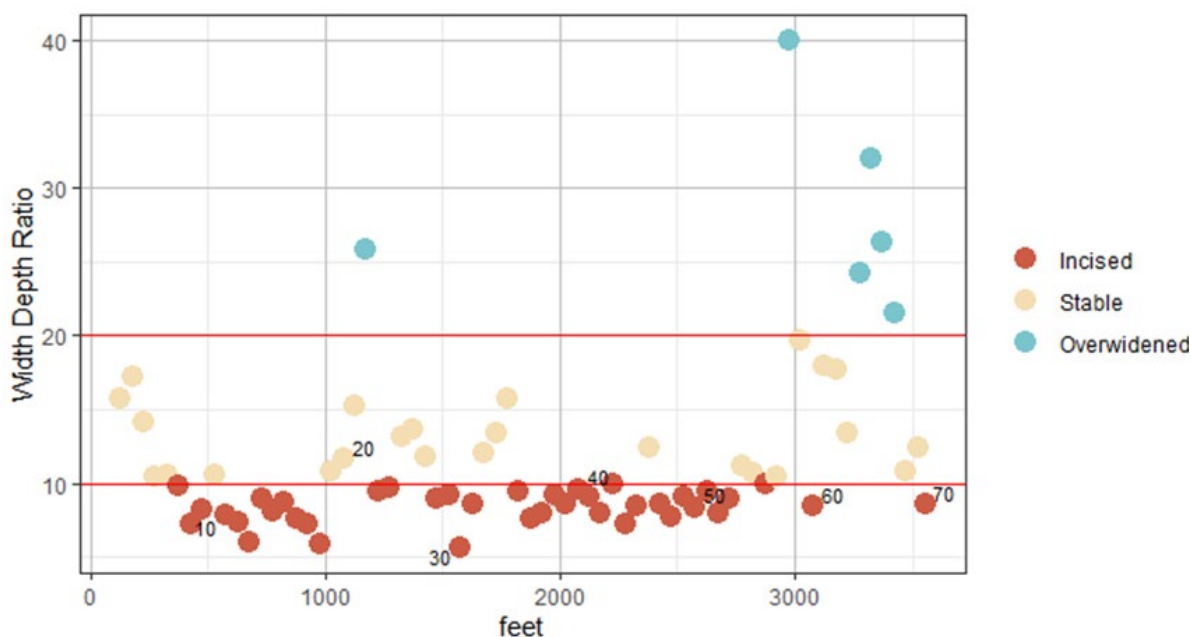


Figure 4-40: Reach 4 W/D Ratios

The W/D's below 10 are classified as incised channels and are areas to look for implementing possible bed stabilization measures. These areas may have cohesive bank materials, bedrock, or stabilization revetments present that provide stable banks even though the channel is incised. Incised channels aren't a bad thing in an urban area where channel capacity is needed so that residential and commercial areas do not flood.

4.2.4 COLE CREEK CONCLUSIONS AND RECOMMENDATIONS

The Cole Creek has recently progressed through a series of channel degradational phases likely caused from culvert changes in Reach 1 and Reach 2. There have been some minor land use changes in the past 25 years and the channel degradation that has occurred in the upstream Reach 4 and 5 is likely from adjusting to subtle changes in runoff and sediment supply. For example, the Reach 5 channel was realigned and stabilized in 2009 and 2010. The channel is now stable and has reduced sediment supply to the downstream reaches. In response to this, Reach 4 has experienced a channel-bed degradation trend as the sediment supply has been reduced by the restoration projects from Reach 5. This is explained in Lane's Balance Example (1955).

Based on the FG Level 1 analysis of water surface slopes and reach cross-sections, the reaches are progressing through various stages of the CEM (Simon and Hupp, 1986), most identified as Stage IV and V. The reaches that are most susceptible to continued local channel erosion are the areas in reaches 1, 2, and 4. These areas should be investigated further to determine what bank materials are present. The generalized CEM trends were identified using the FG Level 1 CSA and are identified by reach. This assessment is based on 2016 data and should be field-validated. Reaches 1 through 4 are experiencing localized bank erosion. Local erosion control projects can be implemented in these cases once a field investigation is completed to verify there is no channel degradation.

Channel Evolution Model (I-VI)**Reach 1: IV/V****Reach 2: IV/V****Reach 3: V****Reach 4: IV/V****Reach 5: VI**

- Reach 1 was visited in 2019. The Level I analysis predicts low W/D and ERs for the section of the reach in Figure 4-40. The Hillsdale Drive culvert is scheduled to be replaced just upstream of the photo. As is typical in urban watersheds, there are large amounts of concrete rubble within the incised channel. In some cases, the rubble is directing flows into the incised channel banks, further destabilizing the streambanks. It would be possible to shape some of the existing concrete rubble and protect the highly erodible streambanks. This could also promote floodplain berm building within the channel margins, if that would be an appropriate option based on hydraulic modeling. A series of GCSs in the reaches would provide added stability and would supplement local bank protection alternatives. Figure 4-41 shows the current conditions in the reach.



Figure 4-41: Cole Creek Downstream of Hillside Drive

- Based on the FG Level I slope analysis, the 2016 water surface slopes are listed in Table 4-2. As expected, the water surface slopes increase in an upstream direction with the steepest slope of 0.0061 ft/ft. The slope ranges in Reach 3 (0.0042 ft/ft) and Reach 4 (0.0047 ft/ft) should be investigated further to determine if it is representative of a stable equilibrium channel slope.

Table 4-2: Cole Creek LiDAR Water Surface Slopes by Reach

Reach	Reach Slope
1	0.0039
2	0.0041
3	0.0042
4	0.0047
5	0.0061

- Based on the Level I FG analysis, the only significant GCSs in the downstream reaches are bridges and road culverts. Reaches 4 and 5 have riprap GCSs and culverts. The GCSs are providing stability to the stream system and should be monitored closely. If invert elevations change, then channel degradation may transfer to upstream reaches; there may be some modifications to the structures that could further stabilize the reaches.
- The best example of a stable channel is Reach 3. It has four bridges/culverts acting as GCSs, stabilizing the channel. The channel slope has stayed at a consistent range of 0.0038 to 0.0041 ft/ft. The structures should be further investigated in the field to determine if there is any operation and maintenance required for the structures to continue to function properly. The GCSs could also enhance the ability to treat local bank erosion problems listed below.
 - Additional analysis of the spacing of the existing GCSs and assessment of stable channel slopes (Table 4-2) could assist in further siting of additional GCSs. In all reaches, the stream channel sections immediately upstream of GCSs were stable or in the process of stabilizing, building floodplain berms.
 - Spacing of GCSs may also reduce local bank erosion by providing stable channel slopes to the local area and reach.
 - Any modifications to existing structures should be carefully considered prior to final construction. Changing the inverts of the structures even if they were not meant to be GCSs will change the base level of the stream. Once this occurs, channel degradation will likely move upstream.
 - Any modification or additions to the GCSs would require hydraulic modeling to determine impacts to water surface profiles.
 - Geotechnical bank conditions will need to be investigated if GCSs are constructed so banks are not destabilized.
- Based on the FG Level II W/D assessment for Reach 4, much of the reach is considered incised (W/D <10), with some areas at the upstream section over-widened. Based on the W/D metrics, construction of additional GCSs could supplement the two existing downstream structures and raise the water surface profile and promote deposition and development of floodplain berms within the incised channel margins. The development of floodplains will reduce shear stress pressure on the existing entrenched streambanks.

- Based on the FG Level II ER assessment for Reach 4, the areas to investigate further stabilization are cross-section locations with low sinuosity, low ER's, low W/D's, and higher shear stress values. These are cross-section locations 2-10 and 46-53.
- Based on aerial photo interpretation, there are areas within the downstream section Reach 4 that have tight meander bends. These areas likely have Radius of Curvature to Bankfull Width (R_c/BW) ratios less than 2.0. Low R_c/BW ratios are outside the range of stable meandering channels and should be further investigated in the field to determine the severity of the erosion and appropriate treatment methods.
- There are very few tributaries that are not in pipe on Cole Creek; however, any areas that are not, should be identified, investigated, and treated as part of a system approach to stabilizing the watershed.

4.3 WEST PAPILLION CREEK FG ANALYSIS

4.3.1 INTRODUCTION

West Papillion Creek is a watershed (approximately 133 square-miles) within the overall Papillion Creek watershed located west of Omaha, NE that generally flows from the northwest to the southeast (Figure 4-42). It merges with Big Papillion Creek (approximately 232 square-miles) approximately 900 feet downstream of South 36th Street Bridge to form Papillion Creek. The reaches in this study are largely developed residential and industrial areas with some small pockets of agricultural land. The upstream end of the study is the South 132nd Street Bridge. The watershed upstream of Reach 5 is an additional 59 square-miles.

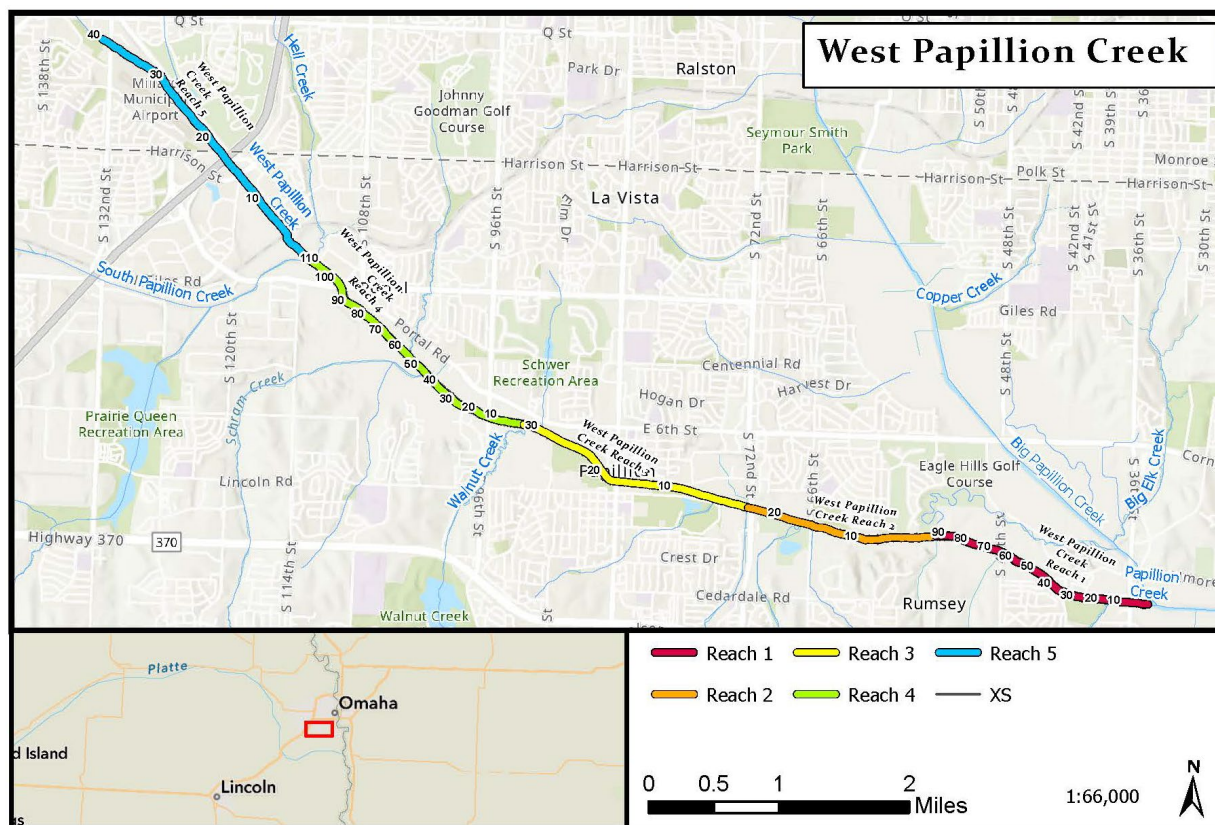


Figure 4-42: West Papillion Creek FG Level I Geomorphic Reaches (1-5)

4.3.2 FG STUDY REACHES AND GENERAL ASSESSMENT

There are many sections of the creek that have some form of revetment, whether it be riprap or other materials present in the channel bed or banks. From site visits, the presence of these materials are providing bed or bank stability. It is not known whether these structures and revetments were designed, or materials were placed in stream to protect utility crossings. In many locations, material has launched and formed GCSs, stabilizing the channel bed in these locations. In some locations in the lower Reaches (1-3), the levee system design cut benches within the channel margins to provide flood flow relief. In other locations, these benches or berms formed from sloughing or eroding banks restabilizing due to the presence of bed and bank revetments and reduced velocities (Figure 4-43). Compared to an incised channel (high banks with no floodplain), the berms provide access to the frequent flood events dissipating flow energy across a wider cross-sectional area. This is a common feature in the urbanized Papillion Creek watersheds that were included in site visits.

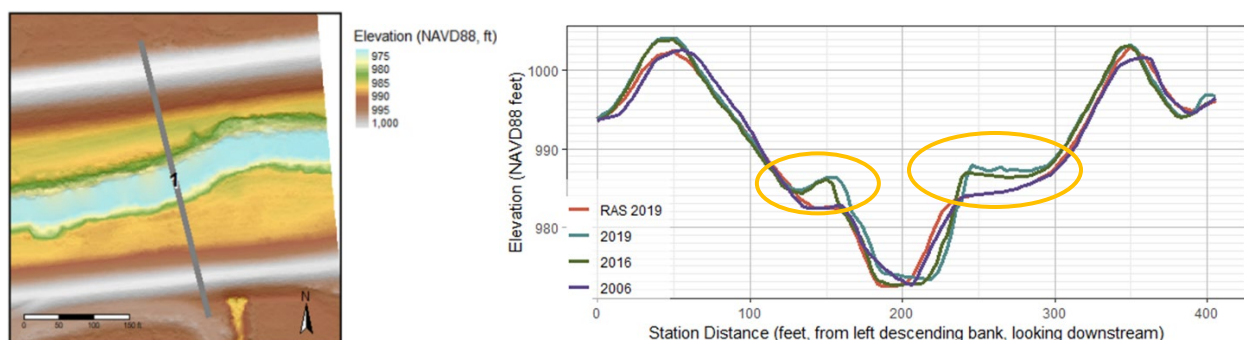


Figure 4-43: Floodplain Berms (orange circles) Developing Upstream of GCSs on West Papillion Creek

The next section provides the overall profile and individual Reach information developed for this study. The FG study reaches are defined in Figure 4-44 with individual FG Reach profile plots (2004/2016 LiDAR and HEC-RAS 2019 Thalweg Profiles) in each section. Some of these locations were field verified but others were not due to time restrictions on fieldwork. Each reach has bulleted descriptions based on geomorphic information collected from the site visits and FG Level I analysis.

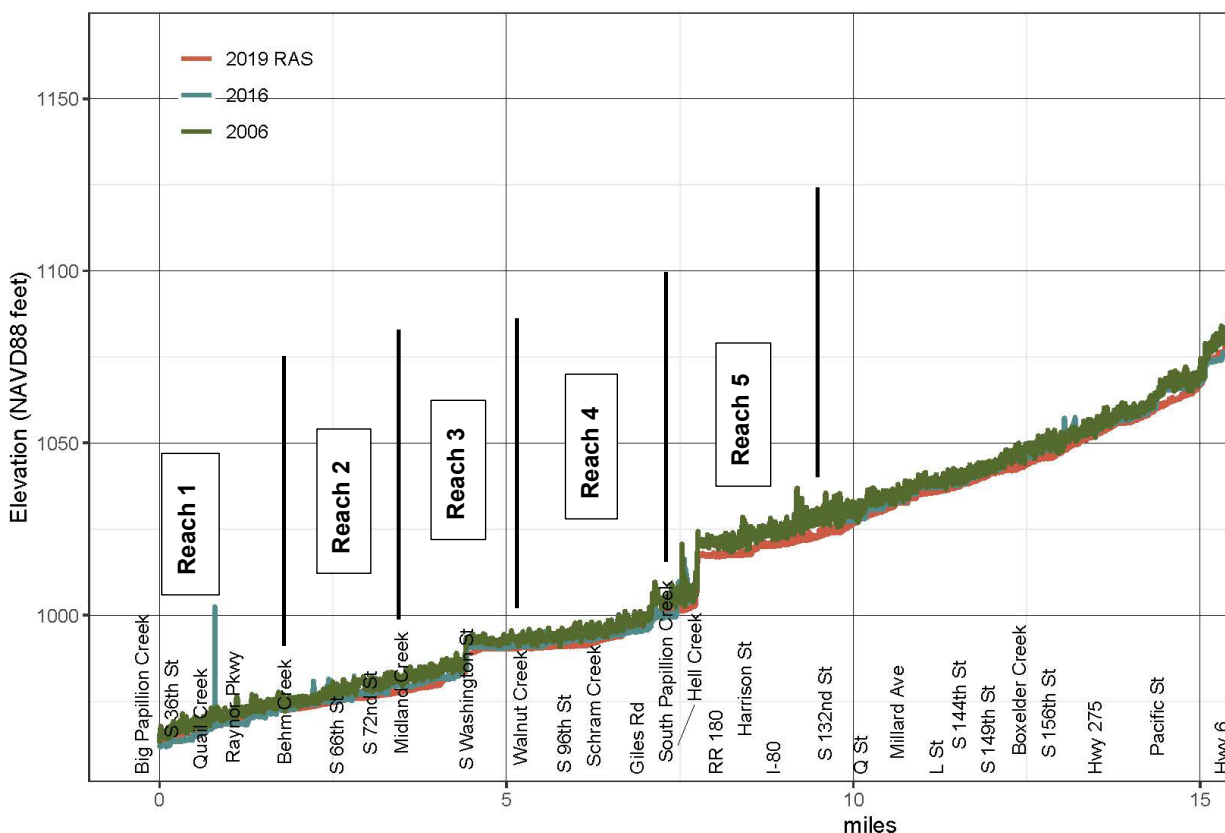


Figure 4-44: West Papillion Creek – FG LiDAR Water Surface Profiles 2019 HEC-RAS Thalweg Profile

Note: GCS locations are labeled in Reach 1-5, Figures 4-45 to 4-49

4.3.2.1 REACH 1: CONFLUENCE OF BIG PAPIILLION CREEK TO BEHM CREEK

Reach 1 starts at the confluence with Big Papillion Creek and is highly modified with levees (confining the river floodplain), greenspace, and trails that separate the agricultural and residential activity from the stream channel. Based on aerial photo investigations, the agricultural areas are developing and will soon be replaced by residential development. The list below describes the assessment for the reach.

- Downstream of Raynor Parkway Bridge, the channel appears to show a trend of degradation. Much of the reach has bank revetments with a meandering pattern starting to form within the incised channel. Early stages of floodplain development are occurring with berms forming where bank slumps have stabilized. Bank failure and continued channel incision will likely continue with increased development in the upstream reaches increasing flows confined within the leveed floodplains.
- Upstream of Raynor Parkway Bridge, the channel is in a Type III phase of the CEM where local bank stabilization measures limit the channel from evolving into a Type IV-V channel. Therefore, the channel will begin to 1) widen in locations where there is no bank protection and 2) potentially undermine current protection.
- There are many locations within Reach 1 that would have access to an active floodplain if levees could be setback to provide more room for flood flows. This is still possible (although maybe not attainable) in areas where agriculture is present.

- This reach is predominantly a sediment pathway with minor sediment sinks with new floodplain berms forming. Still other locations there are areas of bank erosion working through the bank revetments providing minor sediment sources for downstream reaches.
- Establishment of floodplain access areas to dissipate and store floodwater would be a great alternative to establish where applicable to the upstream reaches.

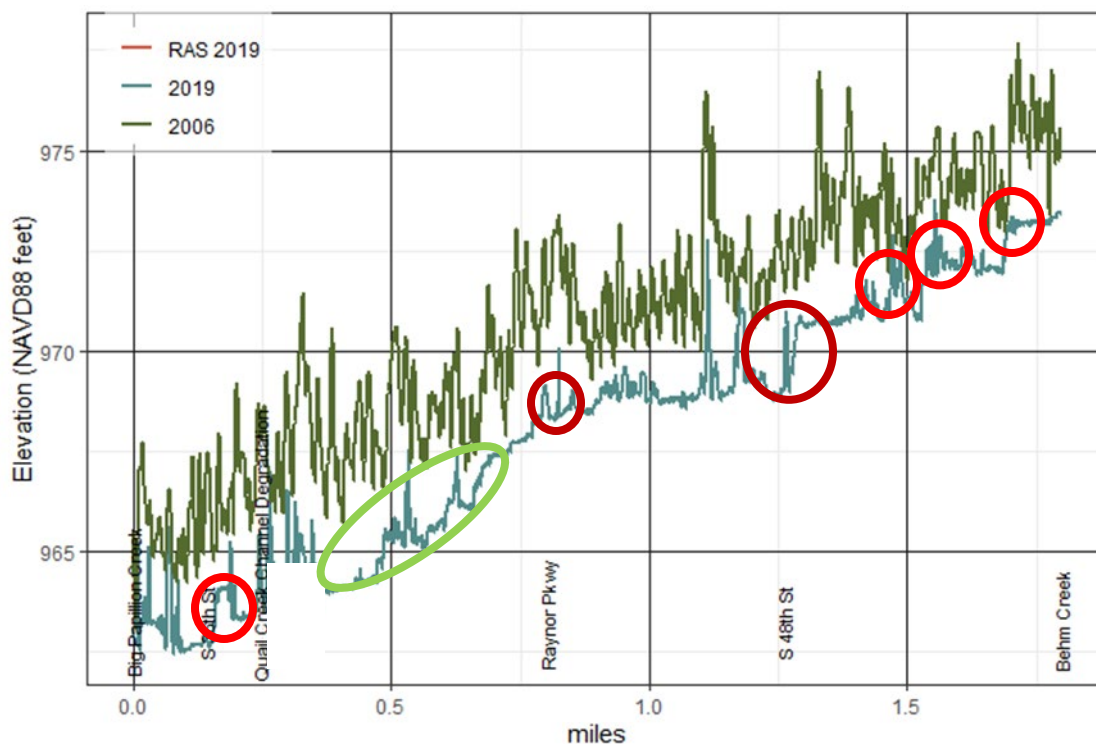


Figure 4-45: West Papillion Creek FG Reach 1

Note: GCSs (red circles) or erosion resistant bed materials present, and GCS with continuous bank revetment in green

4.3.2.2 REACH 2: BEHM CREEK TO MIDLAND CREEK

Reach 2 is a highly modified reach, like Reach 1 but with fewer agricultural areas. It has levees, limited width floodplain/greenspace, and recreational trails that limit the floodplain access. The list below describes the FG and field assessment for the reach.

- Based on the LiDAR trends and comparison to the RAS 2019 thalweg elevations, there appears to be channel degradation in this reach, especially at the South 66th Street Bridge (approximately station 2.75 miles).
- GCSs are spaced out relatively evenly throughout the reach (Figure 4-46). The structures are likely reworked revetment material or were placed to protect utility crossings.
- Reach 2 is likely in an early CEM Stage IV displaying both channel degradation and widening. The degradation is limited due to the extensive rock-line banks and presence of GCSs. The bank revetments act to prevent the channel from meandering and eroding into the levee system.

- Based on the FG cross-sectional analysis, floodplain berms are building within the confined (by levees) floodplain. Like Reach 1, this reach is predominantly a pathway with minor sediment sinks and sources.
- The reach could be enhanced for flood water storage by increasing floodplain connection and access through series of levee setbacks. There are still some areas of agriculture that could be targeted. If sediment delivery to downstream reaches is a priority, then installation of additional bank erosion revetments is recommended.

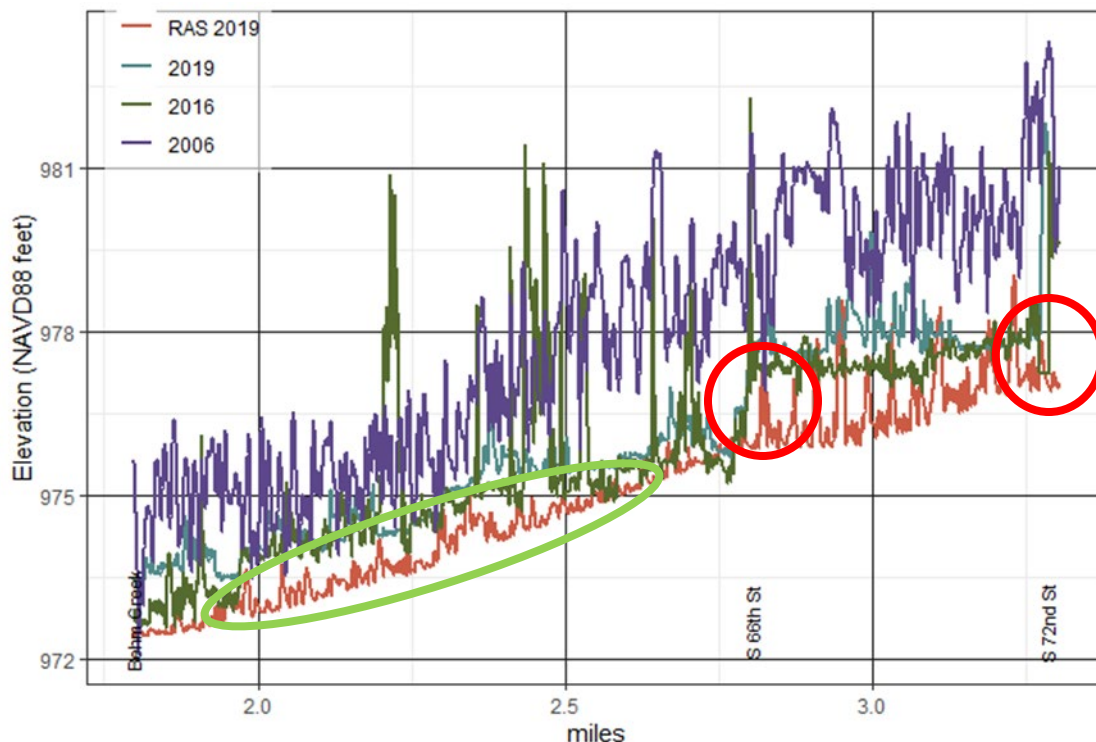


Figure 4-46: West Papillion Creek FG Reach 2

Note: GCSs (red circles) or erosion resistant bed materials present, and GCS with continuous bank revetment in green.

4.3.2.3 REACH 3: MIDLAND CREEK TO WALNUT CREEK

Reach 3 has greenspace with more encroachment and no adjacent agricultural land-use. Overall, the reach is degradational with local widening in areas without bank protection, likely a CEM Stage III-IV channel. The South Washington Street Bridge is serving as a GCS with about a six-foot drop, creating a relatively deep incised channel downstream. The list below describes the assessment for the reach.

- Based on the LiDAR channel surface slope and RAS Thalweg Profile, Reach 3 appears to be over-steepened below South Washington Street Dam. The reach is likely in CEM Stage III-IV downstream of the dam and Stage V-VI upstream.
- Reach 3, like previous reaches, has extensive rock-lined banks to keep the channel from meandering. By hardening streambanks and keeping the channel from meandering, it can only adjust in the vertical direction – causing local incision. Bank stabilization measures are forcing the channel to stay within a CEM Stage III channel.

- Continued channel degradation could cause failure of the concrete dam at S. Washington Street and other bank stabilization projects if the over-steepened reach continues to incise. Based on the field investigation, the dam appears to be in working order with no outward signs of erosion issues at the time of this report.
- Based on the FG cross-section analysis, there is bank erosion in many sections of the reach. Additional bank protection revetments and developing a better understanding of the channel bed stability would be recommended. This reach would be considered a sediment source and areas with little or no erosion a sediment pathway.
- There are minimal locations available within the reach to expand access to floodplain areas behind the existing levees.

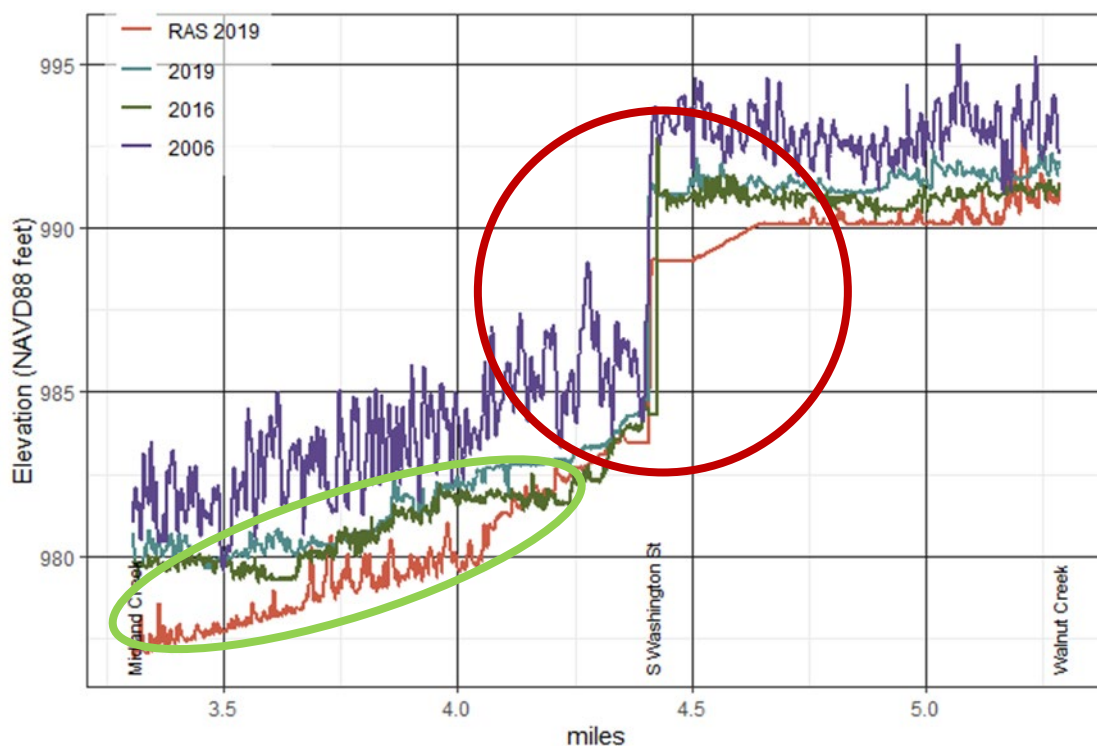


Figure 4-47: West Papillion Creek FG Reach 3

Note: GCSs (red circles) or erosion resistant bed materials present, and GCS with continuous bank revetment in green.

4.3.2.4 REACH 4: WALNUT CREEK TO SOUTH PAPIILLION CREEK

Reach 4 has a highly confined channel and small floodplain between levees, with greenspace and pedestrian trails. The list below describes the FG and field assessments for the reach.

- GCSs are present at bridge locations and other locations within the reach, likely from launching revetment materials (Figure 4-48).
- Based on the LiDAR channel slopes, Reach 4 appears to be in a CEM Stage V. The streambed is stable and there is local bank erosion. New floodplain berms have developed in much of the reach showing a trend of stabilization.

- There is one large GCS in the reach at Giles Road that is providing bed stability to the reach. The water surface elevation drop across the structure is approximately five feet high and should be monitored for maintaining the channel slope.
- If there are any concerns for fish passage within the West Papillion Creek watershed, large GCSs (Reach 2-South Washington Street Dam, Reach 5-RR 180 GCS) like this should be modified to allow reasonable channel slope transitions through these elevation drops. It would also help spread the flow energy across smaller drops across a longer channel profile.
- Reach 4, like Reach 3, has extensive rock-line banks to keep the channel from meandering. Although, by keeping the channel from meandering by hardening the streambanks, the channel can only adjust in the vertical direction – causing channel incision. Bank stabilization measures are forcing the channel to stay within a CEM Stage III channel.
- There are locations behind the existing levees on the right terrace/floodplain available to expand access to potential floodplains.

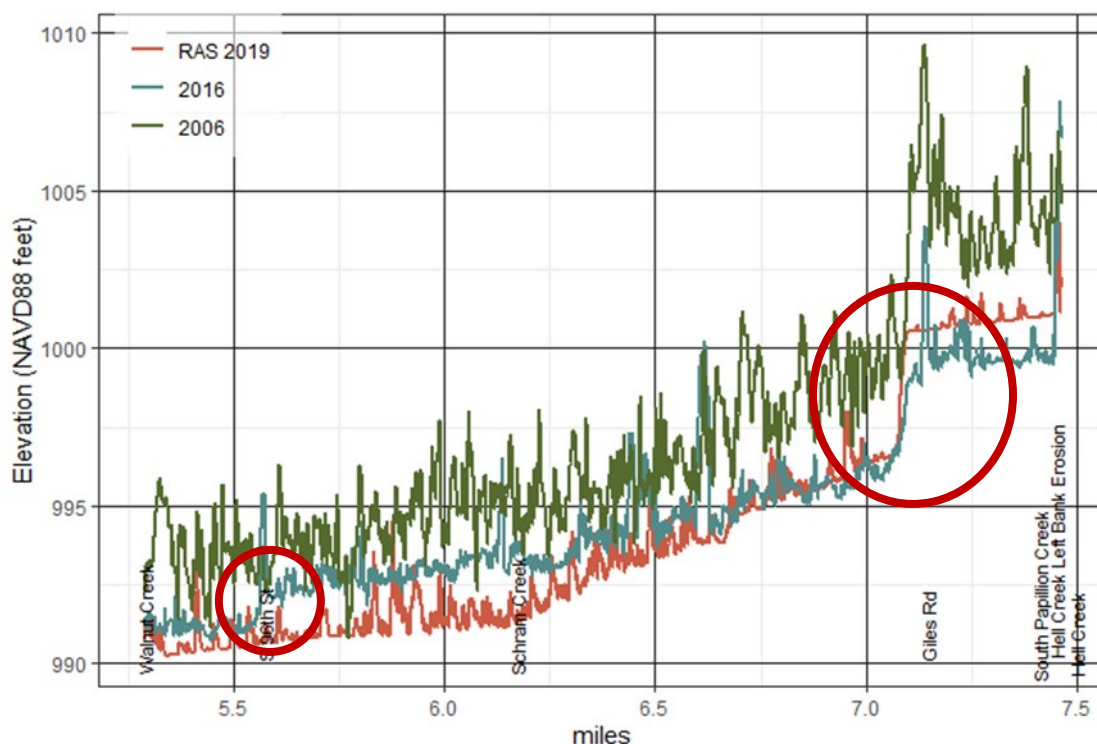


Figure 4-48: West Papillion Creek FG Reach 4

Note: GCSs (red circles) or erosion resistant bed materials present.

4.3.2.5 REACH 5: SOUTH PAPILLION CREEK TO SOUTH 132ND STREET

Reach 5 is similar Reach 4 in floodplain development and urbanization but has more bank erosion throughout as there is less bank revetment protection. The areas downstream of the Railroad 180 GCS and upstream of Interstate-80 (I-80) have the highest erosion rates. The Railroad 180 GCS has stabilized the reach immediately upstream for approximately three-fourths of a mile with its backwater effects and floodplain berm connections. There are minimal

levees in this reach and recreational trail access is only on the right bank. The list below describes the reach conditions and observations based on FG and site visits.

- GCSs are present throughout the reach, with the largest at the Railroad 180 Bridge (Figure 4-49).
- There are additional GCSs or other resistant bed materials located within the reach based on the Figure 4-49 profiles and aerial photo interpretation.
- The reach has a substantial amount of bank sloughing and erosion. Some of the erosion is threatening pipe outlets and pedestrian trails.
- Based on the FG analysis, this reach would be partially considered a sediment source and pathway.
- Downstream of Railroad 180 GCS, the channel is likely a CEM Stage IV; upstream the channel is a CEM Stage VI until approximately the I-80 Bridge. Upstream of the I-80 Bridge, the channel slope increases, and streambank erosion is prevalent.
- This reach is a mix of sediment source (upstream and downstream sections) and pathway at Railroad 180 GCS and upstream for three fourths of a mile.
- There are some locations on the right channel margins to expand access to floodplain. The locations are on the right terrace/floodplain upstream of the confluence with South Papillion Creek (lower reach) and upstream downstream of the South 132nd Street Bridge.

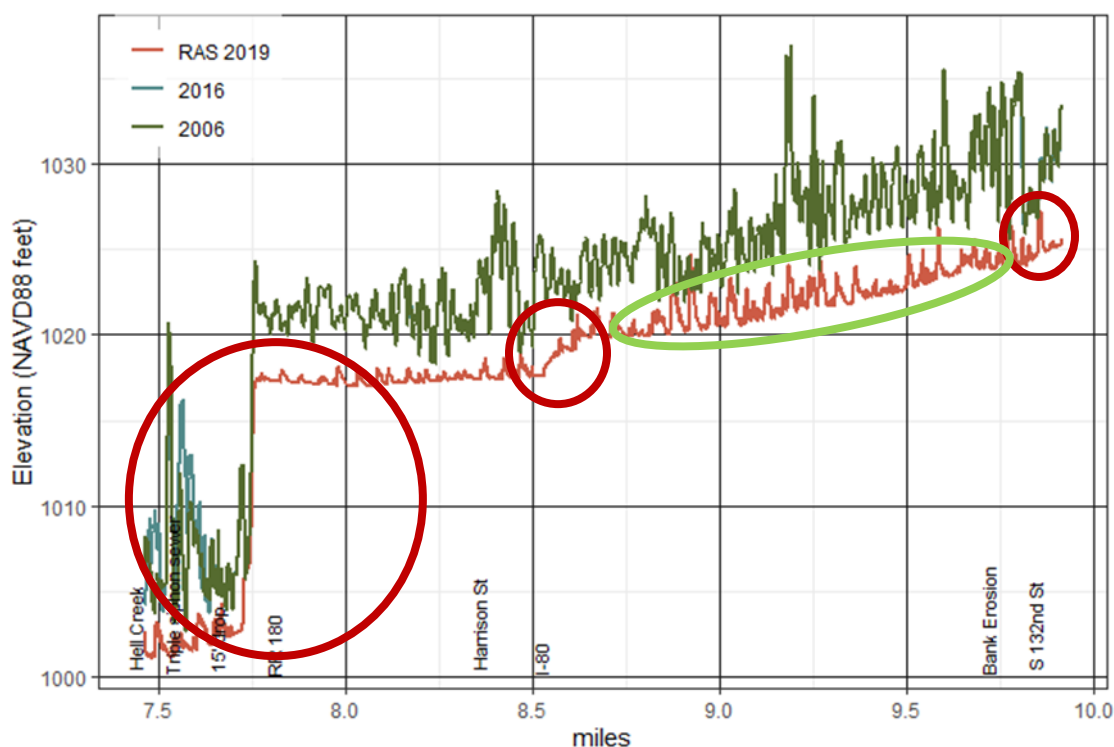


Figure 4-49: West Papillion Creek FG Reach 5

Note: GCSs (red circles) or erosion resistant bed materials present, and GCS with continuous bank revetment in green.

4.3.3 WEST PAPILLION CREEK – STUDY RECOMMENDATION

This report is based on an FG Level I CSA. It is recommended to complete more geomorphic analysis including FG level II and III assessments along with additional field assessments. The study recommendations are listed below. This section is meant to provide the overarching recommendations for priorities based on the FG Level I analysis and assessment. The Priorities are not in order of relevance.

- **Priority #1:** Use existing GCS locations to continue to stabilize the channel. The structures, whether designed or not, are the basis for existing channel stability in the system.
- **Priority #2:** Assess existing structures and other areas within the reaches that are providing channel and bank stability. This is especially important for the structures in Reach 2 (South Washington Street Dam) and Reach 5 (Railroad 180 GCS). If these structures are compromised, rapid channel degradation (widening and deepening) will occur.
- **Priority #3:** A comprehensive mapping system should be developed (if not already completed) to determine utility locations and crossing associated with the West Papillion Creek corridor. This can then be compared to constructed bank revetments, GCS locations (and those acting as GCSs), bridges, resistive bed materials and other natural channel characteristics that are providing stability to the reaches.
- **Priority #4:** Where possible, increased floodplain connections should be re-established. There is limited space for these actions within Reaches 1-5, so targeting those areas to prevent land development should be considered further. Restoration options could include additional GCS construction to re-establish floodplain berms, levee setbacks or cutting floodplain berms into the existing bank lines or a combination of all these options. If any work is done, hydraulic analysis will need to be completed to assess potential impacts to flood flow and increasing flood stages.
- **Priority #5:** Target upland areas for water and sediment retention structures where applicable in reaches upstream of Reach 5.
- **Priority #6:** Complete additional geomorphic analysis on additional Papillion Creek watersheds to determine critical areas for restoration and stabilization focus.

4.4 SOUTH PAPILLION CREEK FG ANALYSIS

4.4.1 INTRODUCTION

This section investigates the South Papillion Creek mainstem that is a moderate-sized mixed rural and urban watershed in the southwestern part of the Omaha metropolitan area (Figure 4-50). The Creek is approximately 39 square-miles. Typical characteristics of urbanized watersheds are described in Section 4.2.1.

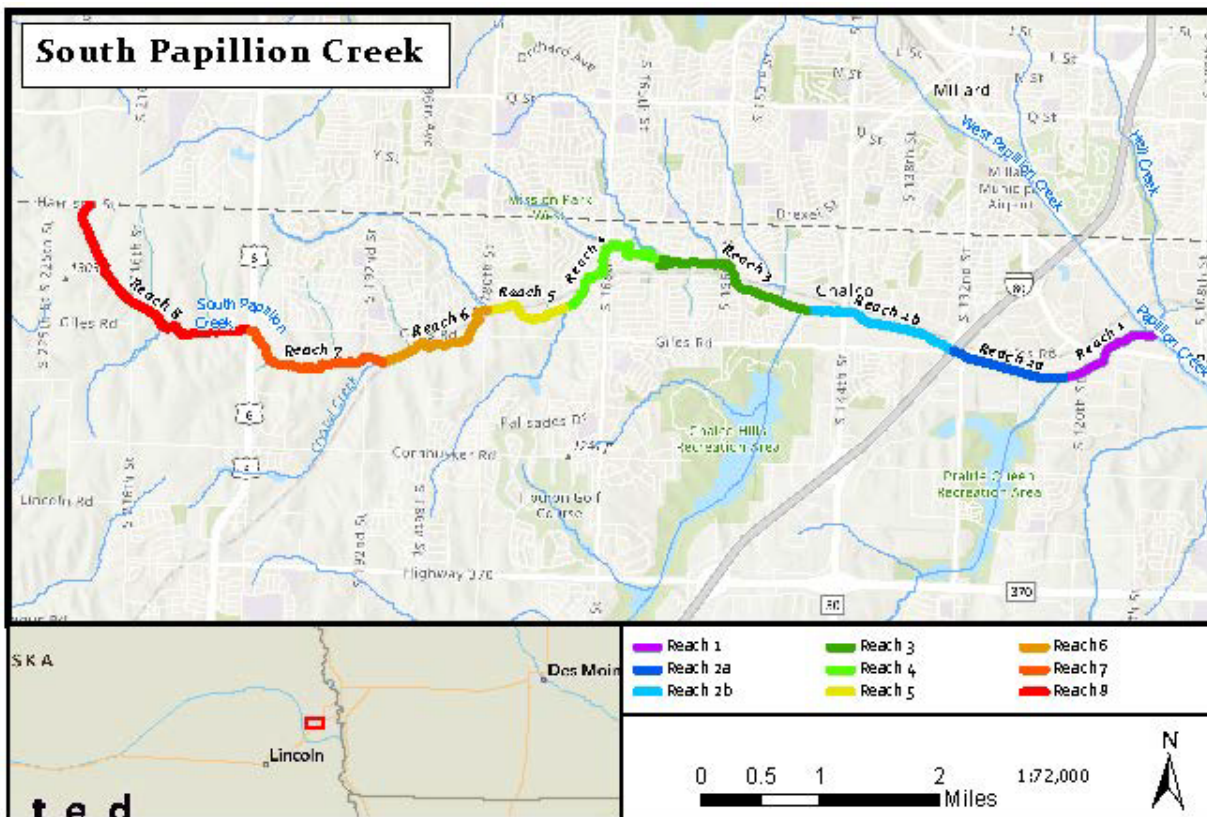


Figure 4-50: South Papillion Creek Watershed, Omaha, NE

The South Papillion Creek watershed has been experiencing disturbances to the fluvial system for many years and can be observed by comparing the LIDAR water surface profiles and cross-sections. Overall, the South Papillion Creek has many locations where revetments have been applied and have helped to re-establish some channel stability. The main revetments are GCS and bank lining with concrete and riprap. For example, during the site visit in April 2019, there is a loose rock riffle GCS in Reach 1 at the Giles Road Bridge (Figure 4-51).



Figure 4-51: Papillion Creek GCS Upstream of the Giles Road Bridge (Reach 1)

The GCS and others in upstream reaches have helped stabilize the stream system by providing bed control to a trending degradational channel system.

There have been wide-scale changes in land-use in the South Papillion Creek watershed and they are continuing today. The changes include stream channelization, agricultural and urban development, and public infrastructure encroachments in the form of bridges, roadways, and utilities. The changes impact soil infiltration and runoff rates changing the characteristic delivery of sediment and hydrologic discharge regimes throughout the watershed. The changes lead to a process of channel bed incision followed by widening and floodplain redevelopment. The presence of multiple terrace and floodplain levels illustrates the geomorphic channel evolution (Figure 4-52) providing evidence of the process.



Figure 4-52: Papillion Creek Channel Facing Upstream with South Papillion Creek Mouth to Left and Hell Creek Grade Control Structure (GCS) on the Right

The local geologic units were investigated to determine what type of materials are deposited within the South Papillion Creek watershed. The description below is taken from the USGS-Surficial Geologic Map of the Greater Omaha Area, Nebraska and Iowa (Shroba et al., 2001). The unit described below is the primary mapped unit for the South Papillion Creek floodplain valley:

- Sheetwash alluvium and stream alluvium, undivided (Holocene): A complex map unit that consists of units Qal and Qsw. Alluvial deposits in low terraces and beneath flood plains commonly consist of clayey silt and thin (0.5-5 cm) lenses of fine sand that locally overlie basal silty fine to coarse sand or sand and pebble gravel. The upper part commonly is dark gray to black. Unit Qss locally forms low, gently sloping fans and aprons on the flood plains of Missouri River and its major tributaries. Unit Qss is equivalent in part to Miller's (1964) terrace alluvium (Qt), slope-wash deposits (Qsw), and alluvial-fan deposits (Qaf) in and near Omaha, and in part to the DeForest Formation of Bettis (1990) in western Iowa. The thickness of unit Qss generally is one to 25 meters.

South Papillion Creek, as well as other watersheds within the greater Omaha area have issues with channel erosion that threaten public and private properties. The objective of this study is to use FG to provide a geomorphic analysis to assess and identify locations of channel instability. The FG approach identifies areas of potential channel degradation and erosion from LiDAR profiles and cross-section analysis. Once the areas are identified and mapped, then further field validation is required to define the stabilization and restoration needs within the watershed. Stabilization and restoration resources can then be targeted to treat the most severe areas. The FG toolkit has been and is being used to assess geomorphic channel conditions for studies in New Mexico, California, Oregon, Nebraska, Kansas, Missouri, Iowa, Illinois, Minnesota, Arkansas, Texas, and Mississippi.

The FG toolbox provides an approach for assessing rapid geomorphic analysis of fluvial systems. The toolbox allows practitioners to use high-resolution, remotely sensed LiDAR terrain data to extract stream channel dimensions, patterns, and profiles for large spatial extents. In addition, if multiply years of LiDAR data are available, temporal assessments can be completed comparing fluvial channel changes from differing time domains. The combination of high-resolution data and the ability to assess vast amounts of spatial and temporal data is important to provide further advancements in geomorphic watershed studies. Additional FG toolbox information is provided in the FG User's Manual (Haring and Dougherty, 2022a) and FG Technical Manual (Haring and Dougherty, 2022b).

To assess the watershed, reaches were developed based on typical hydraulic and hydrologic studies. The beginning and end of reaches are either a bridge/culvert crossing or the confluence of a large tributary with South Papillion Creek.

The South Papillion Creek study area is composed of 10 Reaches (Figure 4-53):

- Reach 1 – Confluence of Papillion and South Papillion Creeks to Westmount Creek
- Reach 2a – Westmount Creek to I-80 West
- Reach 2b – I-80 West to Wehrspann Creek
- Reach 3– Wehrspann Creek to Mission Creek
- Reach 4 – Mission Creek to Tiburon Creek
- Reach 5 – Tiburon Creek to Beadle Creek
- Reach 6 – Beadle Creek to Crystal Creek
- Reach 7 – Crystal Creek to Highway 6
- Reach 8 – Highway 6 to Harrison Street

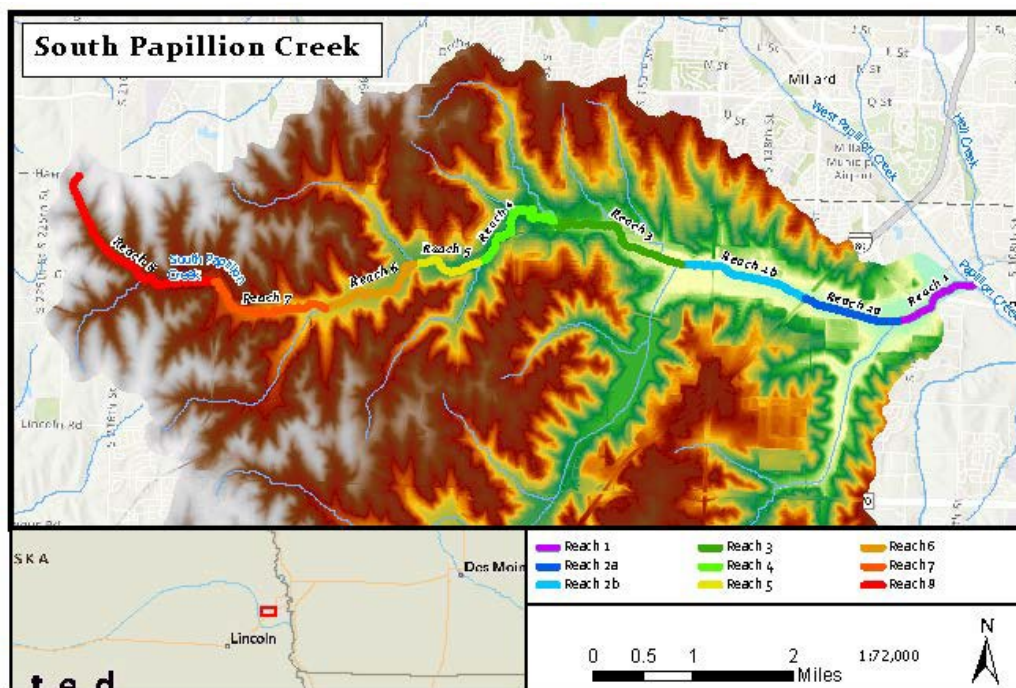


Figure 4-53: South Papillion Creek Study Reaches (1-8)

FG Level I and II analyses were completed for all reaches. To complete the assessment, existing LiDAR from 2004 and 2016 were used to compare spatial and temporal differences in from an x, y, and z perspective. Used in this way, profiles and cross-sections can be compared and used as a diagnostic indicator of channel stability, identifying degradation and aggradation trends. The LiDAR profiles show energy slope relationships and provide insight to where channel slope trends are located and locations of existing GCSs. Cross-sections were used to assess the channel erosion between 2004 and 2016 and some reaches had cross-sections that illustrated floodplain-berm building upstream of GCSs, while other reaches have bed degradational trends with associated channel widening and bank erosion. The FG-toolbox provides a comprehensive approach to investigating geomorphic channel trends and can be used to determine possible stabilization and restoration alternatives.

The two-year recurrence interval was used for geomorphic interpretation and to calculate stream power. The two-year discharges were used from existing HEC-RAS models for South Papillion Creek, each to adjust for tributary inflows:

- Reach 1 = 5600 cfs-(159.1 cms)
- Reach 2 = 5317 cfs-(151.1 cms)
- Reach 3 = 4679 cfs-(132.9 cms)
- Reach 4 = 4458 cfs-(126.6 cms)
- Reach 5 = 3747 cfs-(106.5 cms)
- Reach 6 = 2542 cfs-(72.2 cms)
- Reach 7 = 1485 cfs-(42.2 cms)
- Reach 8 = 887 cfs-(25.2 cms)

The cross-sections for all nine reaches were generally spaced at 150 feet apart, but locally adjusted where data dropouts occurred. The individual lateral cross-section stationing across the channel cross-sections were spaced at one-foot increments. The longitudinal water surface profiles were plotted using approximately three-foot spacing. The Level 1-CSA uses a combination of cross-sections and the longitudinal profile to assess channel stability reach trends.

LiDAR Data and Resolution:

The study used two different LiDAR datasets to complete the FG analysis. The data were from 2004 and 2016. Details for each set of LiDAR is described in the following paragraphs.

The 2004 LiDAR data was collected by Horizons, Inc., on January 4 and 6 2004, for the Metropolitan Area Planning Agency (MAPA). The elevation point data was converted into a geodatabase feature and then into a shapefile for input into the LASTools (LASer), shp2las tool. Once converted into a LAS file the Ground classification tool in ArcPro was run to classify the bare earth points. The bare earth points were used to create a 1-meter resolution raster. The lack of classified water points and the density of 1 point per every 2 meters created challenges with the 2004 LiDAR data.

The 2016 LiDAR data was collected by Woolpert, Inc. for the NE Eastern Nebraska UA LiDAR 2016 B16 from December 8, 2017, to February 3, 2017. The bare earth points were used to create a 1-foot resolution raster. The LAS tiles were classified with ground and water points with a density of 0.7 points per meter.

Analysis Assumptions and Limitations:

FG is not a model, so stating and understanding the limitations of this and other geomorphic and hydraulic data is of utmost importance. Assumptions include:

- The 2004 and 2016 elevation data are compared when the flowline points are calibrated. The higher density 2016 data is used as the baseline when the flowline points tool is run for the 2004 data. Due to the lower density and lack of water points for the 2004 data, cross-sections are drawn to optimize the available data. The 2004 cross-sections are then copied and expanded to match the 2016 flowline, allowing for a comparison of the same portion of the stream from both data sets.
- The LiDAR data used in the analysis does not penetrate the water surface so true channel depth is not measured. The geomorphic metrics are based on the depth captured between the water surface and the bankfull indicators.
- Based on assessing the LiDAR, the three collects were taken during a similar water surface level event as many of the cross-section flow line points are nearly identical. It also appears that there are portions of the LiDAR data sets that may have very minor depth loss due to low water conditions during the collects.
- For Level 2 analysis in distinguishing bankfull channel conditions, riffle cross-over locations were identified to measure bankfull indicators that are essential in identifying channel forming discharge as it shapes an active floodplain and provides a bankfull geomorphic signal.
- The resulting geomorphic metrics reported in this document are based on the FG process of detrending DEM elevations. For this study, geomorphic channel signals were

identified within study reaches to identify and establish relative bankfull channel measurements. Detrending is then used to normalize the floodplain and channel slope to project the bankfull elevation through the reach. This provides a method for projecting the bankfull channel measurement to each cross-section chosen for analysis. The cross-sections are then used to calculate the bankfull channel metrics throughout the reach.

- The interpretation of the LiDAR data needs to be completed in an objective and consistent manner. Depending on the year of collection there are differing levels of accuracy that can be expected and should be considered when assessing and making recommendations while interpreting the data.
- Mean depth was used instead of hydraulic radius to calculate shear stress.
- The LiDAR water surface slope trends are only representing the range of points that the LiDAR collected. Vegetation can affect LiDAR coverage and can have major impacts on the assessment abilities. When assessing the slope trends or cross-sections, aerial photos should be reviewed to determine level of potential vegetation interference.
- Because the LiDAR water surface profiles do not capture water depths below the water surface, the FG W/D ratios will tend to calculate slightly higher W/D ratios. So, the FG W/D ratios are likely elevated where greater channel depths are encountered.
- The FG program is meant to be used to assess stream channel conditions and provide an assessment of where system instability exists. Field visits are required to validate the information.

4.4.2 INTERPRETATION OF GEOMORPHIC DATA

FG Level 1 CSA Analysis:

While the development and creation of LiDAR high-resolution terrain data is a typically common, straightforward procedure, automation and interpretation of resulting terrains, can be more challenging. This is the case with LiDAR, because reliable interpretation requires both insight and appropriate judgement-based decision-making on the part of the investigator. FG provides the automated assessment platform and toolkit (Haring and Dougherty, 2022a-2022b)) to provide step-by-step instructions through the process of transforming LiDAR data into fluvial geomorphic assessments. These assessments can be used by fluvial geomorphologists and water resource professionals to assess stream conditions and identify problems and opportunities. By organizing several complex datasets into standard reports, the FG toolbox concisely presents volumes of data in a concise way to aid analysis.

FG Level 2 CSA Analysis:

CSA analyzes bankfull channel conditions based on LiDAR derived DEMs to compare against empirically based data to assess channel stability. The final products of the CSA are reach level reports that plot and map the metrics at a stream-channel-reach scale. The metrics are compared based on standard existing or user-defined thresholds. The metrics are mapped by color-coded signals. Multiple reaches were analyzed for both FG Level 1 and FG Level 2 analysis on South Papillion Creek. For each section that follows, both Level 1 and 2 analyses are summarized for each reach.

4.4.2.1 REACH 1: CONFLUENCE OF PAPILLION AND SOUTH PAPILLION CREEKS TO WESTMOUNT CREEK

Reach 1-FG Level I Analysis:

The Reach 1 site map is illustrated in Figure 4-54 and the water surface profiles from 2004 and 2016 are plotted in Figure 4-55. Overall, the channel is incised with 25-to-30-foot bank heights (terrace). There is some minor meandering occurring within the incised channel margins with the largest meander upstream of the Giles Road Bridge.

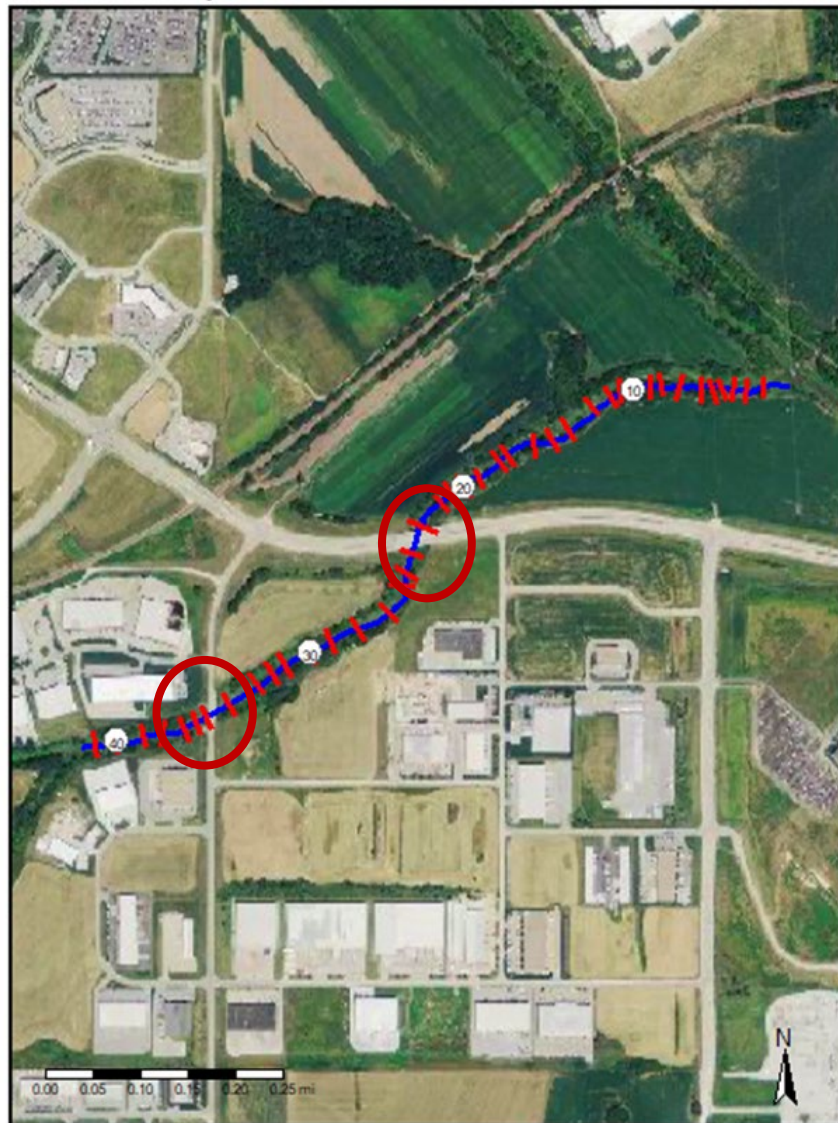


Figure 4-54: South Papillion Creek Reach 1: Cross-section Location Map

Slope and cross-section analysis comparisons of the downstream section of the reach reveals channel degradation and widening (Figures 4-56, 4-57, and 4-58) between 2004 and 2016. There are GCSs at Giles Road Bridge and the South 120th Street Bridge (Figure 4-54 and 4-55, red circles). Based on aerial photo investigation, the GCSs were constructed between 2009 and 2010. They are providing stability to the upstream section of the reach and the slope has

flattened. The water surface profile within this lower reach is consistent at 0.0022 ft/ft. The slope above the GCS is 0.001 ft/ft. Based on the LiDAR trends in the downstream section the reach, the channel bed has dropped approximately three to 3.5 feet (Figure 4-56) and eroded laterally in some locations 20 to 25 feet (Figure 4-57).

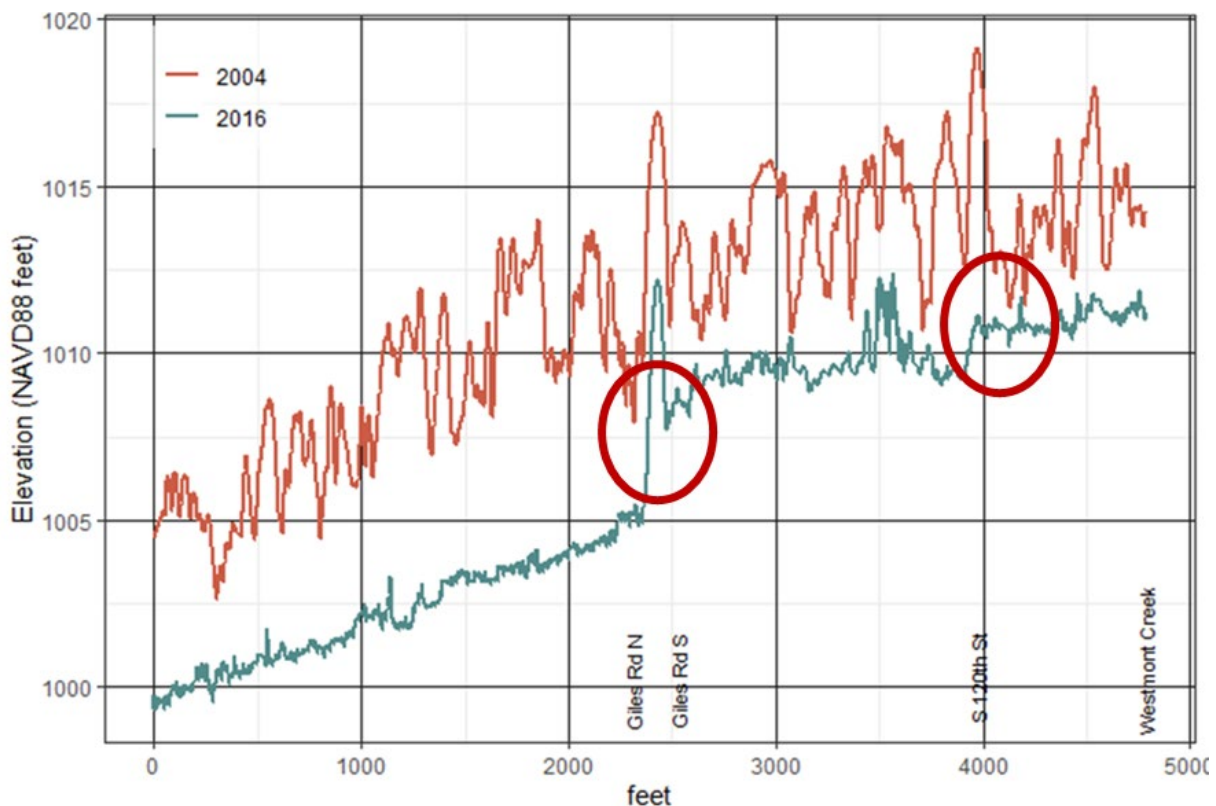


Figure 4-55: FG Level 1, Reach 1 – LiDAR Water Surface Profiles

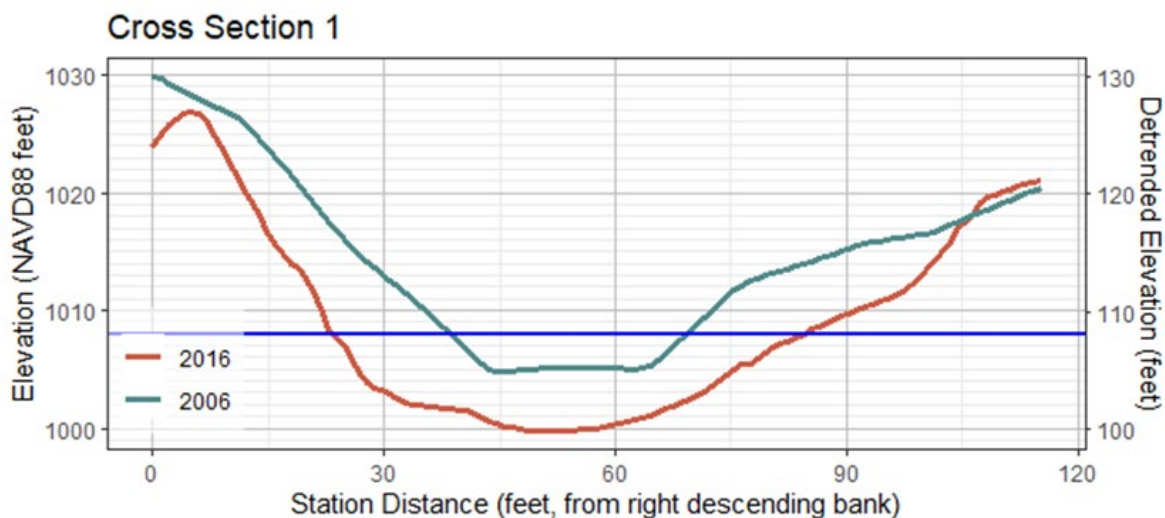


Figure 4-56: Cross-section illustrating channel degradation and widening

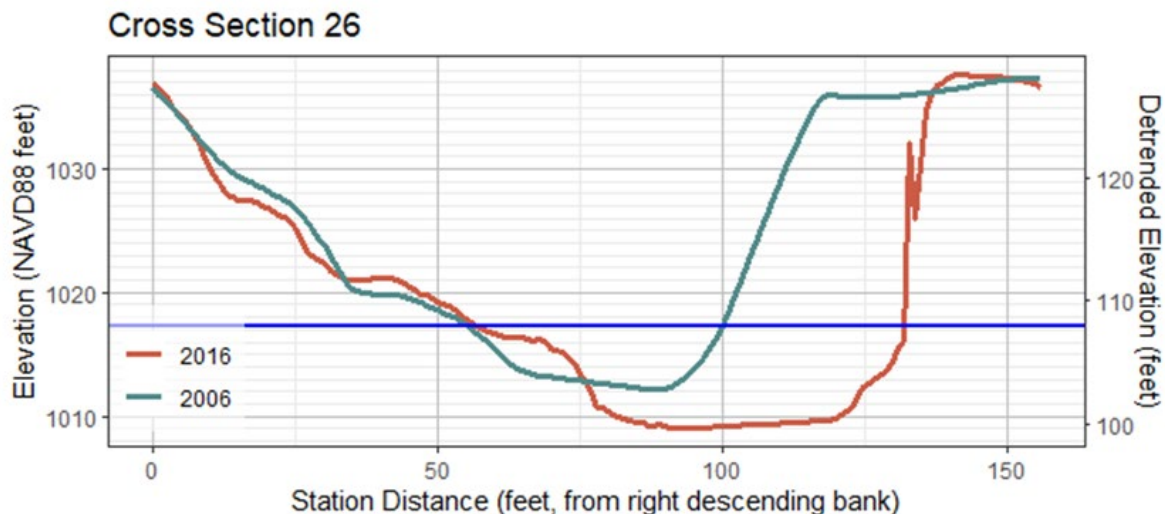


Figure 4-57: Cross-section Illustrating Channel Degradation and Lateral Bank Erosion

The channel has built-floodplain-berms within the incised channel margins shown in Figures 4-57 (left bank), 4-58 (both banks), and 4-59 (left bank). This is typically a sign of the channel adjusting to a new quasi-equilibrium (CEM IV and V) and is indicative of areas upstream of a GCS as the channel adjusts to the new stable channel bed invert and the reaches trend toward stabilizing. There will likely be local channel erosion as the channel continues to adjust. Based on the LiDAR trends in the upstream section of the reach, the channel bed has dropped one to 1.5 feet (Figure 4-58) and eroded laterally in some locations 20 to 25 feet (Figures 4-60 and 4-61).

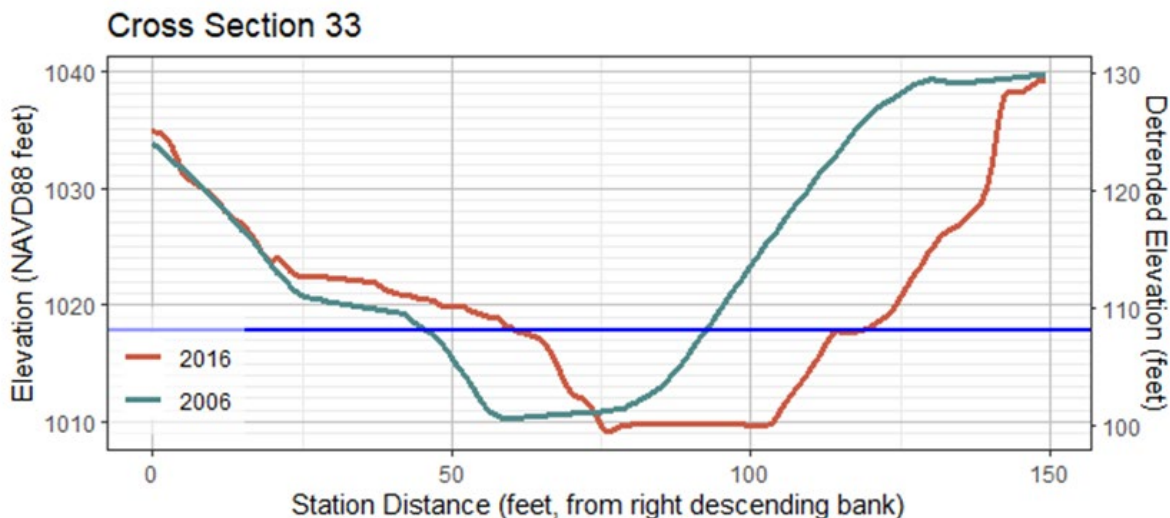


Figure 4-58: Cross-section 84 Illustrating Lateral Bank Erosion

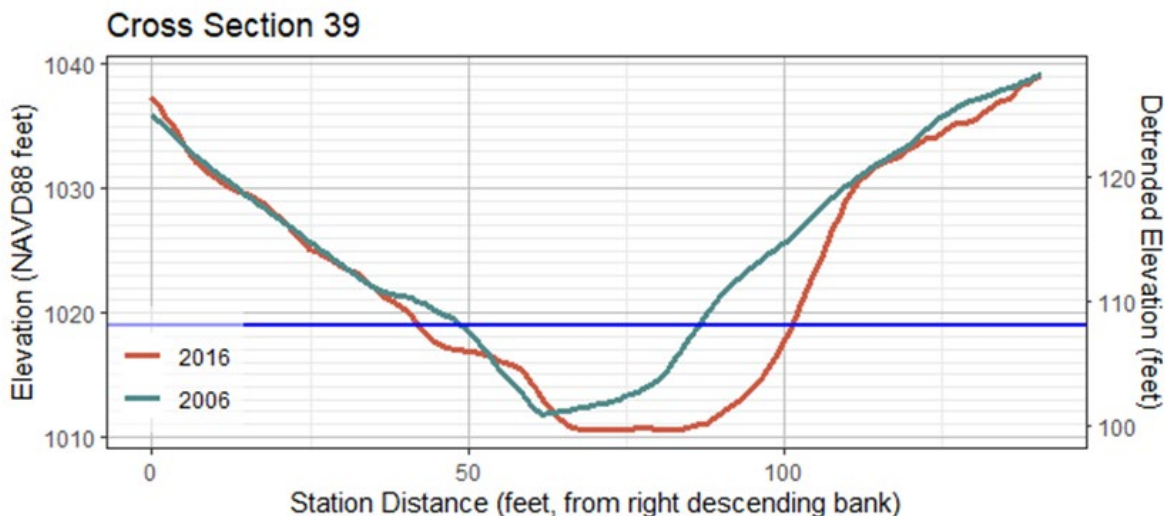


Figure 4-59: Cross-section Illustrating Bank Lateral Erosion

Reach 1 Summary:

Based on the FG Level 1 analysis:

- Reach 1 appears to be stabilizing from a trend of degradation. Based on the WOTUS trip report completed in 2019, there is local bank erosion in locations (Figure 4-60) where the channel is still adjusting, or planform issues are causing accelerated erosion. The downstream section is likely in a late CEM Stage IV transitioning into a CEM Stage V upstream.
- The reach is a CEM stage IV downstream of Giles Road Bridge and CEM stage V upstream.
- The GCS at Giles Road Bridge is providing channel bed stability to the upstream section of Reach 1, this is noted by the presence of new floodplain berms forming in the channel. The structure has also prevented further bed degradation from moving upstream.
- The GCS should be monitored for changes in elevation and scour around the structure. Part of the South Papillion Creek restoration and stabilization plan will likely be enhancing the GCS throughout the watershed.
- Level II analysis was completed on this reach and compiled in the next section.



Figure 4-60: South Papillion Creek Upstream of Giles Road Bridge Showing Right Bank Erosion of Culvert Outlet

Reach 1-FG Level II Analysis:

The geomorphic metrics for Reach 1 are plotted in Figure 4-61. The W/D metrics are spatially distributed in Figure 4-62 and plotted in Figure 4-63.

- The W/D (<10) and ER (<1.4) show locations where the channel is incised and has limited access to an active floodplain (Figures 4-61, 4-62, 4-63). Most of the W/D ratios are below 12 and demonstrate confined channel conditions.
- Upstream of the GCS, there is lower water surface slopes and a slightly trending increase in ER. The ERs are all below the moderately entrenched (1.4-2.2) to entrenched (<1.4) stream-classification breaks. The lower section of the reach has moderately entrenched ER's (1.4-2.2).
- The trend of low W/D, high ER, and higher sinuosity downstream of the GCS may indicate that the channel is narrow with sloughing banks and a widening floodplain developing. The higher W/D, low ER, and sinuosity upstream of the GCS appears to be stabilizing the bed and adjusting width, especially in the meander bend through the Giles Road Bridge section.
- Larger shear stress and USP occur in the lower section of the reach below the GCS. Upstream there is low slope and a slightly decreasing ER with less access to floodplain; bankfull berms are actively building.

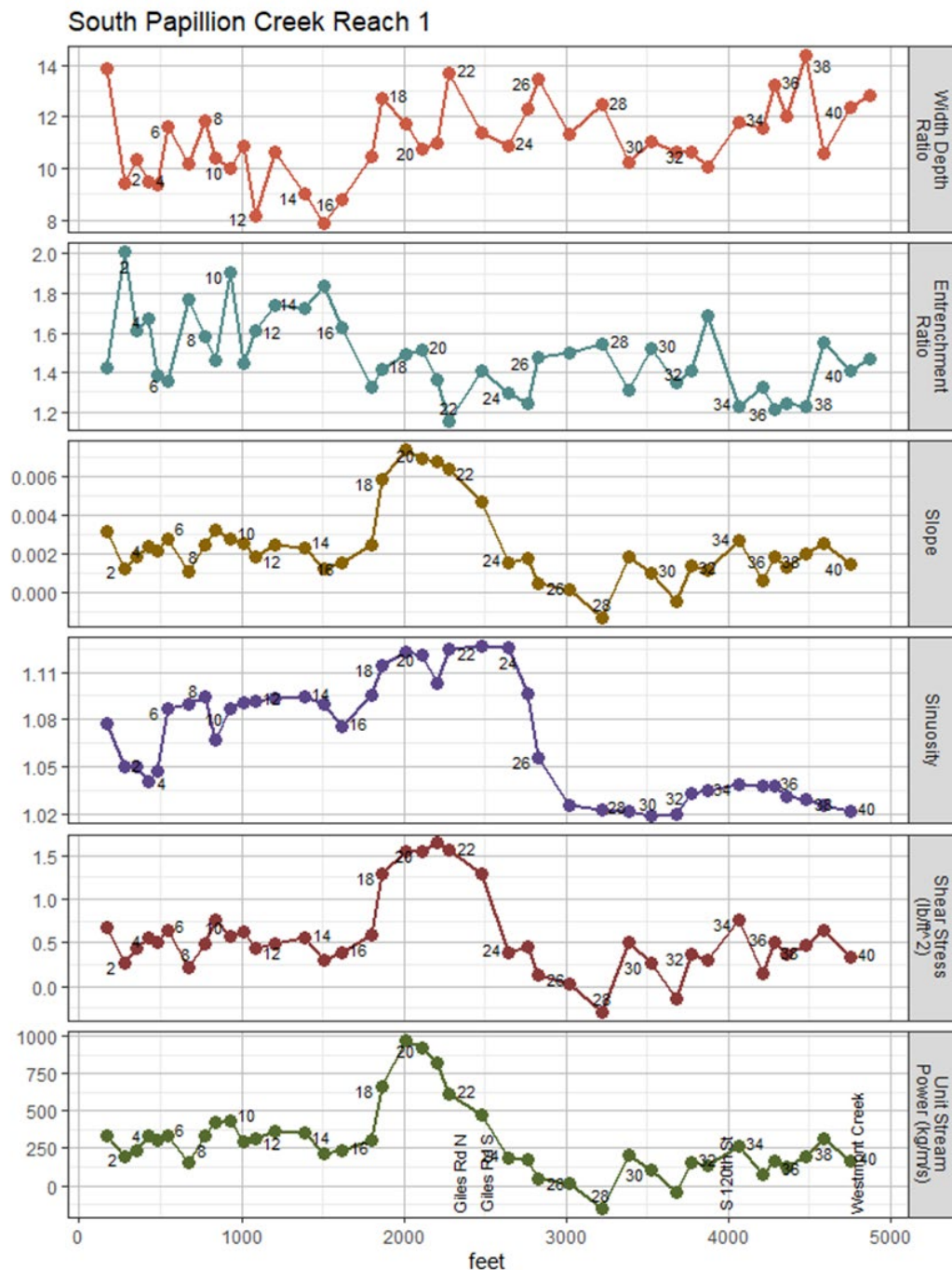


Figure 4-61: FG Level II – Geomorphic Metrics

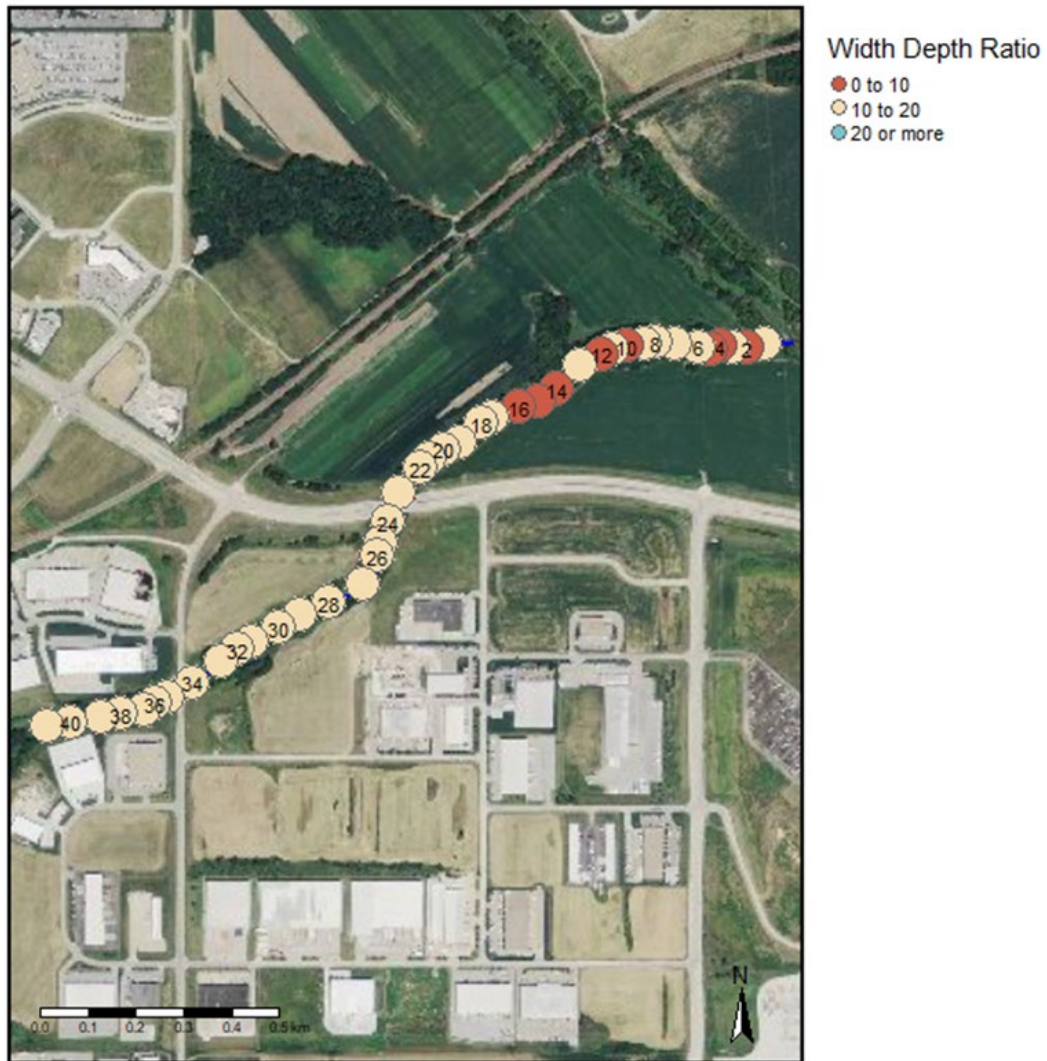


Figure 4-62: FG Level II – Reach 1 W/D Metrics

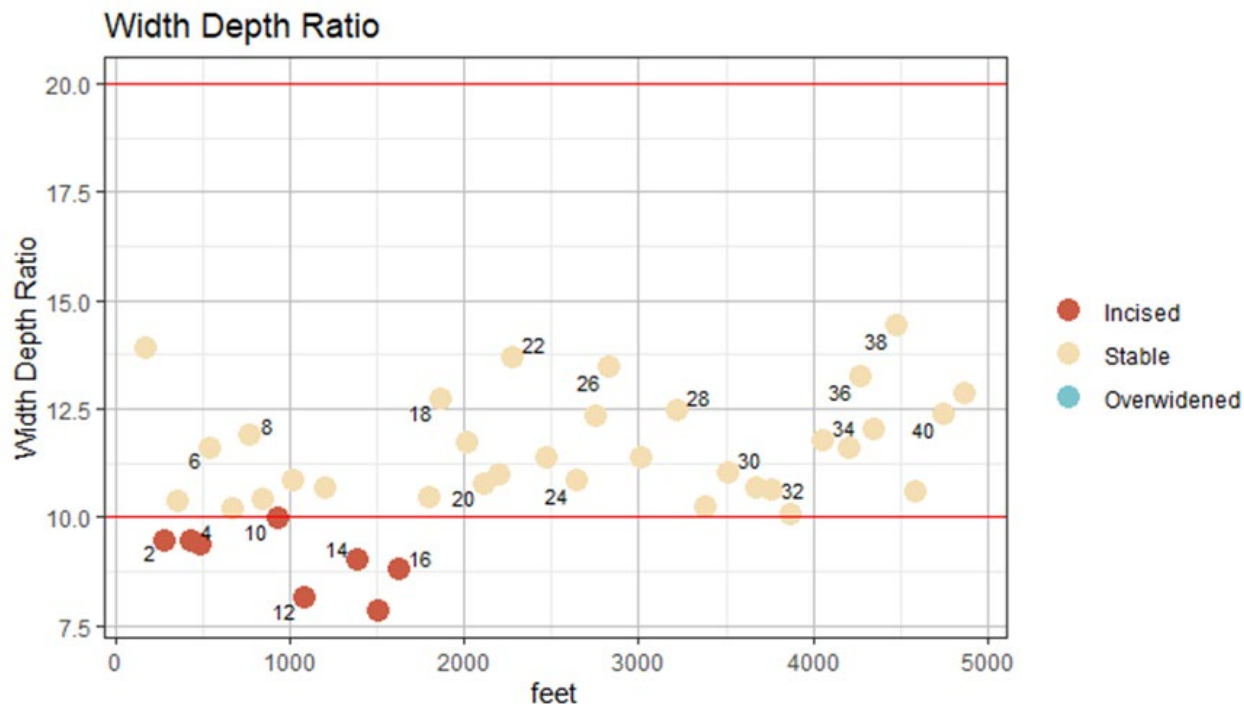


Figure 4-63: FG Level II – Reach 1 W/D Metrics

4.4.2.2 REACH 2A: WESTMOUNT CREEK TO I-80 WEST

Reach 2a-FG Level I Analysis:

The Reach 2a site map is illustrated in Figure 4-64 and the LiDAR water surface profiles are plotted in Figure 4-65. Similar to Reach 1, the channel is incised with 25-to-30-foot bank heights (terrace). This reach is relatively straight.

Slope and cross-section analysis comparisons of the downstream section of the reach reveals channel degradation but relatively no widening (Figures 4-66 to 4-69) between 2004 and 2016. There are GCSs at the South 126th Street Bridge, a two-level GCS approximately 750 feet downstream of the South 132nd Street, and one more located between the South 132nd Street Bridge and I-80 Bridge (Figures 4-64 and 4-65, red circles). Based on aerial photo investigation, the GCSs appear to have been constructed in the same range as the Reach 1 GCS in 2009 or 2010. The GCSs are providing stability to the entire reach and the slope has flattened. The water surface profile within this downstream section of the reach is consistent at 0.0014 ft/ft. The slope in the middle of the reach is 0.00025 ft/ft and the upper section upstream of station 4,000, 0.0016 ft/ft. Based on the LiDAR trends in the downstream and middle sections the reach, the channel bed has dropped approximately three to 3.5 feet (Figure 4-66 and 4-67) and experienced little to no laterally erosion (Figures 4-66 to 4-69).

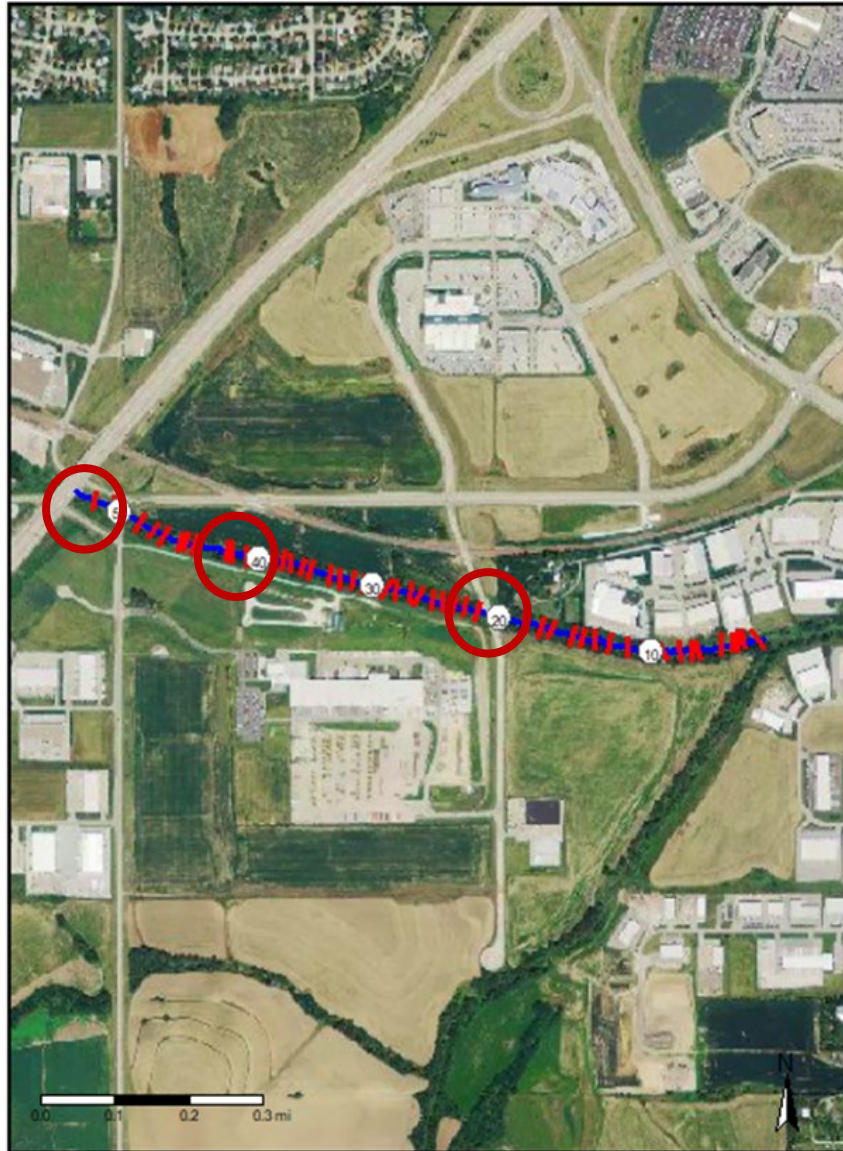


Figure 4-64: South Papillion Creek Reach 2a – Cross-section Location Map

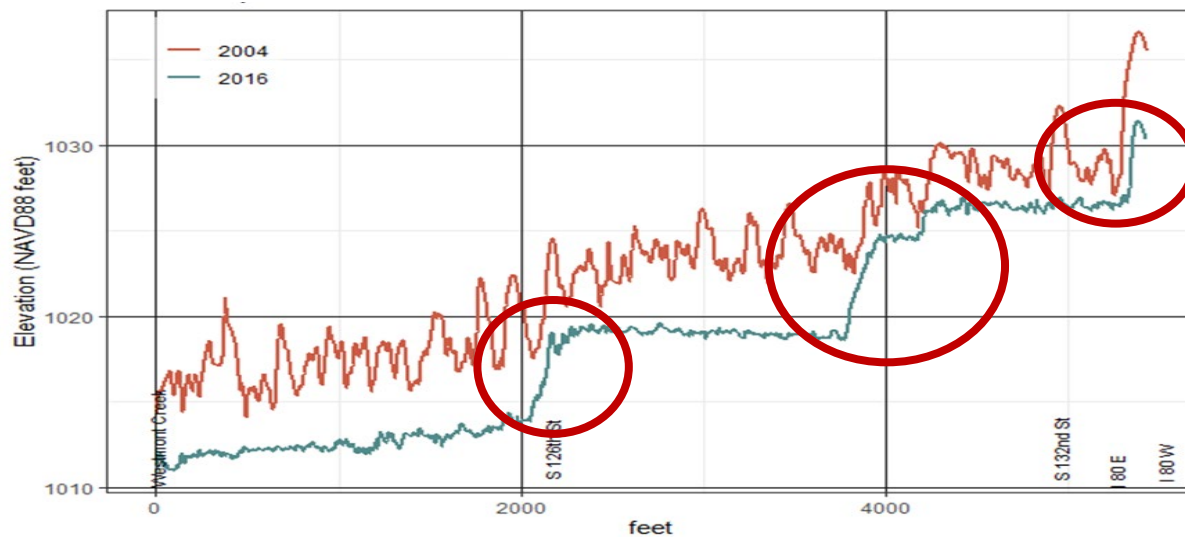


Figure 4-65: FG Level 1, Reach 2a – LiDAR Water Surface Profiles

Cross Section 10

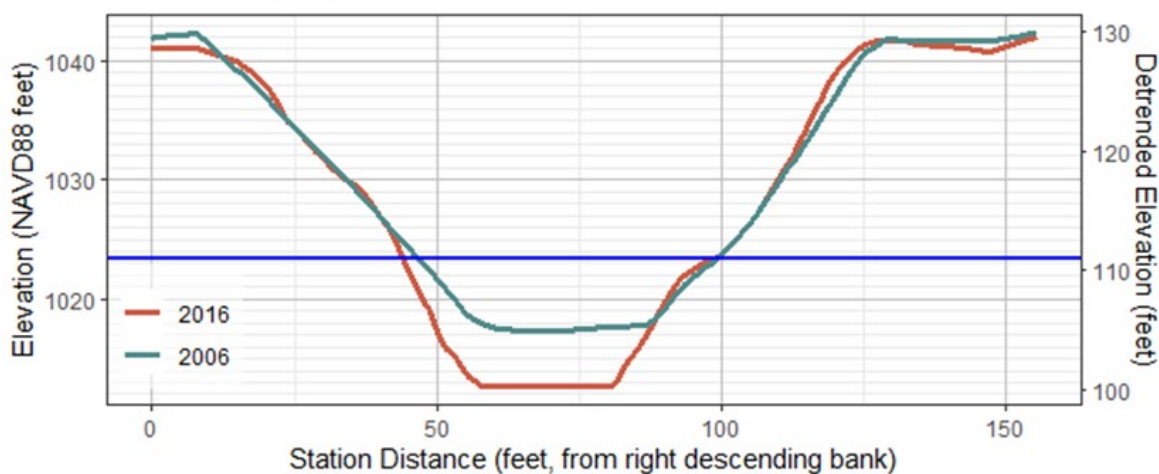


Figure 4-66: Reach 2a – Cross-section Depicting Channel Degradation

Cross Section 29

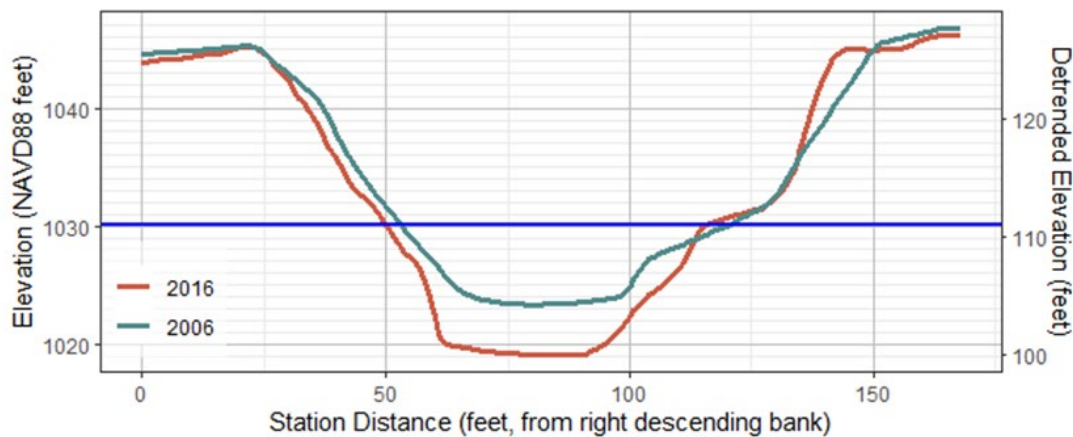


Figure 4-67: Reach 2a – Cross-section Illustrating Channel Degradation

The water surface profiles show a trend of channel degradation in the downstream and middle sections of the reach (cross-sections 1-40) from approximate station 0+00 to 40+00. All sections of the reach appear to have stabilized based on the cross-sectional comparisons. The presence of floodplain berms in Figures 4-68 and 4-69 appears to demonstrate a trend toward reach stability with little bed or bank movement.

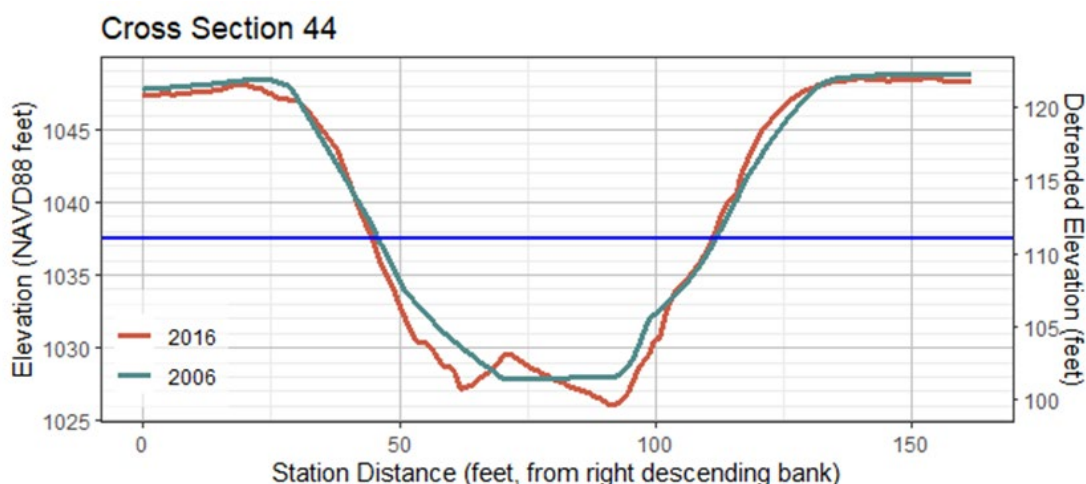


Figure 4-68: Reach 2a – Cross-section 86 Illustrating Stable Channel Bed and Banks

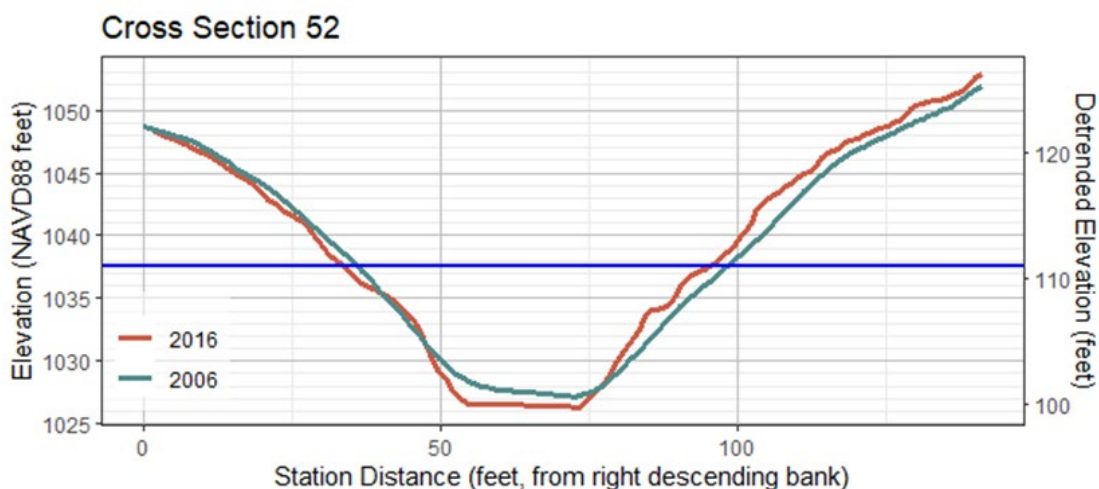


Figure 4-69: Reach 2a – Cross-section Depicting a Relatively Stable Bank

Reach 2a Summary:

Based on the FG Level 1 analysis:

- Reach 2a appears to be stabilizing from a trend of degradation. Based on the WOTUS trip report completed in 2019, there is local bank erosion in locations where the channel is still adjusting, or planform issues are causing accelerated erosion.
- The reach is likely in CEM Stage IV in the downstream and middle sections and Stage V upstream.
- The GCSs are providing channel bed stability to the reach, evidenced by the presence of new floodplain berms forming in the channel.

- The GCSs should be monitored for changes in elevation and scour around the structures or any other failure modes. Part of the South Papillion Creek restoration and stabilization plan will likely be enhancing the GCSs throughout the watershed.
- Level II analysis was completed on this reach and compiled in the next section.

Reach 2a-FG Level II Analysis:

The geomorphic metrics for Reach 2a are plotted in Figure 4-70. The W/D metrics are spatially shown in Figure 4-71 and plotted in Figure 4-72.

- The W/D and ER show locations where the channel is incised and has limited access to an active floodplain. Most of the W/D ratios are below 12 and demonstrate confined channel conditions.
- Overall, the GCSs are providing stability to the reach and the slopes are relatively low upstream of the structures.
- The ERs are all below the moderately entrenched stream-classification break of 2.2 (Rosgen, 1996), with the lower section of the reach having ER's less than 1.8. The overall ER reach trend is slightly increasing upstream providing more access to developing floodplains in the upper section of the reach.
- Sinuosity is between 1.0 and 1.1, as the channel is relatively straight.
- Shear stress and USP are fairly consistent except where elevated values are associated with GCS locations.
- The reach appears to be relatively stable. The GCSs are providing bed stability and the lower streambanks are stabilizing. This conclusion should be field-validated.

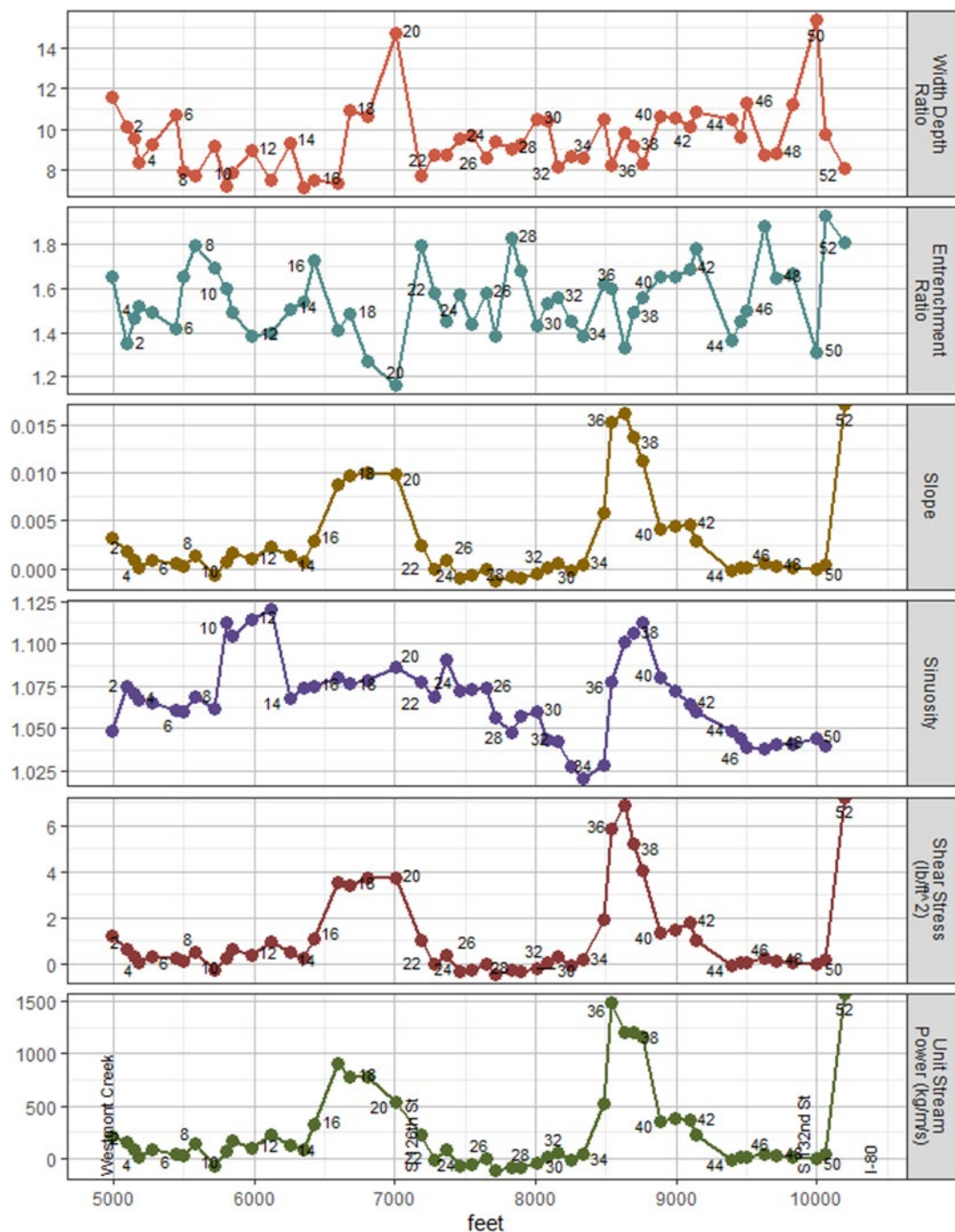


Figure 4-70: FG Level II – Geomorphic Metrics



Figure 4-71: FG Level II – Reach 2a W/D Metrics

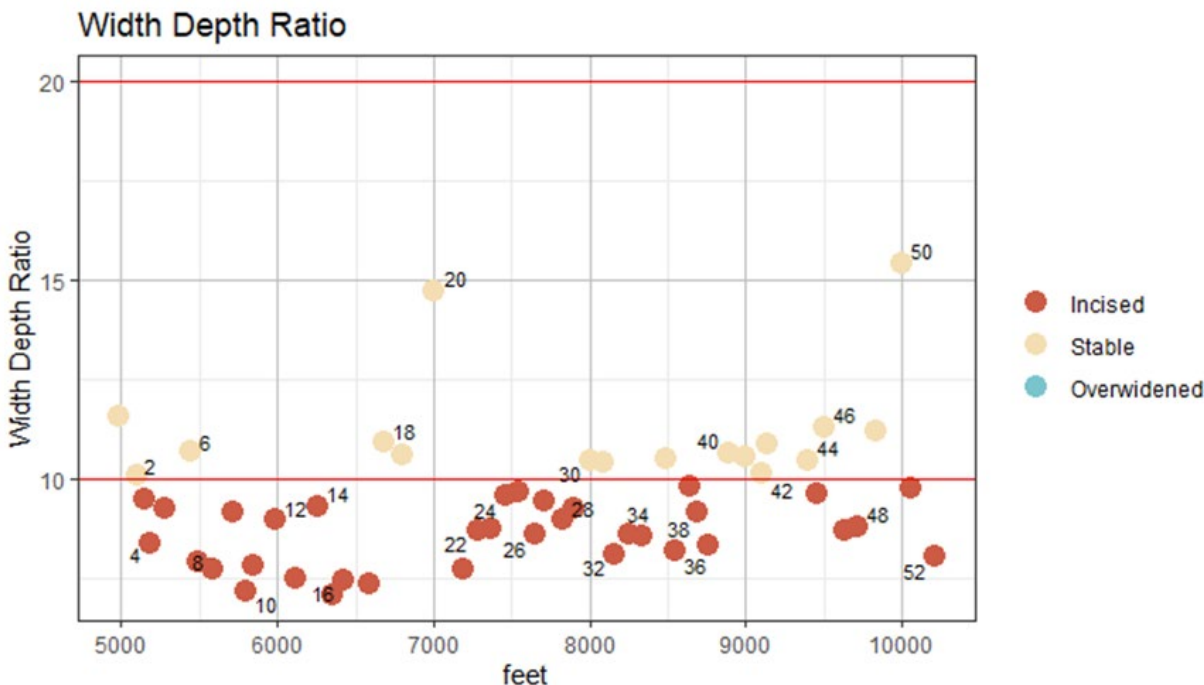


Figure 4-72: FG Level – Reach 2a W/D Metrics

4.4.2.3 REACH 2B: I-80 WEST TO WEHRSPANN CREEK

Reach 2b - FG Level I Analysis:

The Reach 2b site map is shown in Figure 4-73 and the LiDAR water surface profiles are plotted in Figure 4-74. The reach is relatively stable based on the profile (Figure 4-73) and cross-section analysis (Figures 4-75 to 4-78). The profile comparison shows little or no change between the 2004 and 2016 water surface slopes. Like Reach 2a, this reach is relatively straight.

Based on the water surface profile and aerial photo investigation, there is only one GCS in the reach, approximately 800 feet upstream of the I-80 West Bridge (Figures 4-73 and 4-74, red circles). The water surface profile at the GCS fits the 2004 and 2016 very closely. In addition to the GCS, there is likely erosion resistant materials in the channel bottom and banks upstream throughout the reach. The water surface profile within the reach is consistent at 0.0017 ft/ft. This slope should be analyzed further to determine if this slope could be used as a template for determining stable channel slopes for other reaches. Based on the LiDAR water surface slope there are no discernable bed degradational trends (Figures 4-75 and 4-78); however, there is some local scour and erosion as depicted in Figure 4-76.

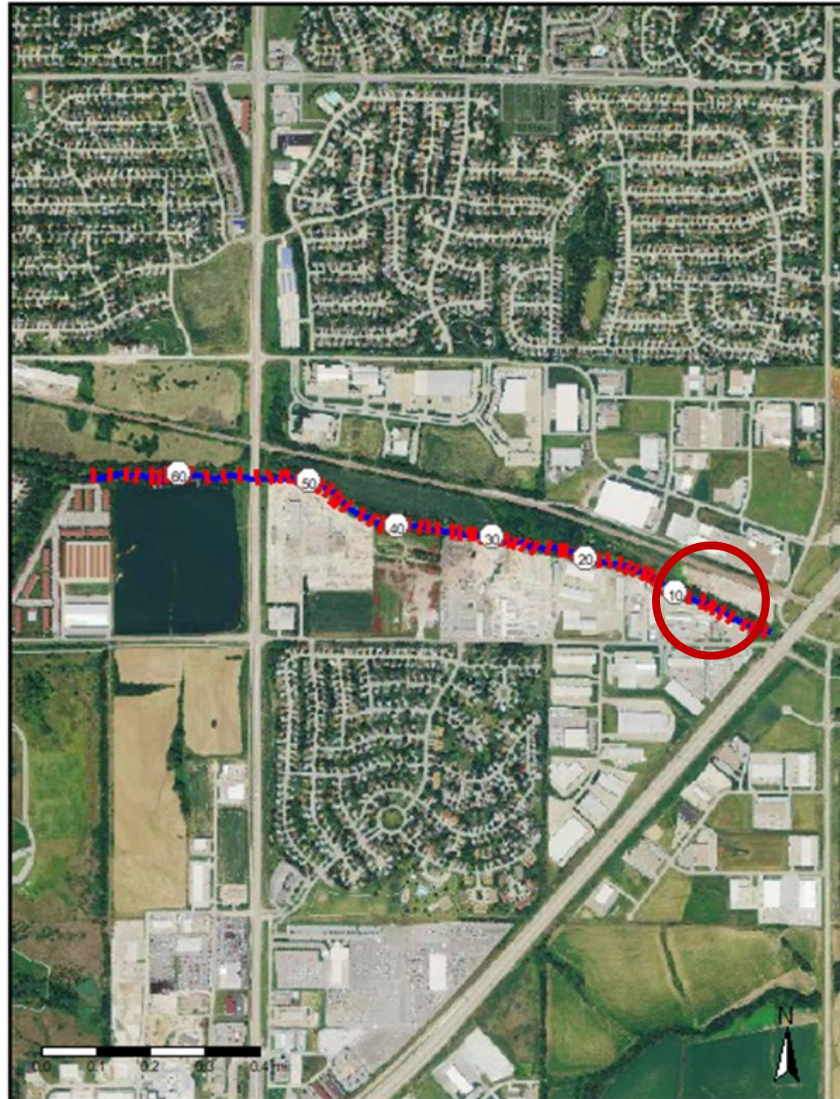


Figure 4-73: South Papillion Creek Reach 2b – Cross-section Location Map

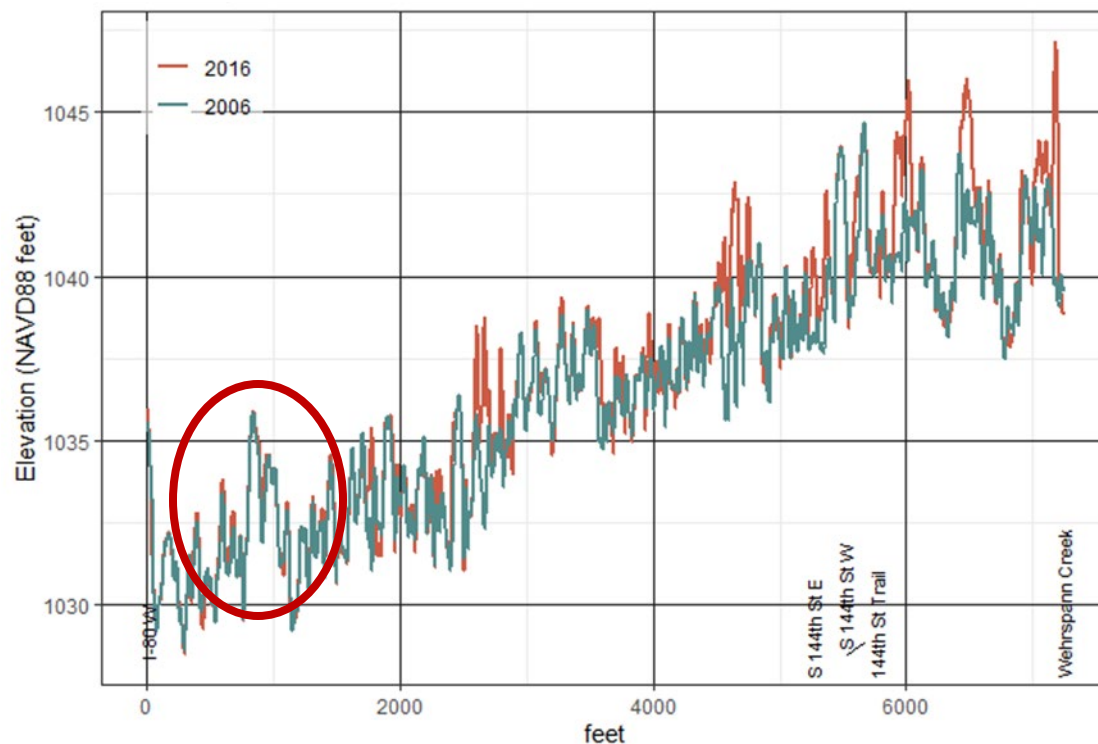


Figure 4-74: FG Level 1-Reach 2b: LiDAR Water Surface Profiles

There are floodplain berms in the reach that were used to identify the bankfull channel conditions. The berms are shown in Figure 4-75 (left bank), 4-76 (left and right bank), and 4-77 (left bank).

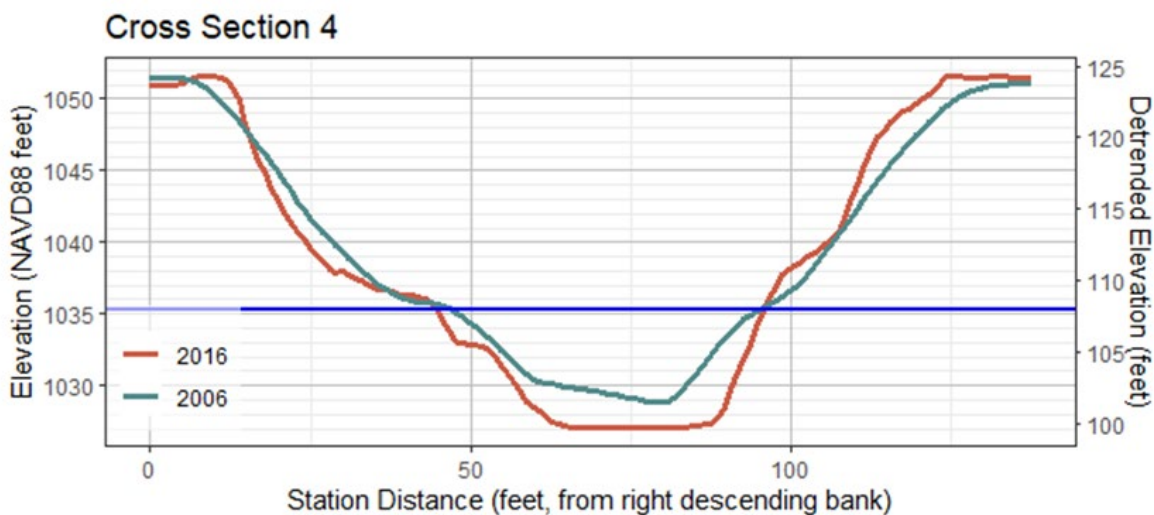


Figure 4-75: Reach 2b – Cross-section Depicting Relatively Stable Banks

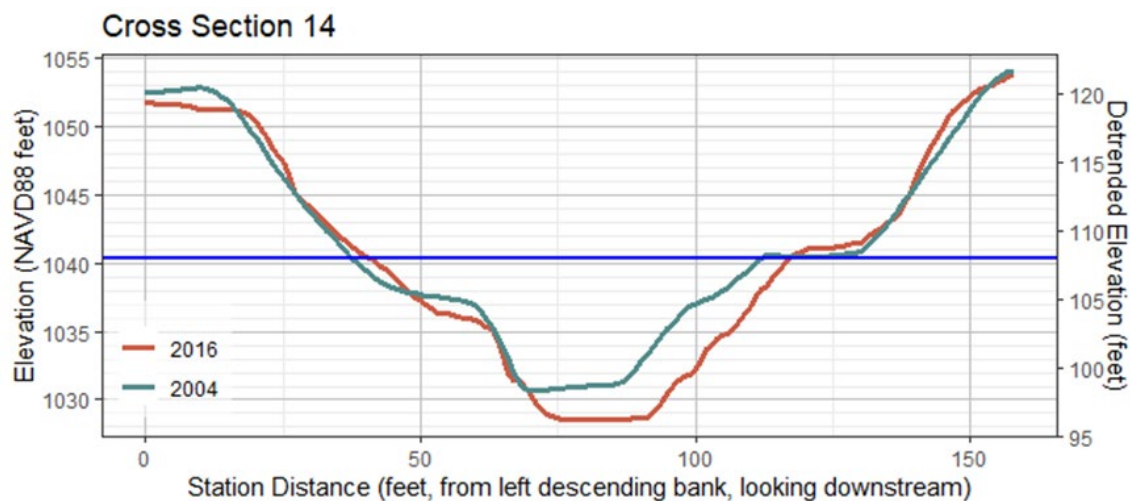


Figure 4-76: Reach 2b – Cross-section Depicting Slight Bed and Bank Erosion

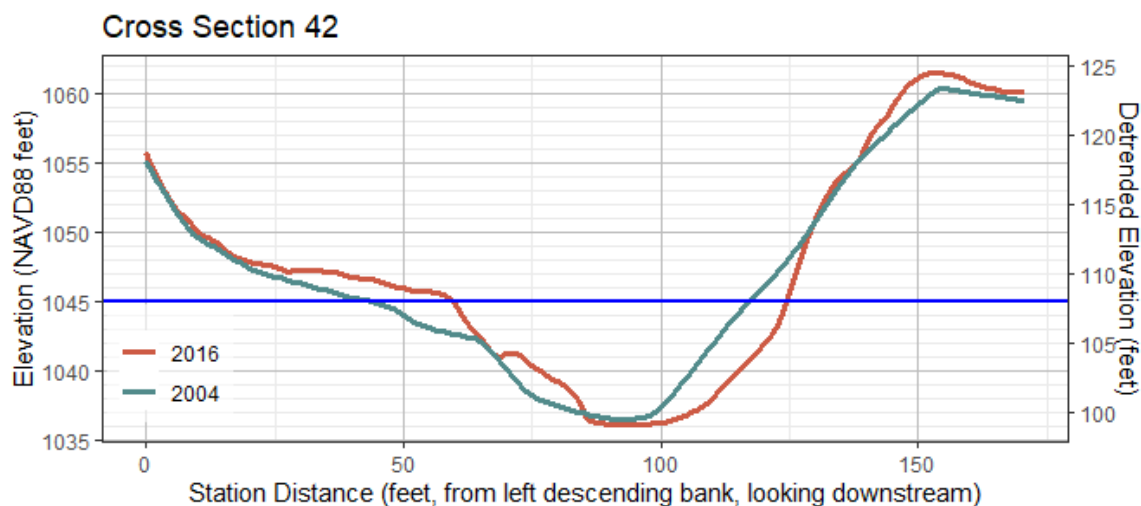


Figure 4-77: Reach 2b – Cross-section Depicting a Relatively Stable Bank

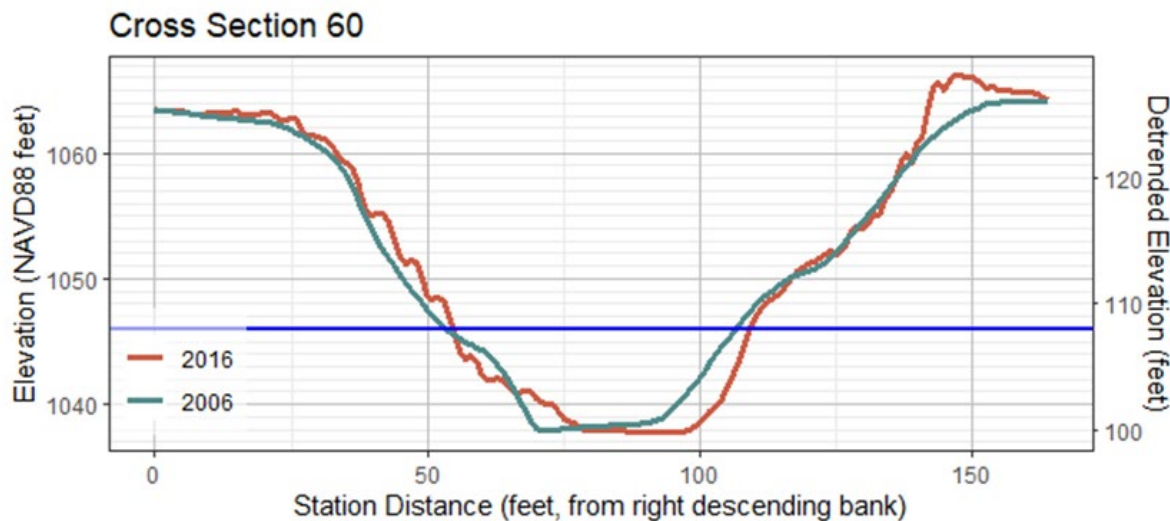


Figure 4-78: Reach 2b – Cross-section Depicting a Relatively Stable Bank

Reach 2b Summary:

Based on the FG Level 1 analysis:

- Based on the slope analysis, Reach 2b appears to be stable. The reach is likely in CEM Stage IV and V.
- There is one GCS in the reach approximately 800 feet upstream of the I-80 West Bridge. This structure should be monitored for maintaining the channel slope and reach stability.
- New floodplain berms are forming in much of the reach showing a trend of stabilization.
- There are likely more GCSs located within the reach, but this could not be verified with the LiDAR or aerial photo interpretation. The reach should be further field-investigated to determine what materials and conditions persist that provide stable conditions to the reach.
- Part of the South Papillion Creek restoration and stabilization plan will likely be enhancing the GCSs throughout the watershed which will include closer examination of this reach and its stable trend.
- Level II analysis was completed on this reach and compiled in the next section.

Reach 2b-FG Level II Analysis:

The geomorphic metrics for Reach 2b are plotted in Figure 4-79. The W/D metrics are spatially shown in Figure 4-80 and plotted in Figure 4-81.

- The W/D and ER show locations where the channel is incised and has limited access to an active floodplain (Figures 4-79, 4-80, 4-81). Most of the W/D ratios are below 12 and demonstrate confined channel conditions.
- All the reach ERs are below the moderately entrenched stream-classification break of 2.2 (Rosgen, 1996). Moderate to entrenched sections are likely continuing to develop an active floodplain so will likely continue to cause bank erosion as the channel continues to adjust. This may be lessened by resistant lower bank materials (cohesive materials), vegetation and existing stabilization materials in the bed or bank.
- Reach sinuosity ranges from 1.0 to 1.15 as the channel is relatively straight.
- The GCS is providing stability to the reach. The channel slope of 0.0017 ft/ft is stable upstream of the structure.
- The reach appears to be relatively stable. The GCS is providing bed degradation protection and the lower banks are stabilizing. This should be field validated.

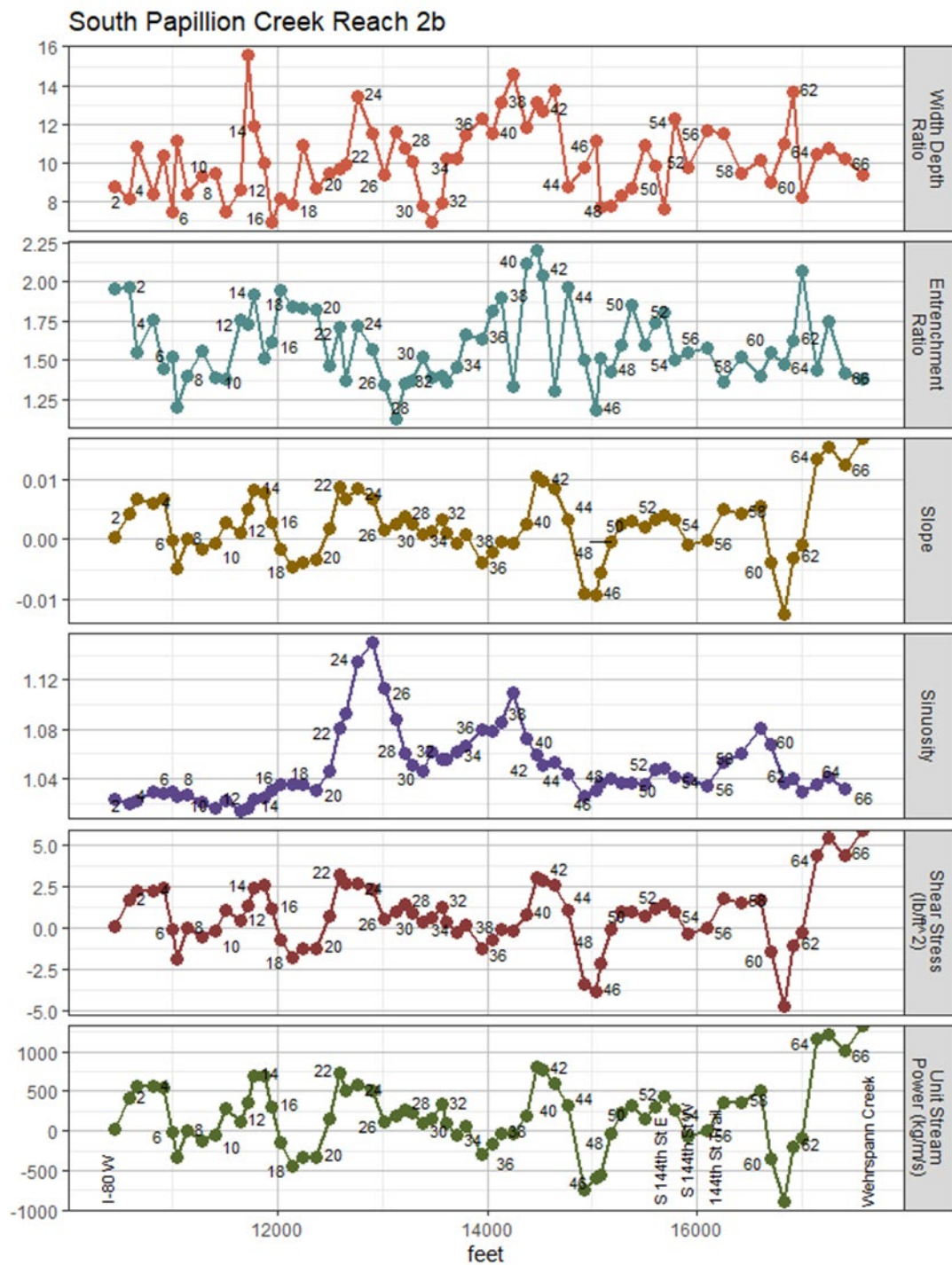


Figure 4-79: FG Level II – Geomorphic Metrics



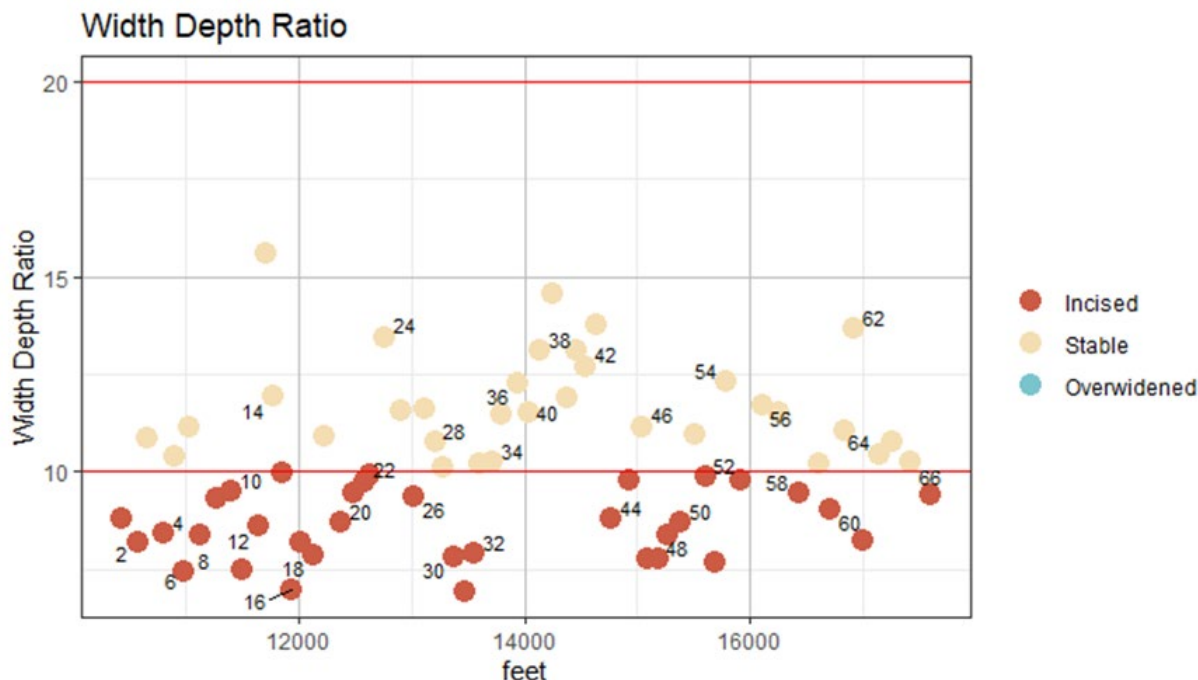


Figure 4-81: FG Level II – Reach 2b W/D Metrics

4.4.2.4 REACH 3: WEHRSPANN CREEK TO MISSION CREEK

Reach 3 - FG Level I Analysis:

The Reach 3 site map is illustrated in Figure 4-83 and the LiDAR water surface profiles are plotted in Figure 4-83. The reach has a stable streambed based on the profile (Figure 4-83) and is experiencing local channel erosion based on the changes to the cross-sections (Figures 4-84, 4-85, and 4-86). The profile comparison shows little or no change between the 2004 and 2016 water surface slopes. The reach has two straight segments upstream and downstream of the Railroad and South 156th Street Bridges. There is meandering channel on the upstream section of this reach.

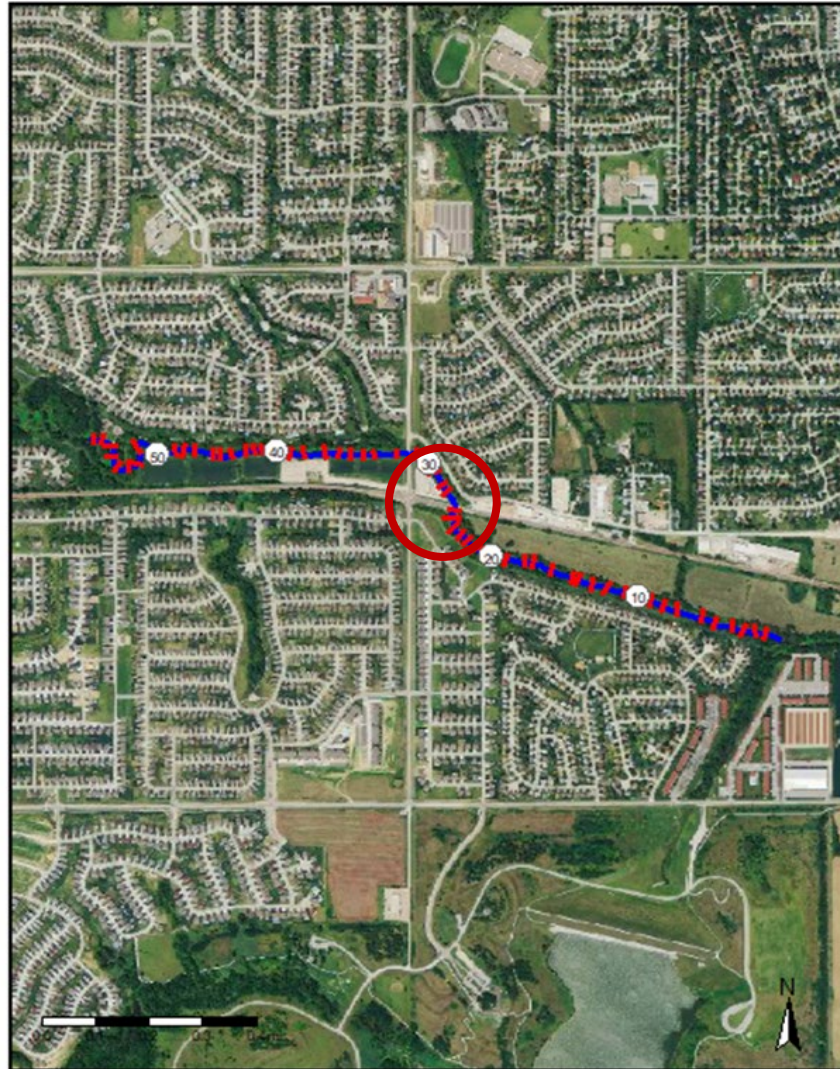


Figure 4-82: South Papillion Creek Reach 3 – Cross-section Location Map

Based on the water surface profile and aerial photo investigation, there is only one GCS in the reach (Figure 4-82 to 4-84, red circle), at the Railroad Bridge, just downstream of the South 156th Street Bridge. When comparing the 2004 and 2016 channel slope profiles, the stream channel at the GCS is a near perfect match; however, downstream of the structure (Figure 4-85) local channel erosion is occurring and there is riprap bank protection that was added between 2016 and 2017.

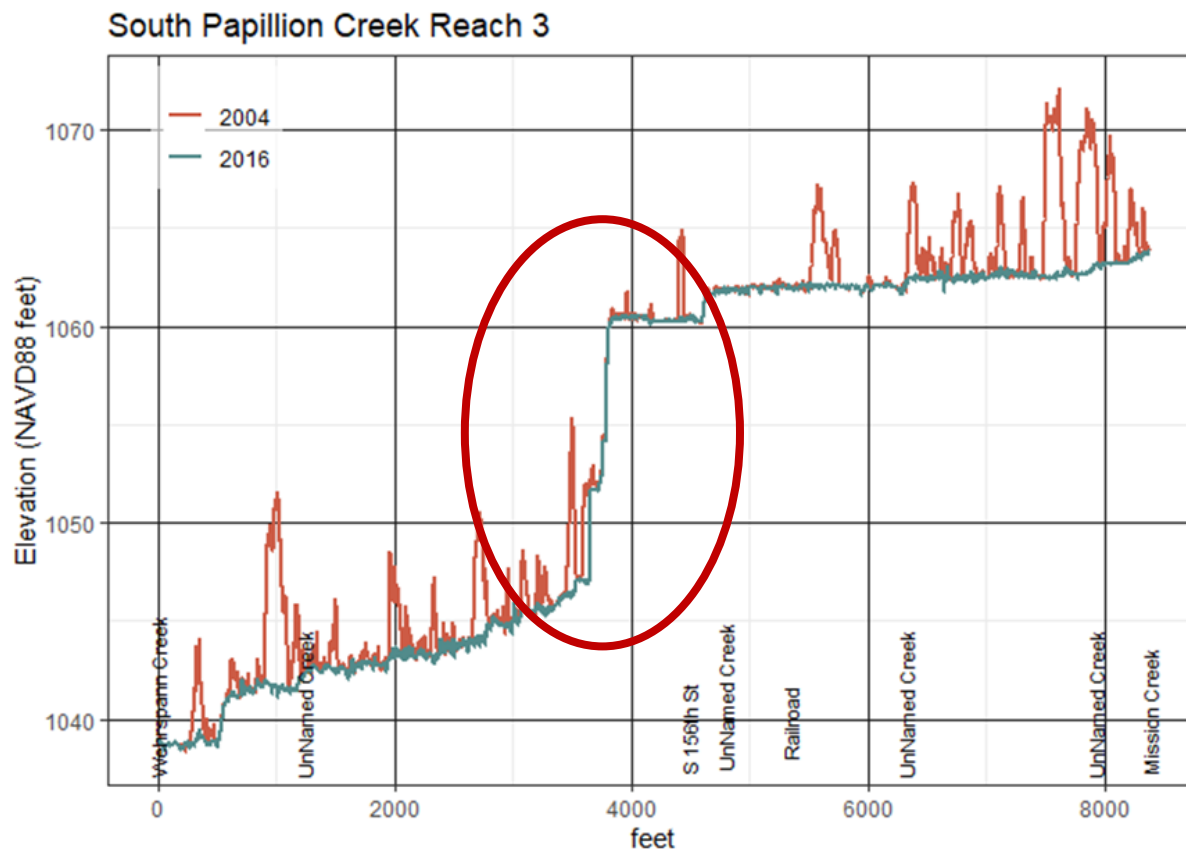


Figure 4-83: FG Level 1, Reach 3 – LiDAR Water Surface Profiles

The water surface profile within the reach below the GCS is 0.0023 ft/ft. Upstream of the GCS the channel slope is much flatter at 0.0009 ft/ft. Based on the LiDAR slope there is no discernable bed degradational trends (Figure 4-83).

Based on cross-section analysis, there is a significant amount of local channel erosion in the reach (Figures 4-84 to 4-87). The streambank erosion appears to be the worst in the upper section where there is a meandering course at the mouth of Mission Creek.

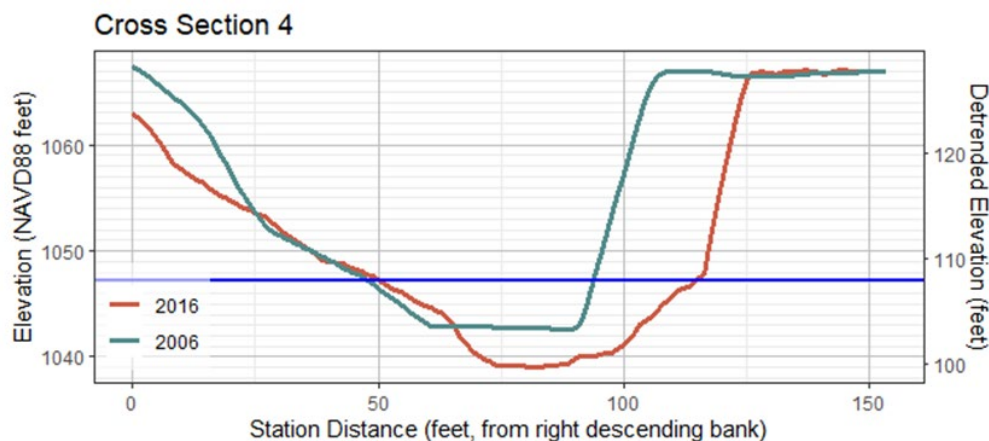


Figure 4-84: Reach 3 – Cross-section Illustrating Right Bank Erosion

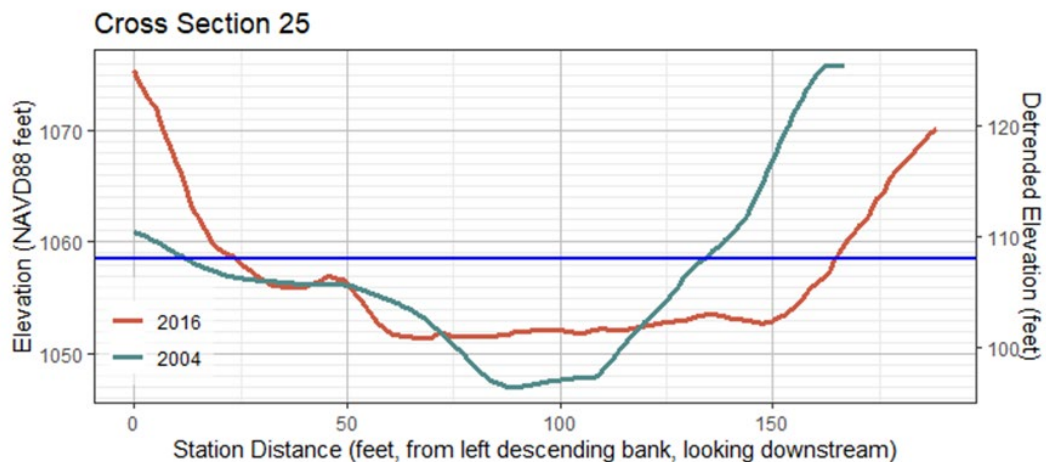


Figure 4-85: Reach 3 – Cross-section Showing Channel Widening Downstream of GCS

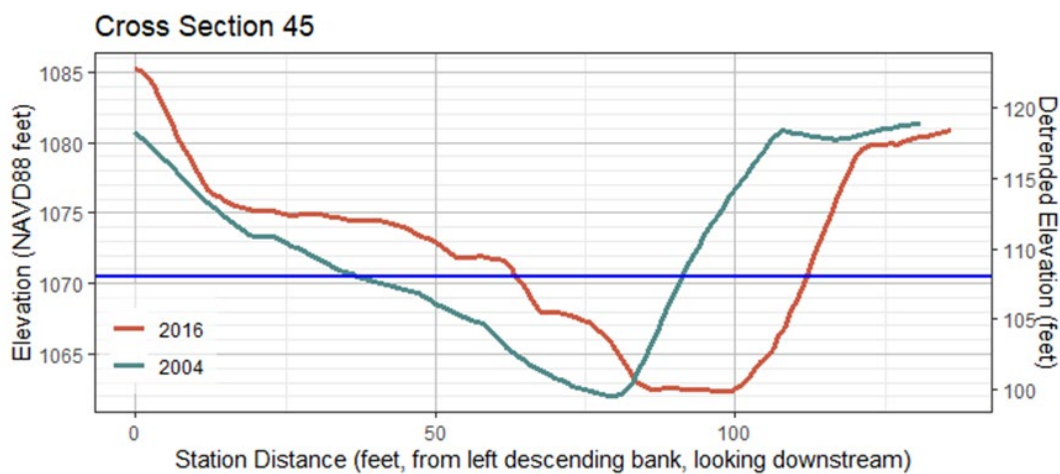


Figure 4-86: Reach 3 – Cross-section with Right Bank Erosion and Left Bank Deposition

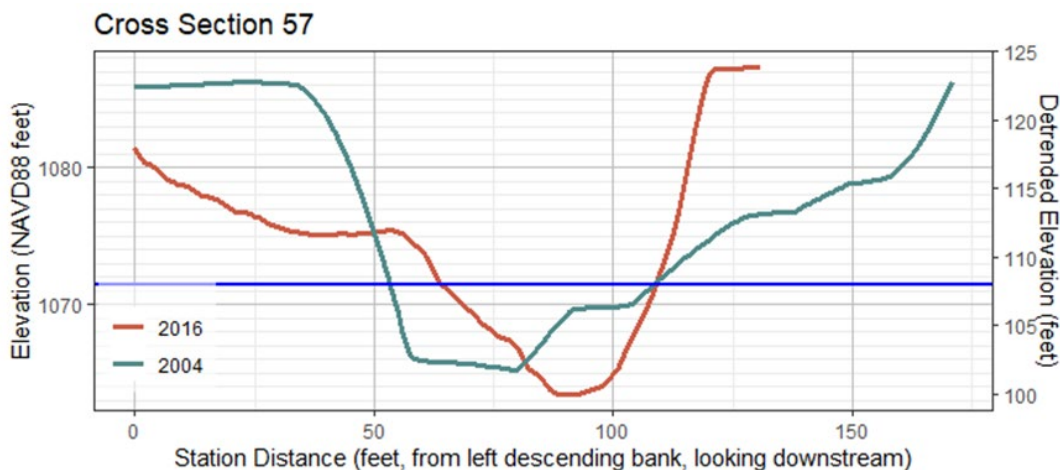


Figure 4-87: Reach 3 – Cross-section with Right Bank Deposition and Left Bank Erosion

Reach 3 Summary:

Based on the FG Level 1 analysis:

- Based on the slope analysis, Reach 3 appears to be in CEM Stage V. The streambed is stable and there is local bank erosion. New floodplain berms have developed in much of the reach showing a trend of stabilization.
- The meandering pattern through the upstream section of the reach is tortuous. Stabilization of these bank erosion sites will likely require channel re-meandering.
- There is one GCS in the reach approximately at the Railroad Bridge that is providing bed stability to the upstream section of the reach. The structure is approximately 10 feet high and should be monitored for maintaining the channel slope.
- If there are any concerns for fish passage within the South Papillion Creek watershed, large GCSs like this should be modified to allow reasonable channel slope transitions through these elevation drops.
- Part of the South Papillion Creek restoration and stabilization plan will likely be enhancing the GCSs throughout the watershed that will include closer examination of this reach and its stable trend.
- Level II analysis was completed on this reach and compiled in the next section.

Reach 3-FG Level II Analysis:

The geomorphic metrics for Reach 3 are plotted in Figure 4-88. The W/D metrics are spatially shown in Figure 4-90 and plotted in Figure 4-91.

- The W/D and ER show locations where the channel is incised and has limited access to an active floodplain (Figures 4-88 to 4-90). Most of the W/D ratios are below 15 and trend toward a stabilizing confined channel.
- Most ER values are below the 2.2 moderately-entrenched threshold. The lower ERs should be targeted to investigate further as these are the locations where floodplain connection access is low.
- The reach slope values are showing a consistent pattern of a riffle and pool (Figure 4-88) sequence.
- Sinuosity is below 1.2 for most of the reach showing little variability in meander pattern.
- Shear stress and USP are consistent through the reach with the one exception, the cross-sections downstream of the GCS structure are elevated based on slope and channel over widening.
- The GCS is providing stability to the reach. The channel slope of 0.0023 ft/ft downstream and 0.0009 ft/ft upstream. There is widespread bank erosion occurring throughout the reach.
- Additional field-validation is recommended to determine if the reach is relatively stable with such low W/D, ER, and sinuosity values. The bed stability is at least partly from the GCS but may also have resistive cohesive bank materials.

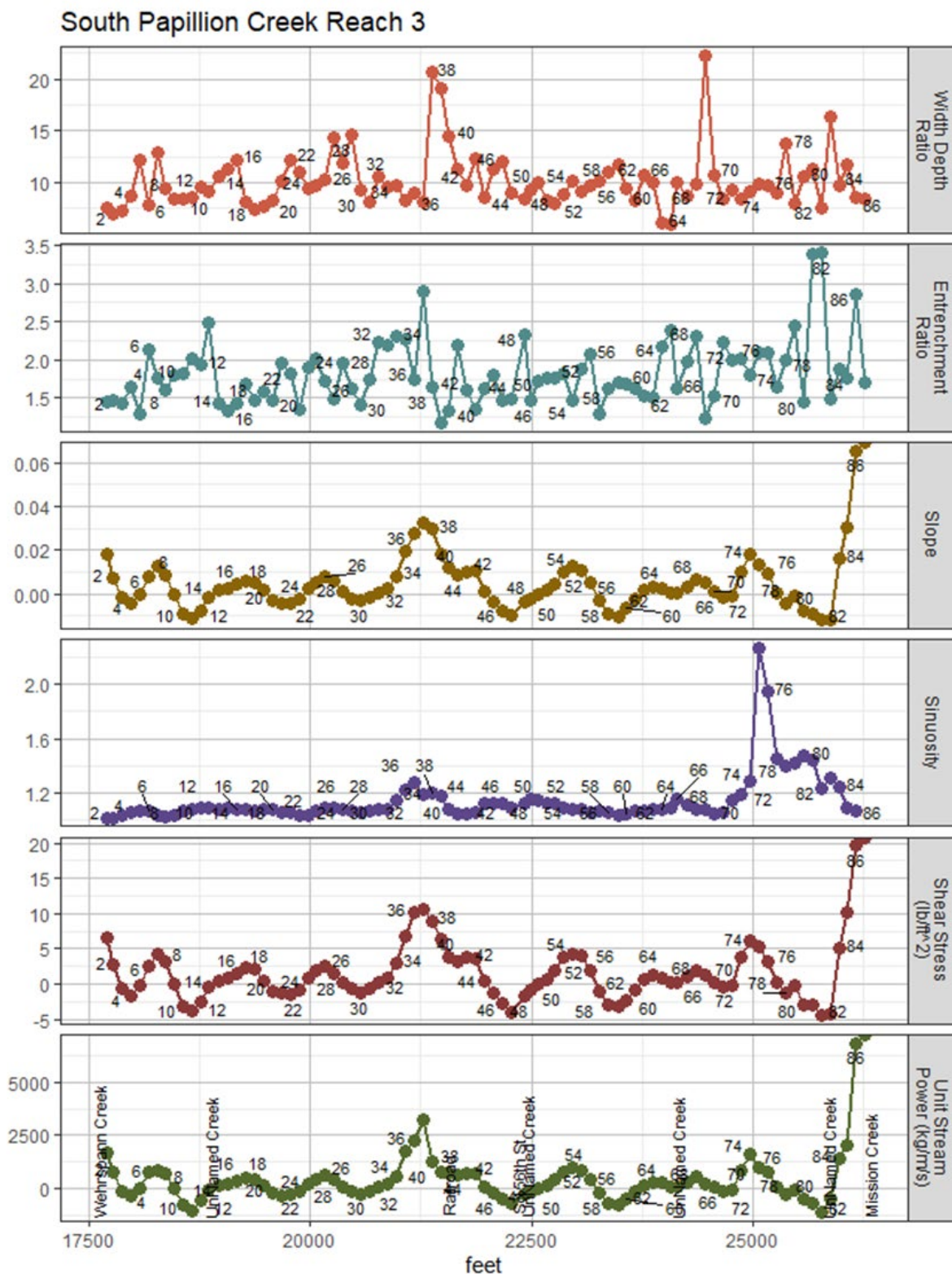
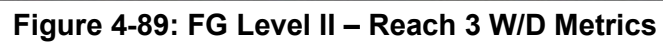


Figure 4-88: FG Level II – Geomorphic Metrics



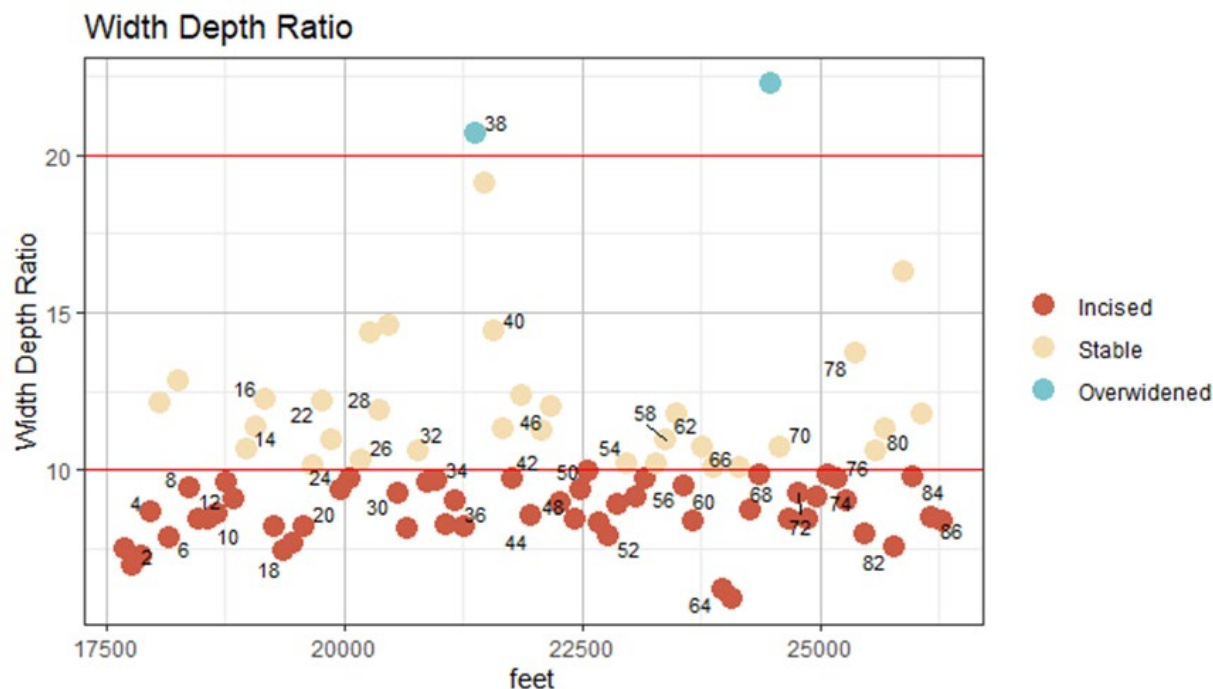


Figure 4-90: FG Level II – Reach 3 W/D Metrics

4.4.2.5 REACH 4: MISSION CREEK TO TIBURON CREEK

Reach 4 - FG Level I Analysis:

The Reach 4 site map is illustrated in Figure 4-91 and the LiDAR water surface profiles are plotted in Figure 4-92. The reach has a riparian buffer with meandering pattern as it intersects the South 168th Street and Railroad Bridges. The reach has a stable streambed based on the profile (Figure 4-92); however, based on the cross-sectional analysis (Figures 4-93 to 4-96), much of the reach is experiencing local bank erosion. The profile comparison shows little or no change between the 2004 and 2016 water surface profiles.

Based on the water surface profile and aerial photo investigation, there are four GCSs in the reach (Figures 4-91 and 4-92, red circles). There is one at the South 156th Street Bridge, two just downstream of the Railroad Bridge, and one at Briar Street. The structures were installed prior to the 2004 LiDAR.

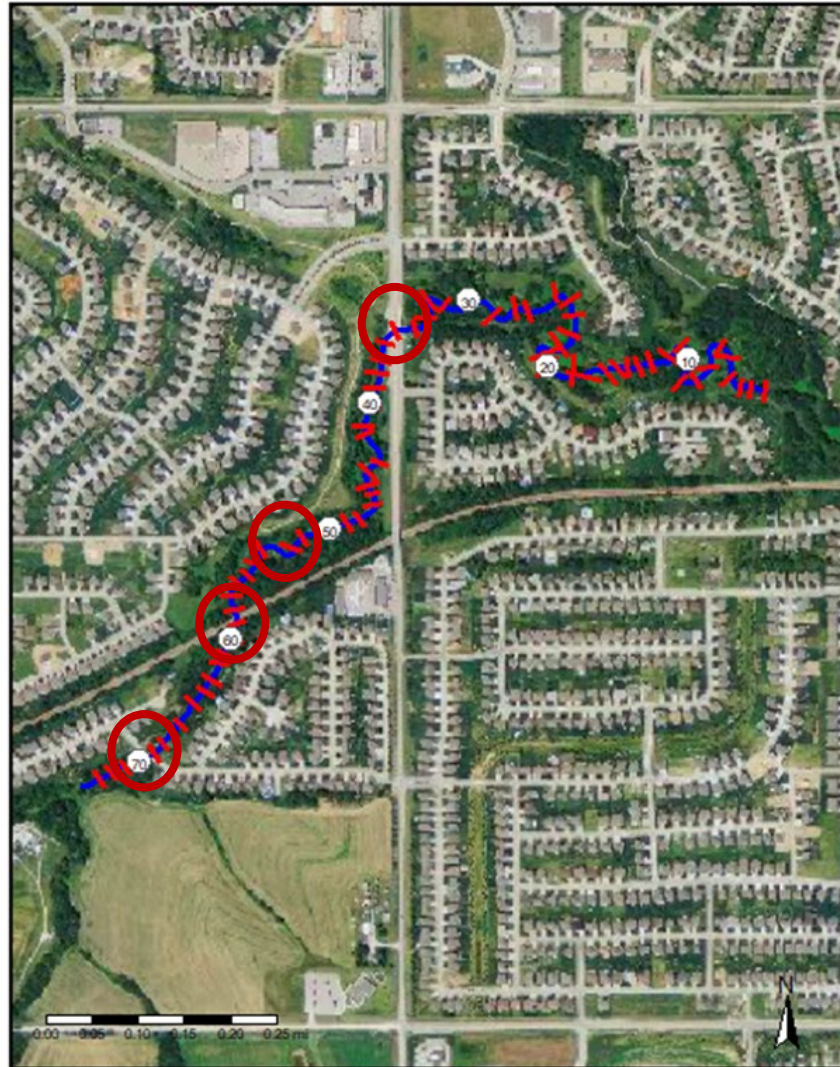


Figure 4-91: South Papillion Creek Reach 4 – Cross-section Location Map

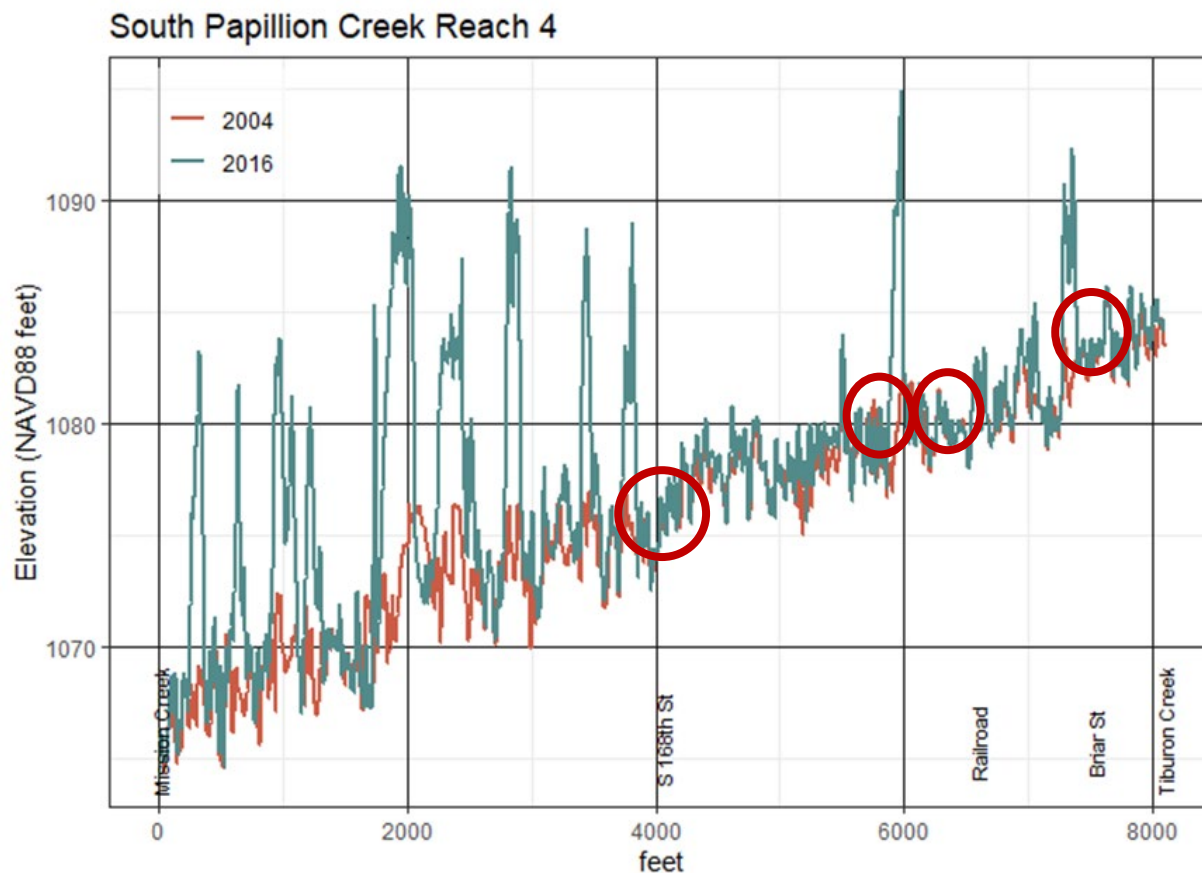


Figure 4-92: FG Level 1, Reach 4 – LiDAR Water Surface Profiles

There is a significant amount of local channel erosion in the reach. Local streambank erosion is occurring, specifically downstream of the South 168th Street Bridge, where there was a channel cutoff that occurred between 2006 and 2009. The channel downstream of the bridge has very tight meander bends and would be difficult to stabilize based on the tortuous stream meanders.

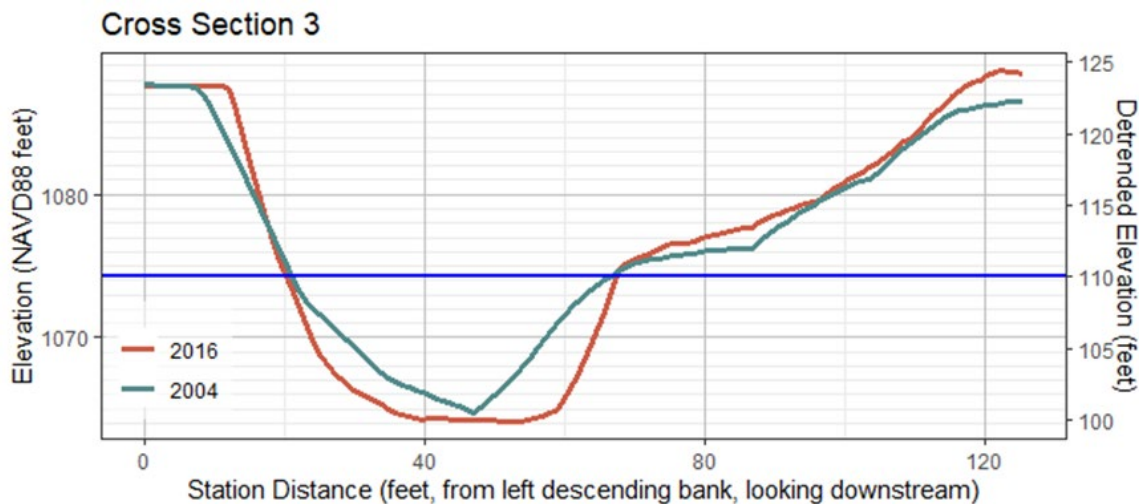
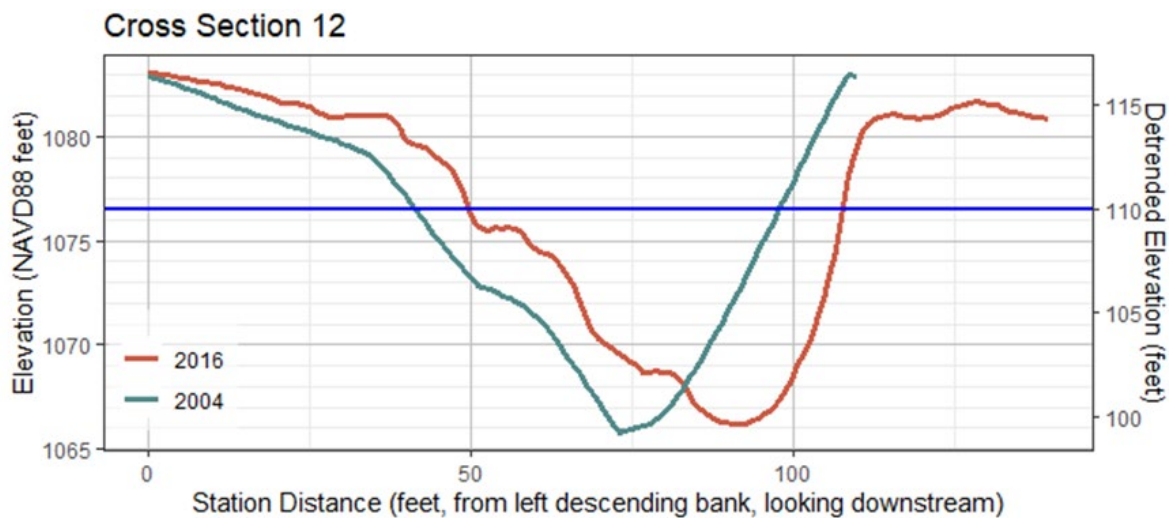
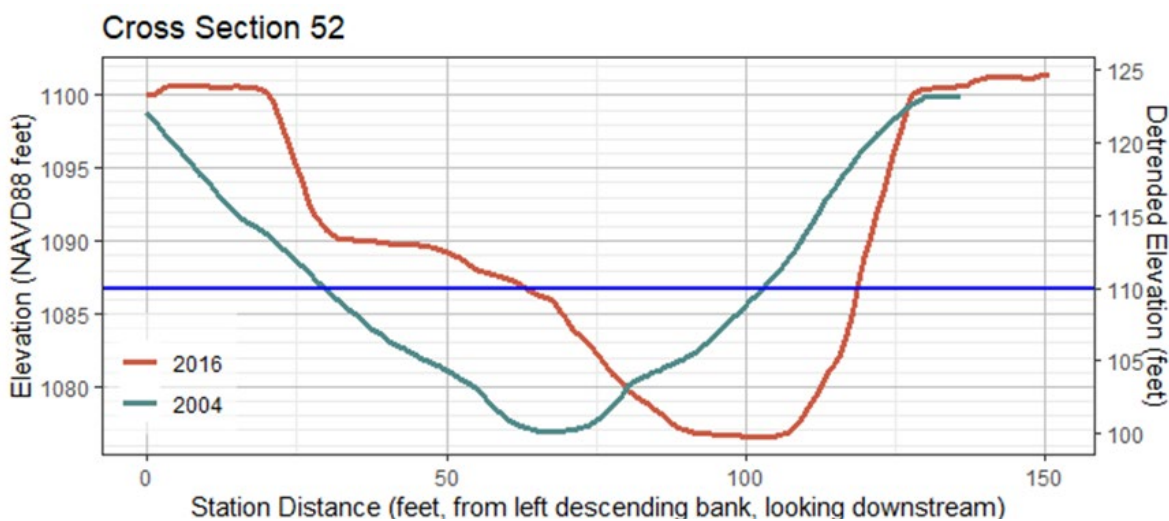
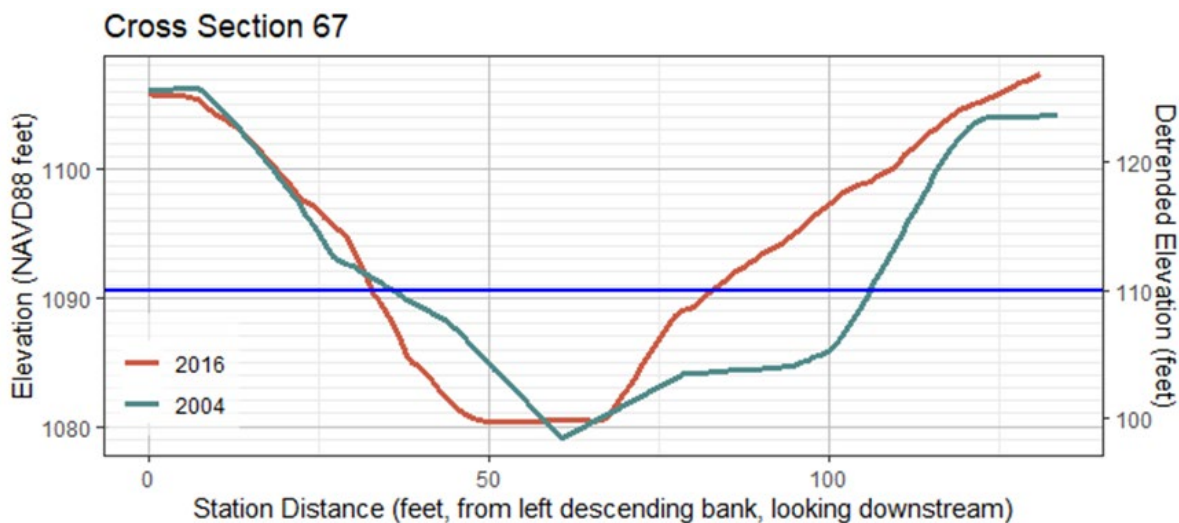


Figure 4-93: Reach 4 – Cross-section Depicting a Relatively Stable Bank

**Figure 4-94: Reach 4 – Cross-section Illustrating Channel Migration****Figure 4-95: Reach 4 – Cross-section Illustrating Channel Migration****Figure 4-96: Reach 4 – Cross-section Illustrating Channel Migration**

Reach 4 Summary:

Based on the FG Level 1 analysis:

- Based on the slope analysis, Reach 4 appears to be in a CEM stage IV and possibly early-stage V. The streambed is stable and there is local bank erosion. New floodplain berms are forming in much of the reach showing a trend of stabilization (Figures 4-93 and 4-95).
- There is widespread streambank erosion occurring in the reach. The bank erosion is exacerbated by the presence of a tortuous meandering pattern through the downstream section. Stabilization of bank erosion sites will likely require floodplain reconnection and channel re-meandering or realignment.
- There are four GCSs in the reach: one approximately at the South 168th Street Bridge, two immediately downstream of the Railroad Bridge, and one at Briar Street. These structures are providing bed stability to the reach. This structure should be monitored for maintaining the channel slope.
- Part of the South Papillion Creek restoration and stabilization plan will likely be enhancing the GCSs throughout the watershed; that will include closer examination of this reach and its stable trend.
- Level II analysis was completed on this reach and compiled in the next section.

Reach 4-FG Level II Analysis:

The geomorphic metrics for Reach 4 are plotted in Figure 4-97. The W/D metrics are spatially shown in Figure 4-98 and plotted in Figure 4-99.

- The W/D and ER show locations where the channel is incised and has limited access to an active floodplain (Figure 4-97). Most of the W/D ratios are below 12 and the ER trends in the downstream section of the reach are very low (<1.25).
- There are no W/Ds greater than 20 so there is likely no issue with sediment transport and deposition within the active channel.
- The ERs in the reach have a wide range of values showing variability in floodplain access. The lower reach ERs should be targeted to investigate further as these are the locations where the floodplain connections and access are low.
- There are higher sinuosity values in the lower section of the reach matching with the meandering channel pattern of upper Reach 3. Overall, there is much more variability in the channel meandering within this reach than the reaches downstream.
- Shear stress and USP are consistent through the reach with one exception; they are elevated in the cross-section downstream of the South 168th Bridge GCS structure, based on the steep slope.
- The GCS is providing bed degradation protection and the lower banks are stabilizing. The channel slope is consistent through the reach at 0.0024 ft/ft.
- The channel bed appears to be stable but there is widespread bank erosion as the channel continues to adjust. These conclusions should be field-validated.

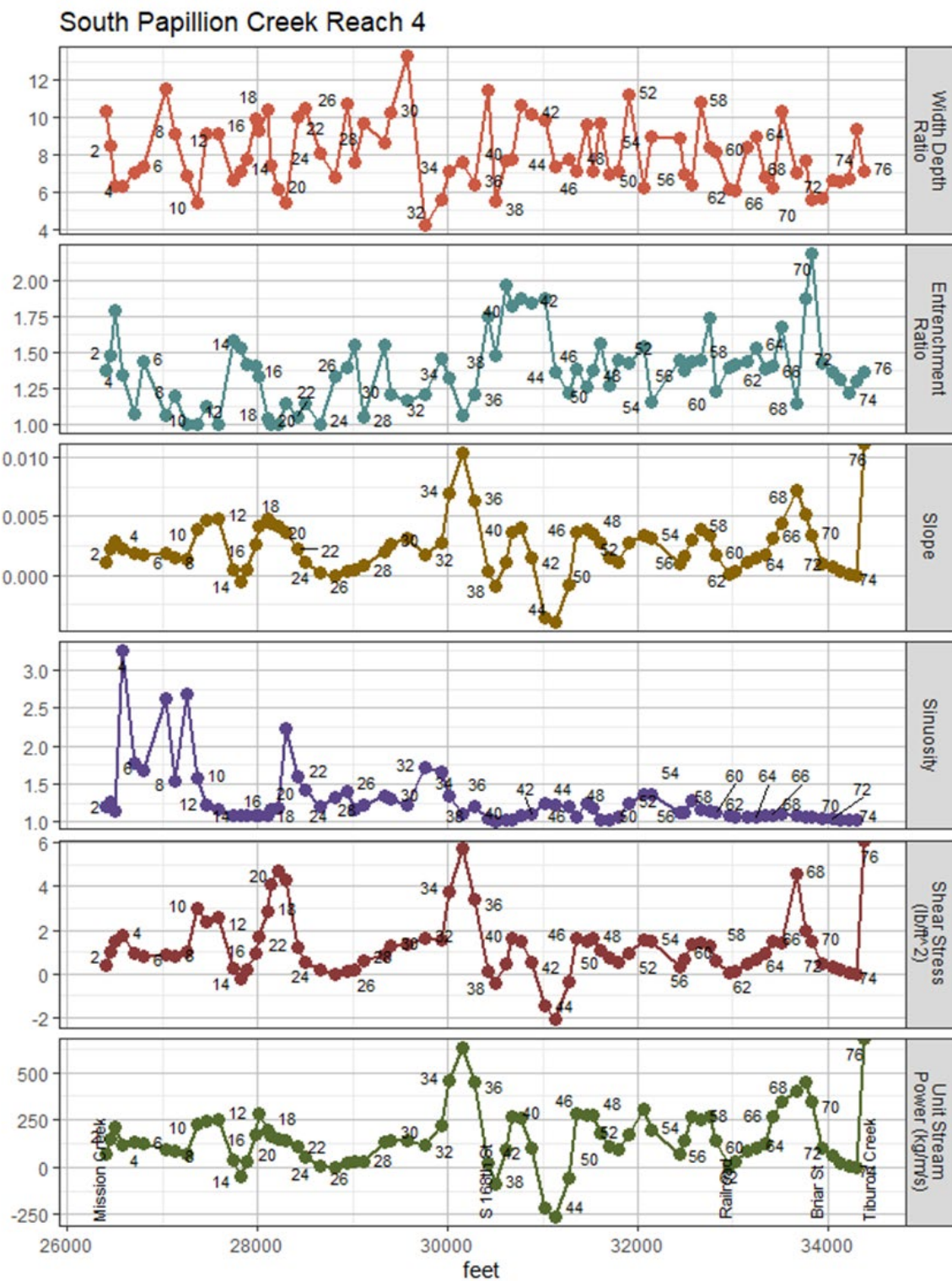


Figure 4-97: FG Level II – Geomorphic Metrics

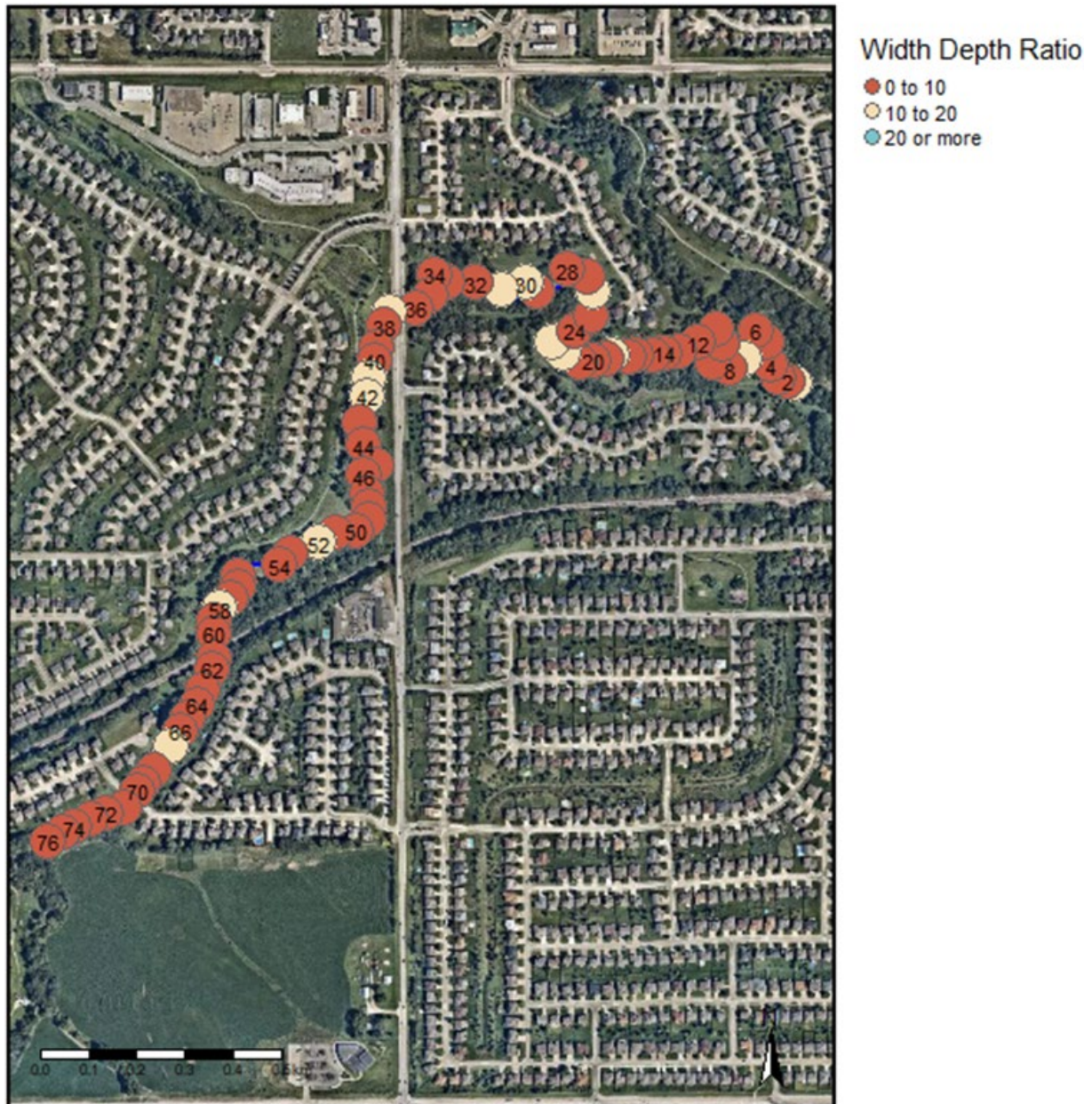


Figure 4-98: FG Level II – Reach 4 W/D Metrics

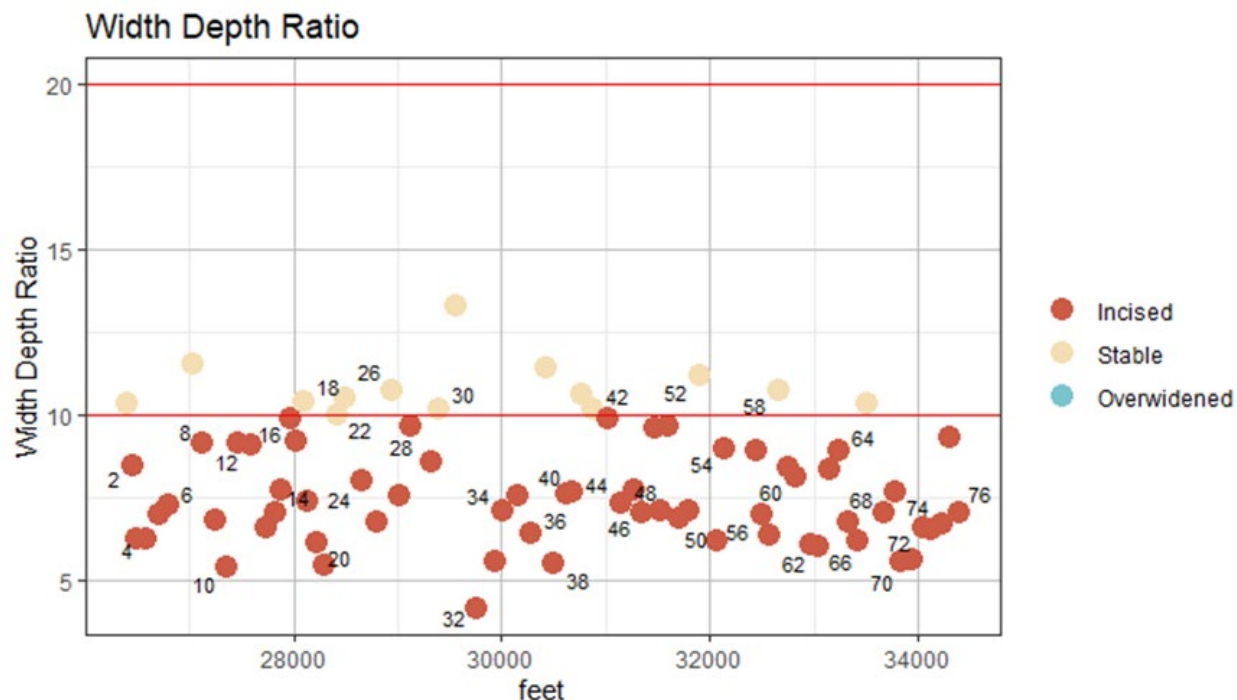


Figure 4-99: FG Level II – Reach 4 W/D Metrics

4.4.2.6 REACH 5: TIBURON CREEK TO BEADLE CREEK

Reach 5 - FG Level I Analysis:

The Reach 5 site map is illustrated in Figure 4-100 and the LiDAR water surface profiles are plotted in Figure 4-101. The reach has straightened, entrenched sections with some minor meandering as it intersects the Railroad Bridge. Bank heights range from approximately 15 to 20 feet downstream of the Railroad Bridge to 25-to-30 feet upstream. Based on the slope profile trends, the streambed has degraded slightly in the range of one to two feet between 2004 and 2016 (Figure 4-101). Based on the profiles and aerial photo investigation, there is one GCS in the reach (Figures 4-100 and 4-101, red circle), at the Railroad Bridge. The structure appears to have been constructed prior to the 2004 LiDAR. It is approximately four feet high. The cross-sectional analysis (Figures 4-102 to 4-105) shows much of the reach is experiencing local bank erosion.

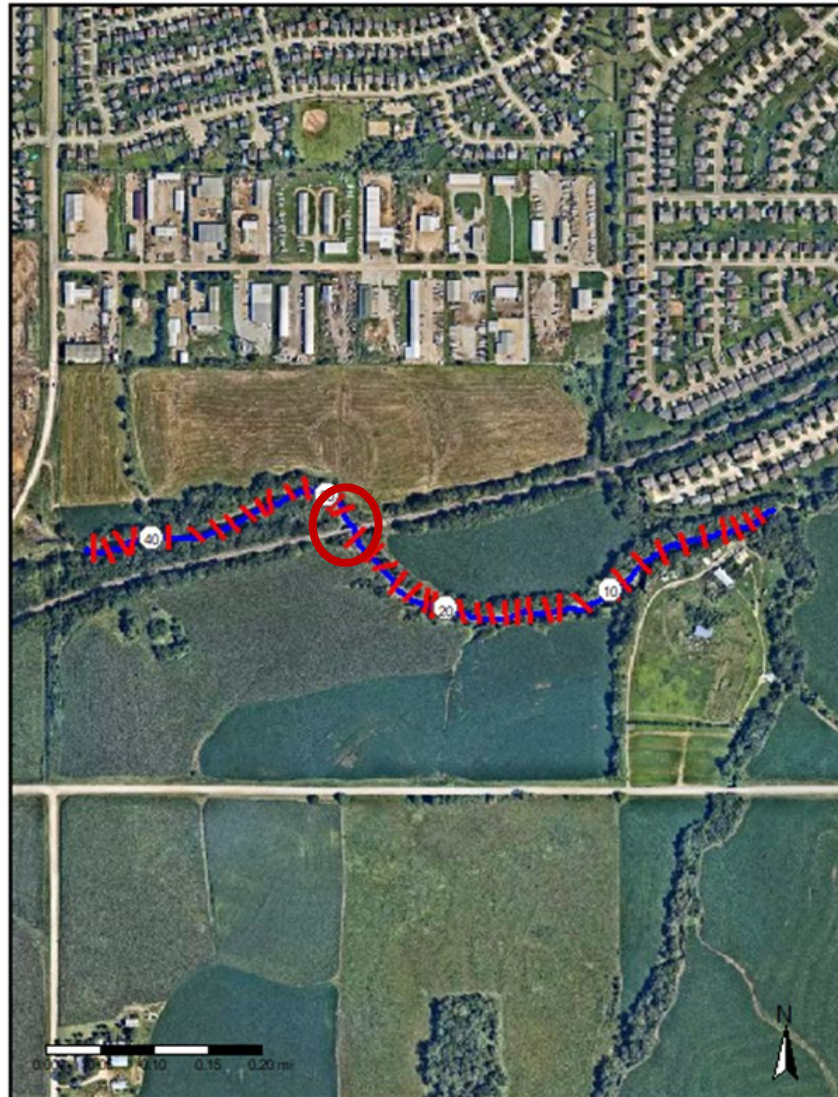


Figure 4-100: South Papillion Creek Reach 5 – Cross-section Location Map

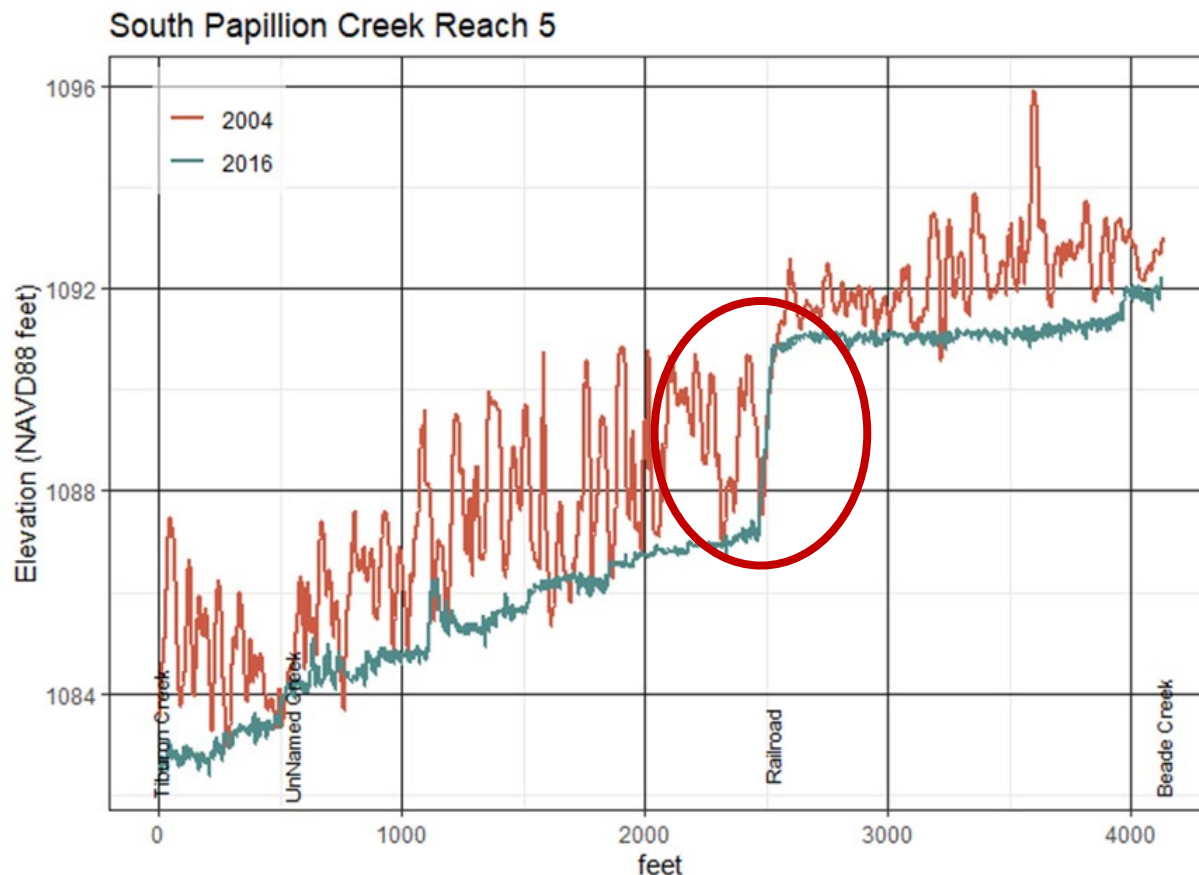


Figure 4-101: FG Level 1, Reach 5 – LiDAR Water Surface Profiles

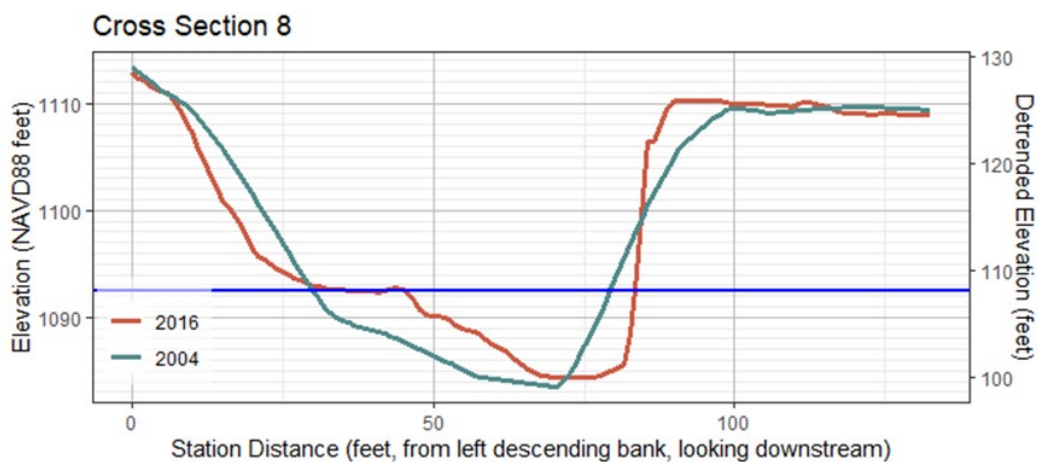


Figure 4-102: Reach 5 – Cross-section with Right Bank Erosion and Left Bank Deposition

The water surface profile within the reach below the GCS is 0.0018 ft/ft. Upstream of the GCS the channel slope is much flatter at 0.0009 ft/ft. The channel is likely continuing to adjust to channel bed lowering as there is a significant amount of streambank erosion. The reach is showing signs of stabilizing with the building of active floodplain berms in Figures 4-102 through 4-105.

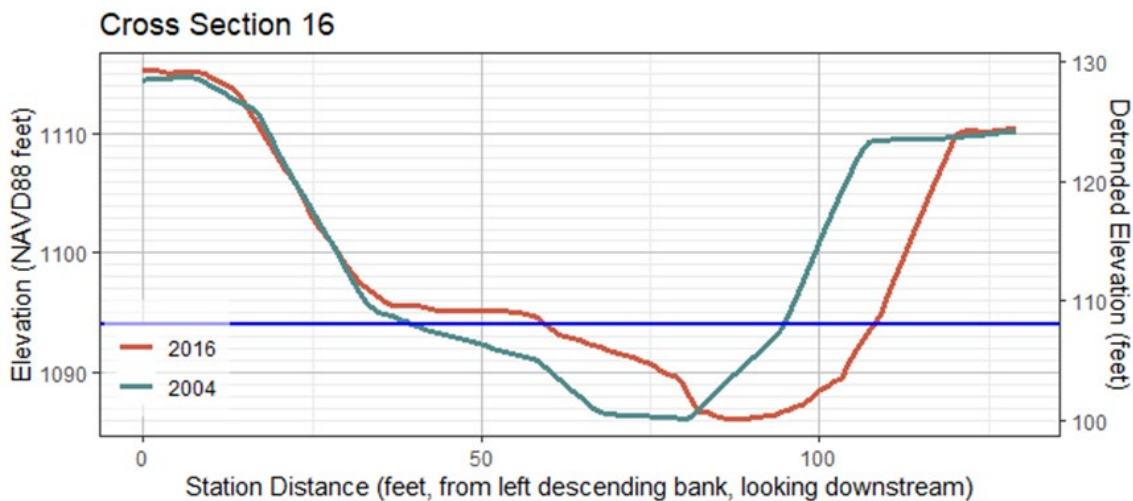


Figure 4-103: Reach 5 – Cross-section with Right Bank Erosion and Left Bank Disposition

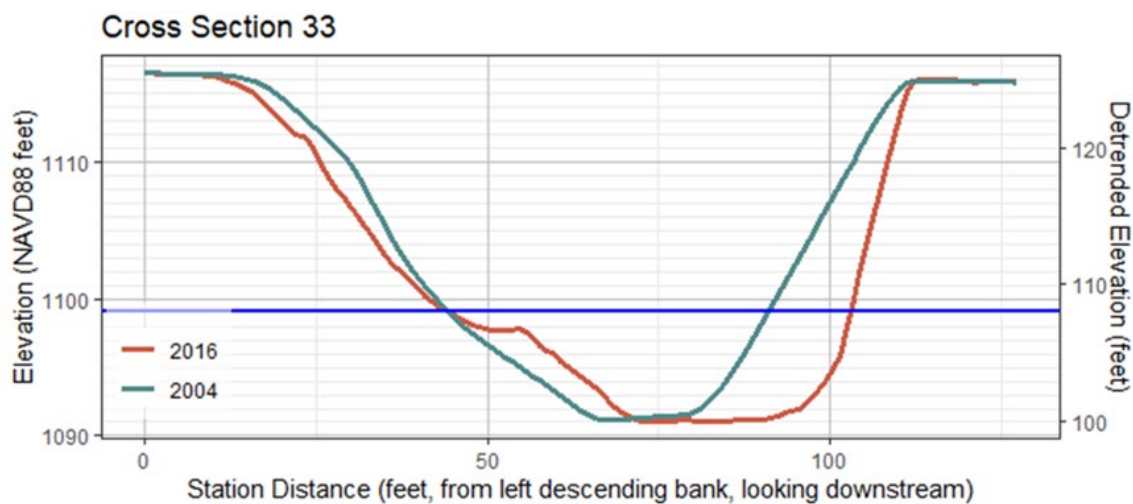


Figure 4-104: Reach 5 – Cross-section Illustrating Right Bank Erosion

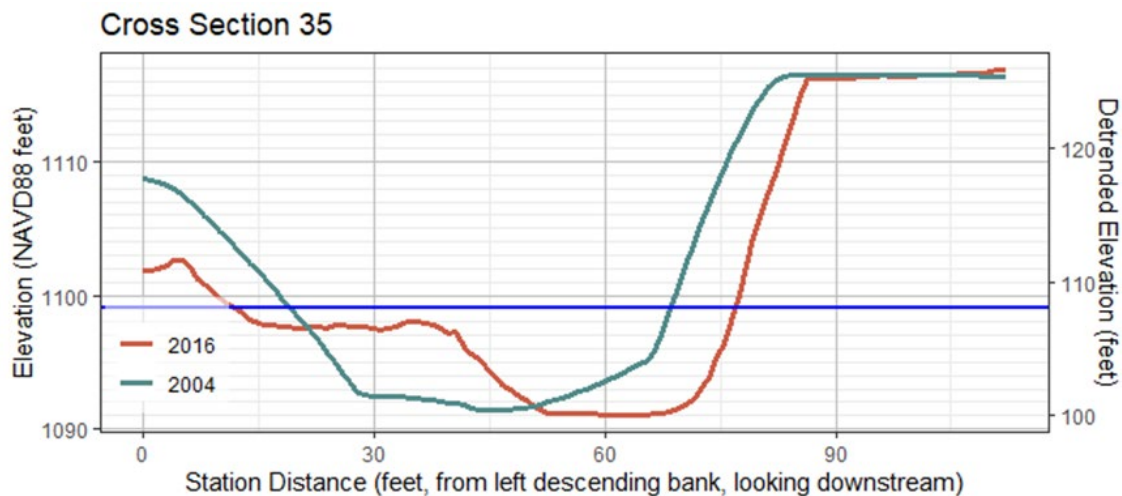


Figure 4-105: Reach 5 – Cross-section with Right Bank Migrations with Left Bank Berm Forming

Reach 5 Summary:

Based on the FG Level 1 analysis:

- Based on the slope analysis, Reach 5 appears to be in an early CEM Stage V. The streambed has recently transitioned to being relatively stable, but there is local bank erosion. New floodplain berms are forming in much of the reach showing a trend of stabilization (Figures 4-102 to 4-105).
- There is widespread streambank erosion occurring in the reach. Stabilization of bank erosion sites will likely require local treatments or more of a reach-wide floodplain reconnection and channel re-meandering project.
- There is one GCS at the Railroad Bridge. The structure is providing much needed bed stability to the reach. This structure should be monitored for maintaining the channel slope.
- Part of the South Papillion Creek restoration and stabilization plan will likely be enhancing the GCSs throughout the watershed; that will include closer examination of this reach and its stable trend.
- Level II analysis was completed on this reach and compiled in the next section.

Reach 5-FG Level II Analysis:

The geomorphic metrics for Reach 5 are plotted in Figure 4-106. The W/D metrics are spatially shown in Figure 4-107 and plotted in Figure 4-108.

- The W/D and ER show locations where the channel is incised and has limited access to an active floodplain (Figure 4-106). All but four of the reach W/D ratios are below 12 and the ER trends in the upstream section are mostly below 1.6.
- The lower ERs should be targeted to investigate further as these are the locations where the floodplain connections and access are low. The ERs downstream of the Railroad Bridge have a broader range of values showing the variability and wider channel cross-sections (>ER).
- The GCS is providing stability to the upstream section of the reach. Water surface slopes are consistent upstream and downstream of the GCS.
- There are higher sinuosity values in the upper section of the reach transitioning into a more meandering channel pattern of Reach 6. Overall, there is not a lot of variability in the channel meandering within this reach.
- Shear stress and USP are consistent through the reach with the exception being in the vicinity of the GCS.
- The GCS is providing bed degradation protection and the lower banks are stabilizing. There is widespread bank erosion as the channel continues to adjust. These conclusions should be field validated.

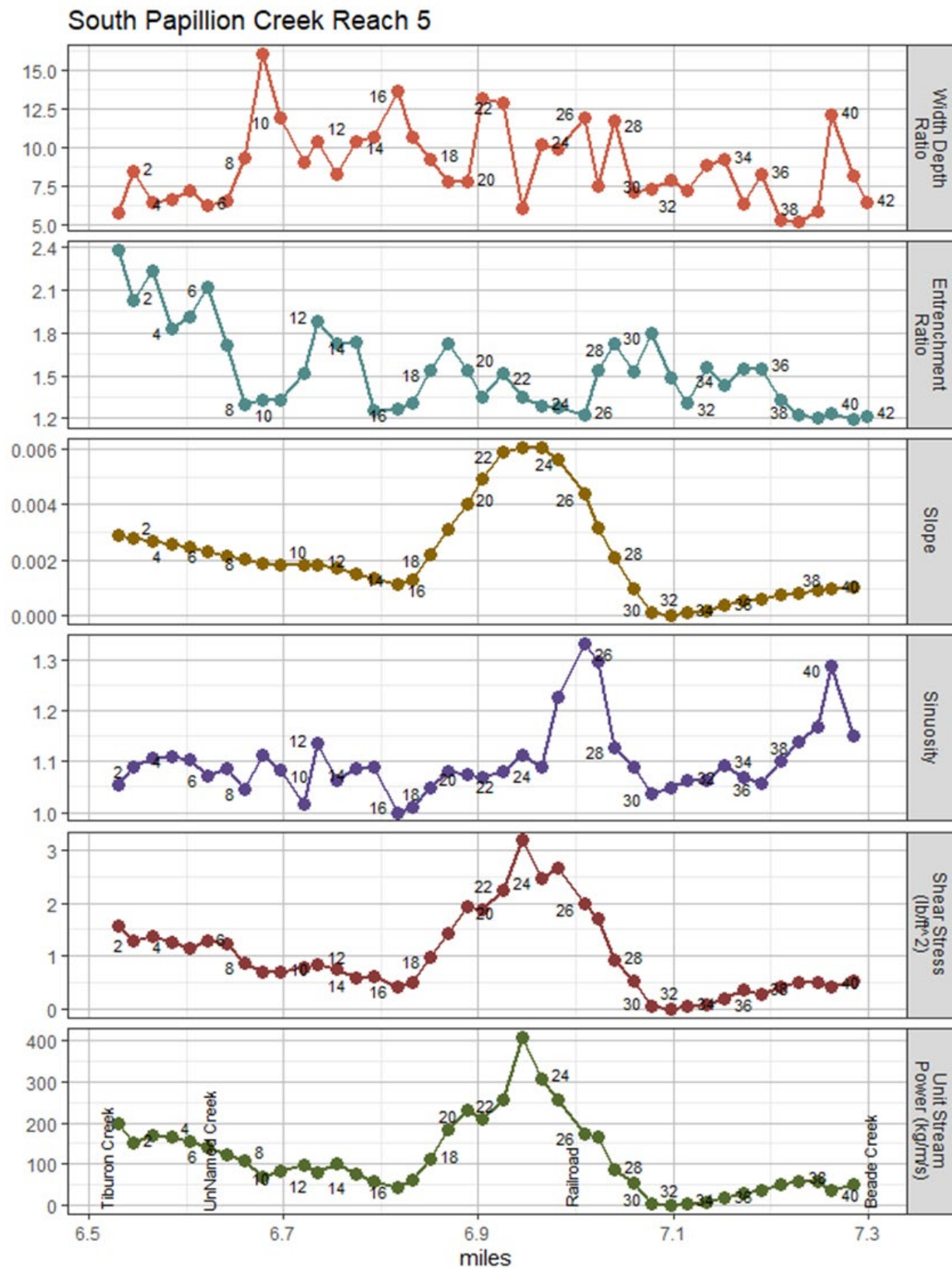


Figure 4-106: FG Level II – Geomorphic Metrics

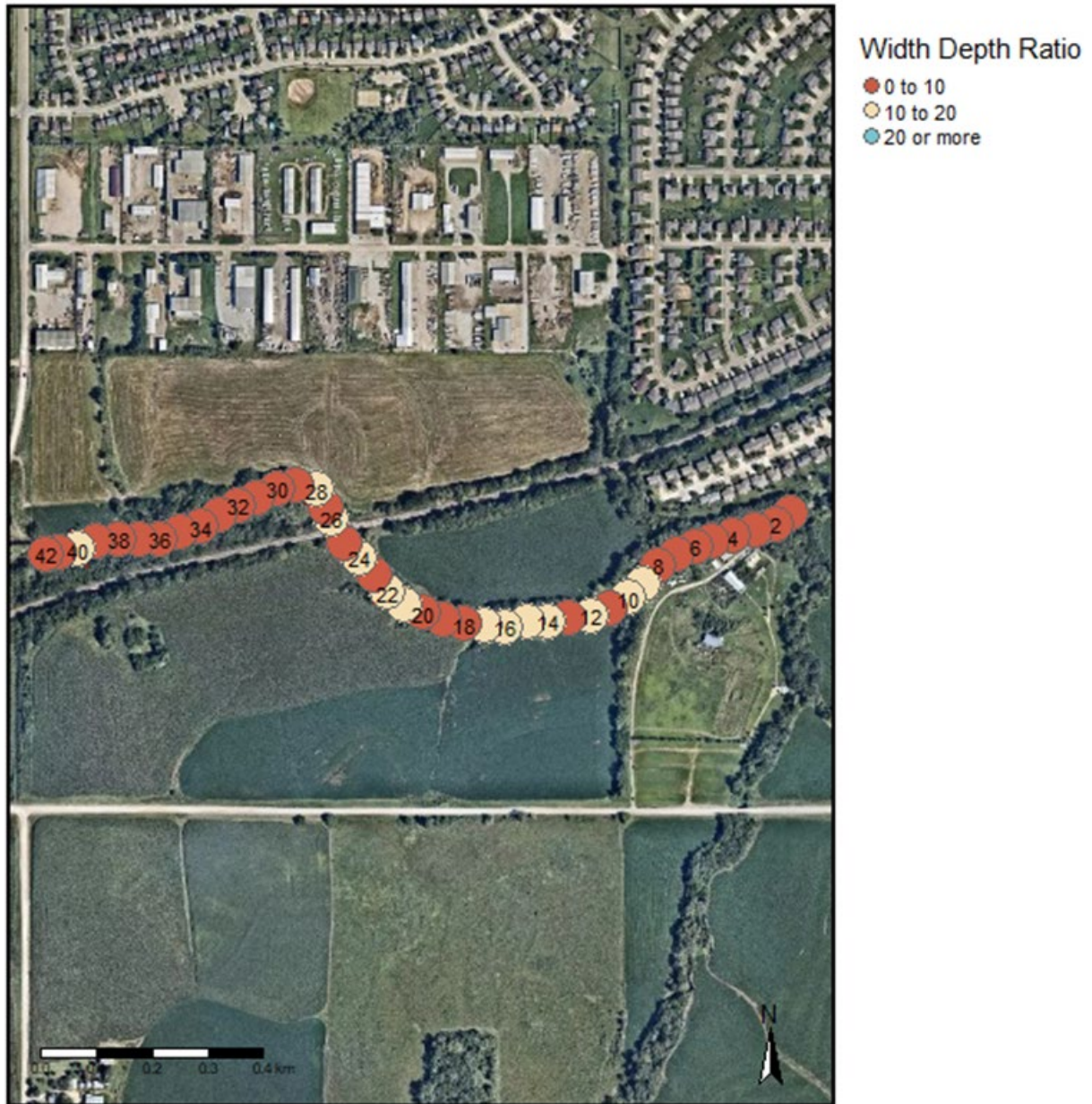


Figure 4-107: FG Level II – Reach 5 W/D Metrics

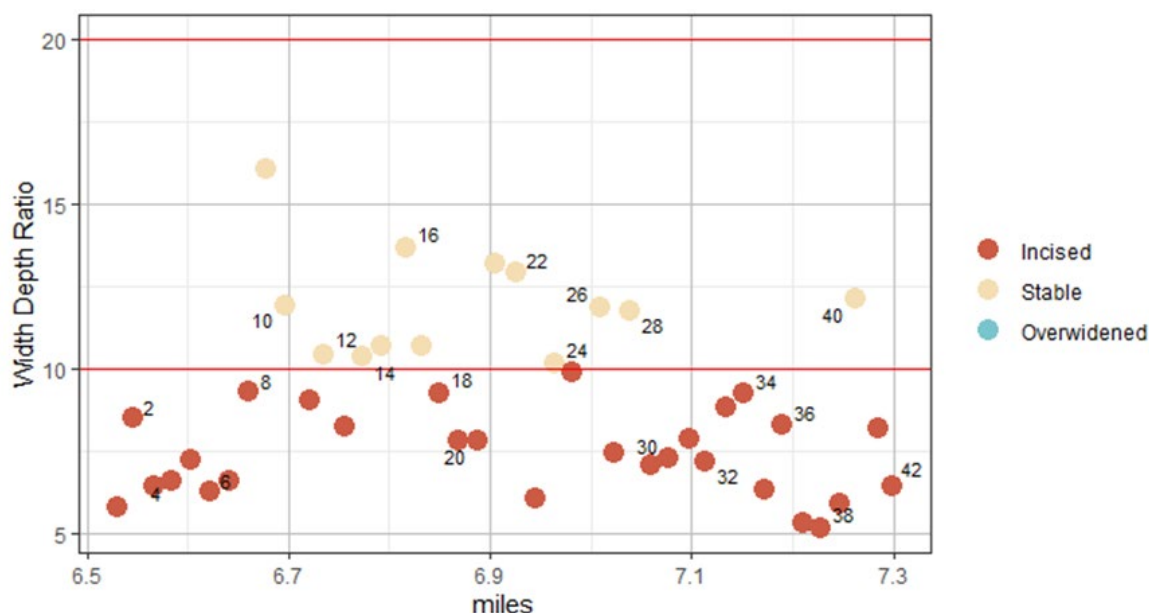


Figure 4-108: FG Level II – Reach 5 W/D Metrics

4.4.2.7 REACH 6: BEADLE CREEK TO CRYSTAL CREEK

Reach 6 - FG Level I Analysis:

The Reach 6 site map is illustrated in Figure 4-109 and the LiDAR water surface profiles are plotted in Figure 4-110. The reach has a meandering pattern with bank heights ranging from approximately 15 to 20 feet downstream of the Giles Road Bridge. The bank heights then transition to approximately eight to 10 feet in the middle of the reach where the channel has filled due to the GCSs, then transitions again in the upper section with incised channel bank heights of 20 to 25 feet.

Based on the slope profile trends, the streambed has maintained a similar profile in its downstream section and has channel fill upstream of Giles Road ranging from one to 3.5 feet. The most upstream section of the reach shows a trend of one to two feet of degradation (Figure 4-110). Based on the profiles and aerial photo investigation, there are a series of at least eight GCSs in the reach (Figures 4-109 and 4-110, red circles).

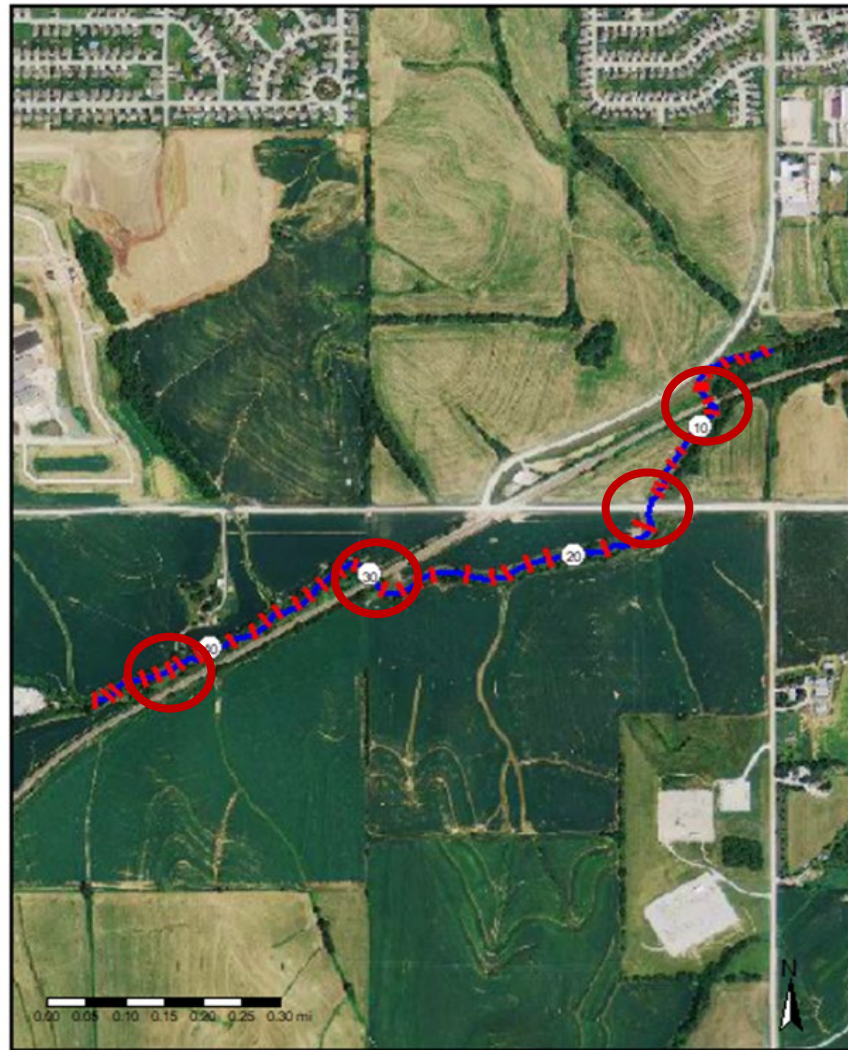


Figure 4-109: South Papillion Creek Reach 6 – Cross-section Location Map

The major structures are located at the Railroad Bridges, Giles Road, and a utility crossing at approximate station 5700. The Giles Road GCS is approximately seven feet high. Upstream of the Giles Road GCS, a series of GCSs appear to have been constructed between 2003 and 2004. This has provided additional bed and bank stability and sediment has infilled the previously incised channel as illustrated in Figures 4-112 and 4-113.

The cross-sectional analysis (Figure 4-111 to 4-118) shows much of the reach is stable with some areas experiencing localized bank erosion. The water surface profile within the reach below the Giles Road Bridge GCS is 0.0039 ft/ft. Upstream of the GCS the channel slope is flatter at 0.0026 ft/ft. The channel upstream of the GCS is adjusting to the bed raising as there is a significant amount of sediment deposited in the previous incised channel. The reach is showing signs of stabilizing with the building of active floodplain berms (Figures 4-111 through 4-114).

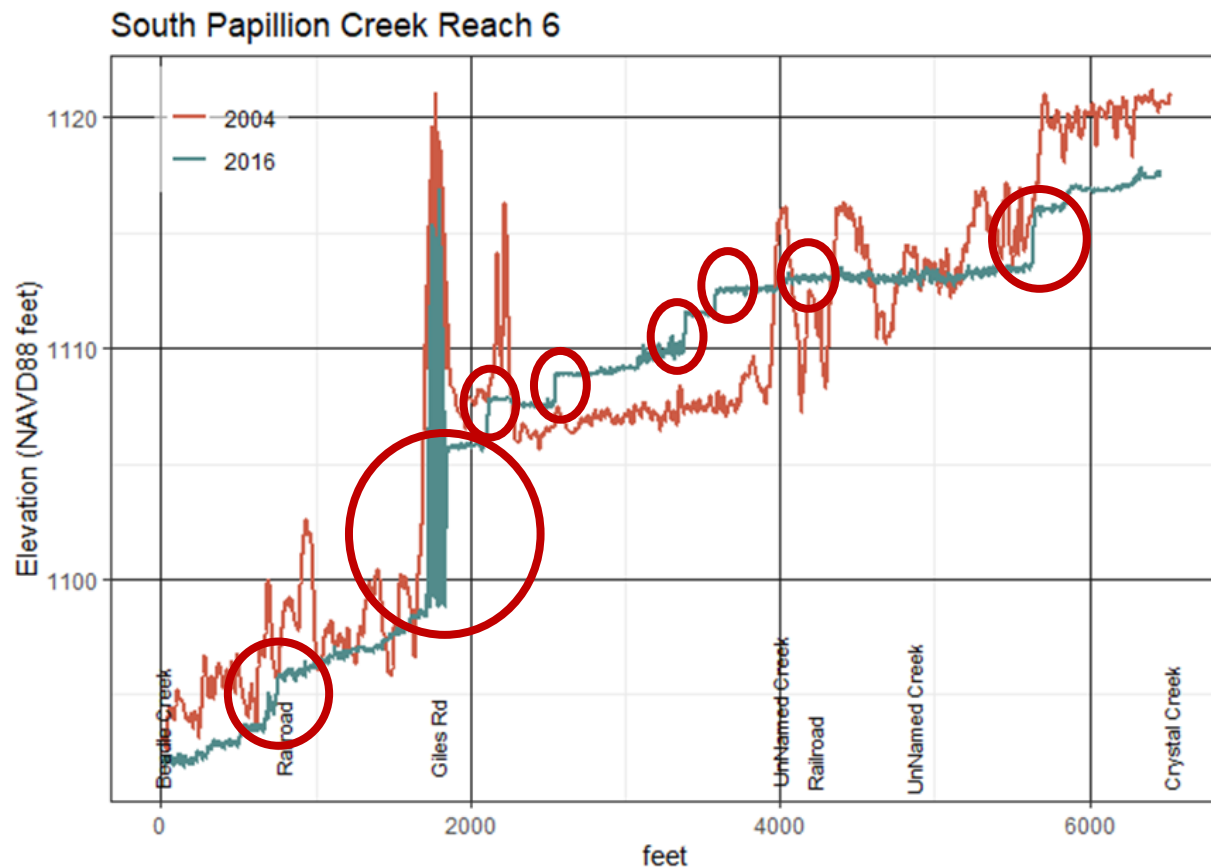


Figure 4-110: FG Level 1-Reach 6 – LiDAR Water Surface Profiles

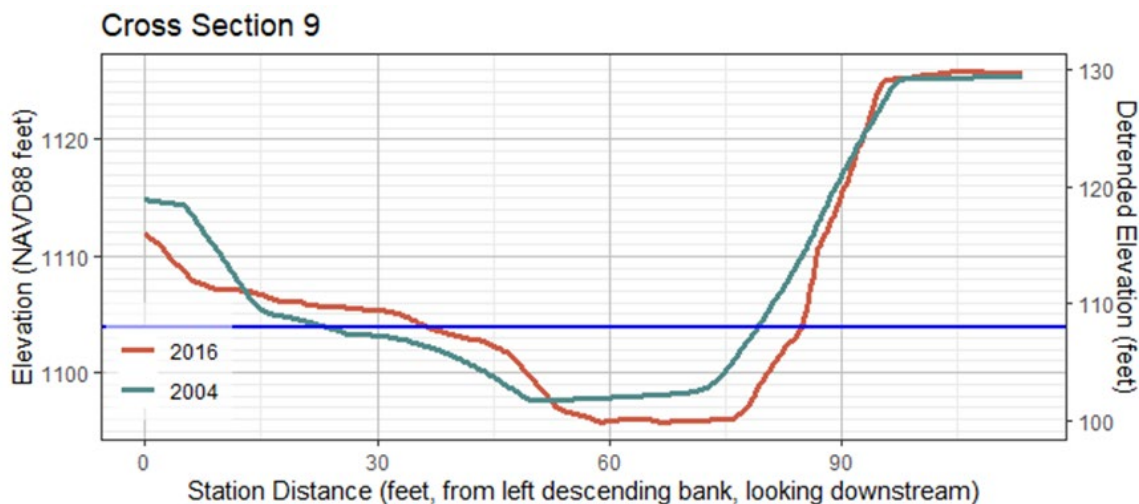


Figure 4-111: Reach 6 – Cross-section Depicting Channel Erosion and Deposition

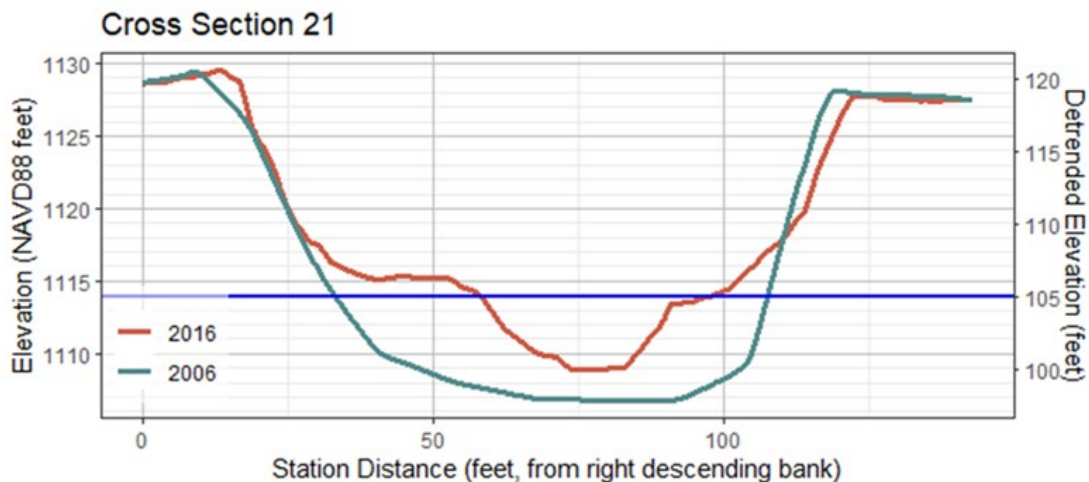


Figure 4-112: Reach 6 – Cross-section with Channel Fill and Floodplain Development

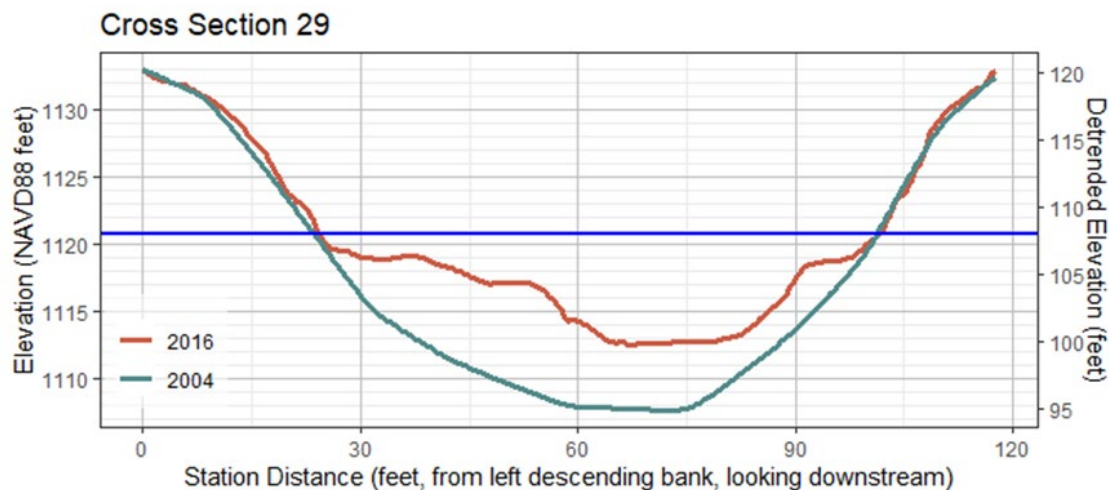


Figure 4-113: Reach 6 – Cross-section with Channel Fill and Floodplain Development

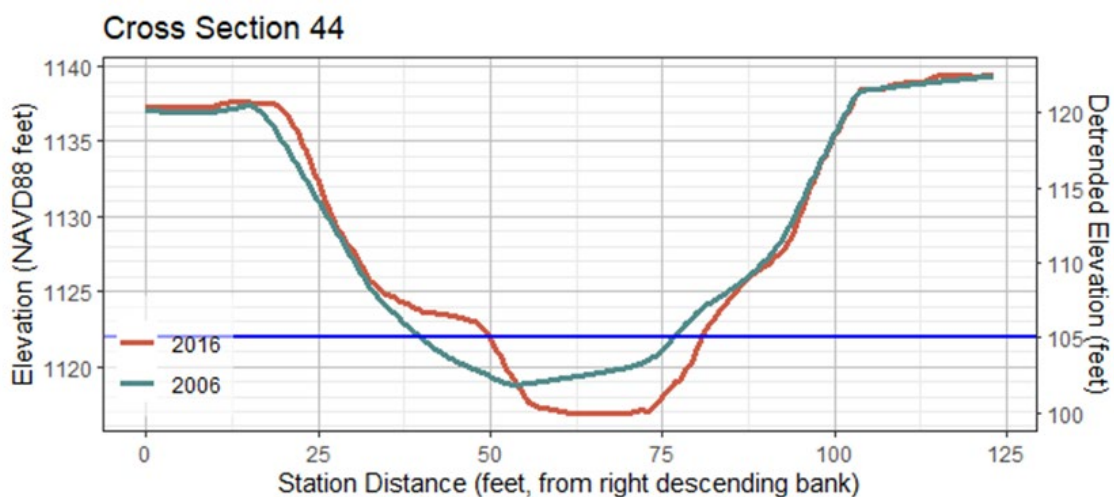


Figure 4-114: Reach 6 – Cross-section Illustrating Bed Changes Between 2004 and 2016

Reach 6 Summary:

Based on the FG Level 1 analysis:

- Based on the slope and cross-section analysis, the lower section of the reach appears to be in a late to early Stage V. The middle section of the reach where the channel has infilled is in a late Stage V to early Stage VI. The upstream section of the reach is likely in a late Stage IV to and early Stage V. This should be validated in the field.
- This is the only reach where we have a new channel forming directly within the old, incised channel with floodplain berms forming, showing a trend of stabilization (Figures 4-112 and 4-113).
- There is local streambank erosion occurring in the reach, some appearing to be located at the GCS. Stabilization of bank erosion sites will likely require local treatments. The pipeline GCS appears to be degraded as the pipeline is exposed in the recent aerial photos.
- The GCSs are providing needed bed stabilization and have also provided bank erosion control protection within the reach.
- Part of the South Papillion Creek restoration and stabilization plan will likely be enhancing the GCSs throughout the watershed; that will include closer examination of this reach and its stable trend.
- Level II analysis was completed on this reach and compiled in the next section.

Reach 6-FG Level II Analysis:

The geomorphic metrics for Reach 6 are plotted in Figure 4-115. The W/D metrics are spatially shown in Figure 4-116 and plotted in Figure 4-117.

- The W/D and ER show locations where the channel is incised and has limited access to an active floodplain (Figure 4-115). The W/D ratios trend low below 12 in the downstream and upstream sections of the reach. The middle of the reach has more variability and higher values. There are high W/D values (>20) that require field validation to determine stable reach conditions.
- Most reach ER's trend below 2.0 with the lowest values in the middle of the reach. The lower ERs should be targeted to investigate further as these are the locations where the floodplain connections and access maybe low. The ERs downstream of the Giles Road Bridge have a broader range of values showing the variability and wider channel cross-sections.
- The GCSs are providing stability to the reach. The channel slope is steepest downstream of the Giles Road Bridge at 0.0039 ft/ft and 0.0026 ft/ft upstream.
- As shown in Figure 4-115, Sinuosity is higher downstream of the Giles Road culverts. This is likely caused by channel planform change through the structures.
- Higher shear stress and USP values indicate the location of the larger GCS within the reach.
- The GCSs are providing bed degradation protection and the lower banks are stabilizing and building a new floodplain within the middle section of the reach. There is minor bank erosion as the channel continues to adjust and notably in the vicinity of the GCSs.

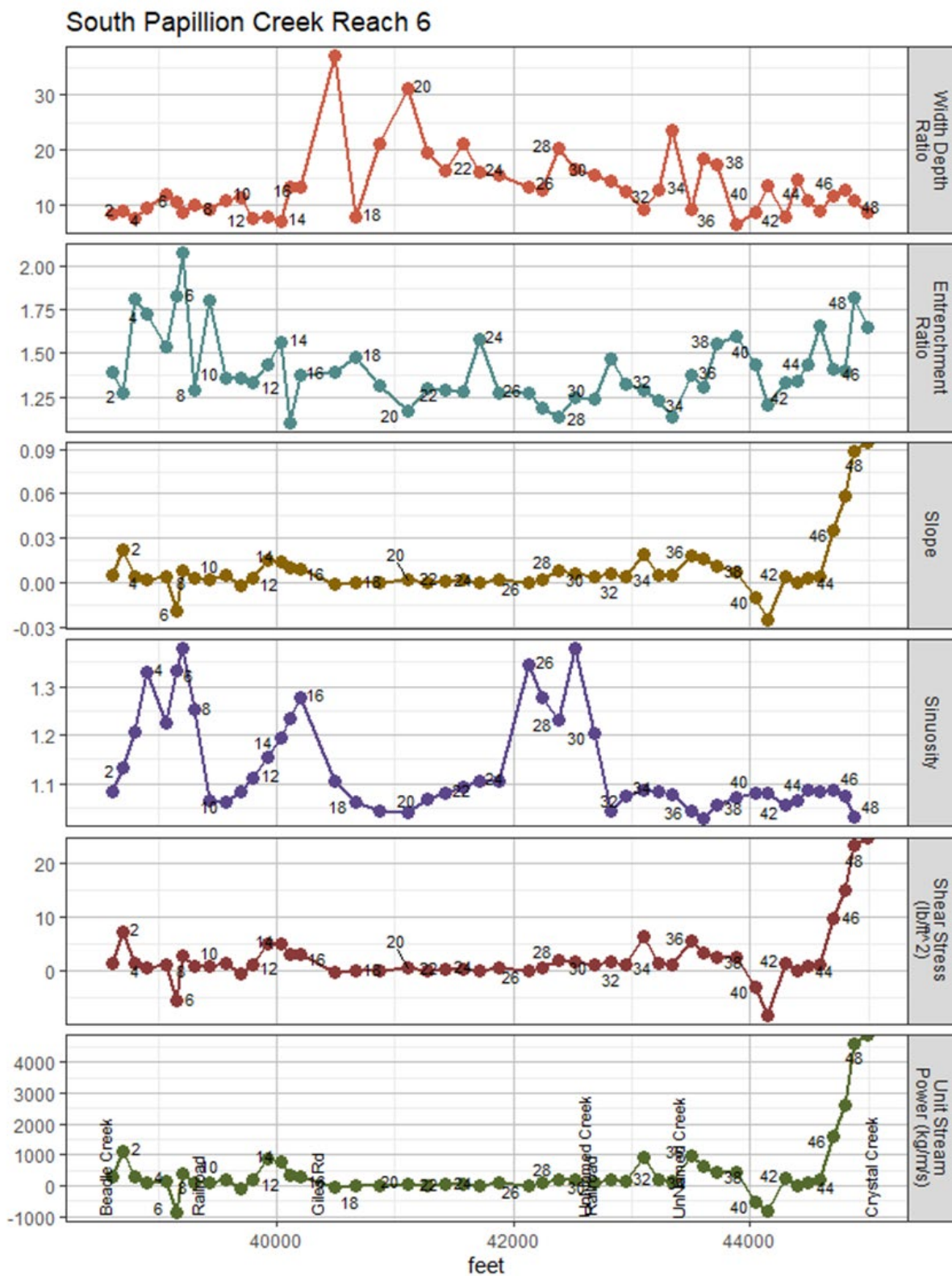


Figure 4-115: FG Level II – Geomorphic Metrics



Figure 4-116: FG Level II – Reach 6 W/D Metrics

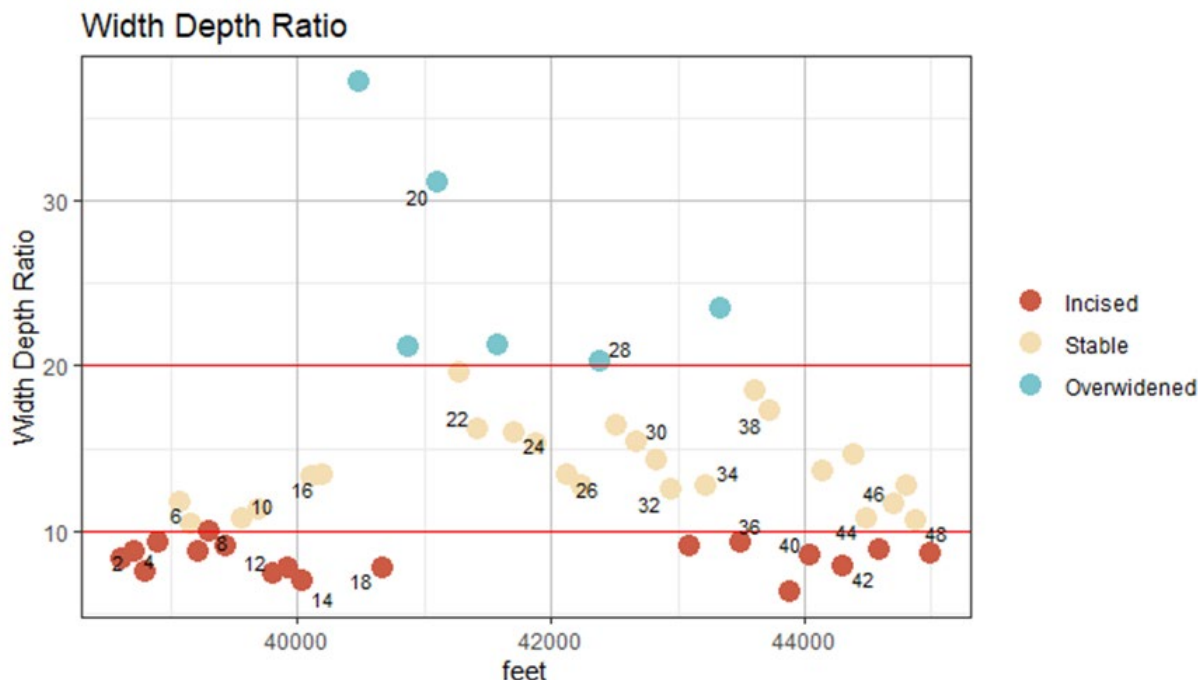


Figure 4-117: FG Level II – Reach 6 W/D Metrics

4.4.2.8 REACH 7: CRYSTAL CREEK TO HIGHWAY 6

Reach 7 - FG Level I Analysis:

The Reach 7 site map is illustrated in Figure 4-118 and the LiDAR water surface profiles are plotted in Figure 4-119. The reach has a meandering pattern with bank heights ranging from approximately 15 to 20 feet downstream of cross-section 20 (culvert location). Upstream of cross-section 20 the bank heights range from eight to 12 feet. This change in bank height is likely a remnant from channel incision working from the downstream to the upstream then encountering the culvert that effectively stopped the channel degradation and widening.

Based on the slope profile trends, the streambed has maintained a similar profile throughout the reach. Based on the profiles and aerial photo investigation, there are a series of at least five GCSs in the reach (Figures 4-118 and 4-119, red circles). There appears to be some resistant bed/bank materials upstream of the Highway 10 Bridge between GSCs (Figure 4-119, green circle). This section of the reach requires further investigation.

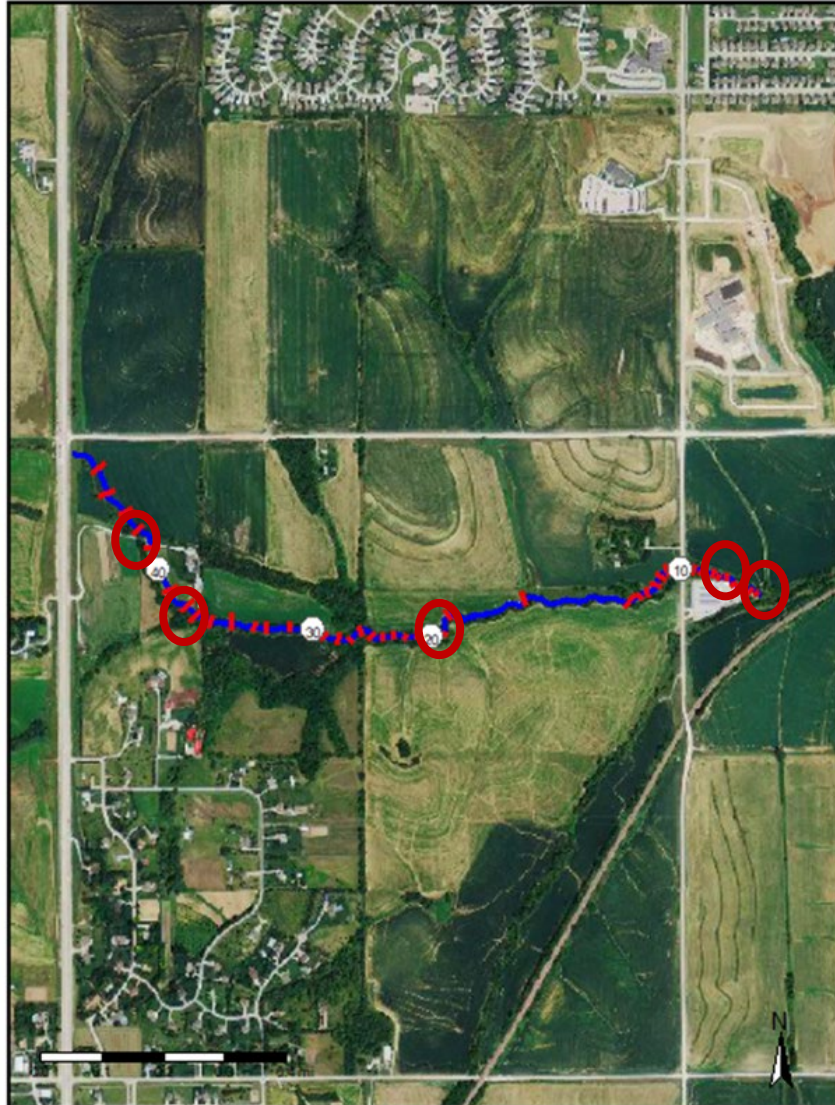


Figure 4-118: South Papillion Creek Reach 7 – Cross-section Location Map

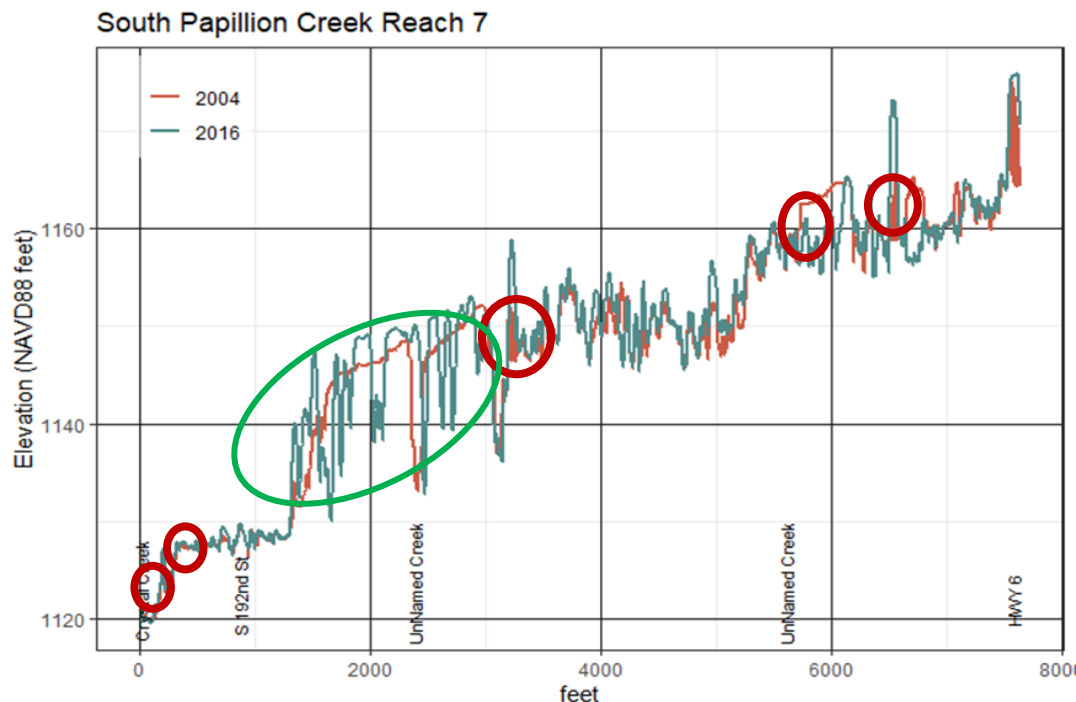


Figure 4-119: FG Level 1-Reach 7 – LiDAR Water Surface Profiles

The major GCSs from downstream to upstream are two loose-rock GCSs, a farm crossing culvert, a riffle in channel (riprap?), and a driveway culvert. There is approximately 21 feet of drop in the channel between the GCSs at the downstream end and the farm crossing culvert in the middle of the reach. The slope for that section of the reach is 0.0067 ft/ft. Upstream of the farm crossing culvert the slope is 0.0033 ft/ft.

The cross-sectional analysis (Figures 4-120 to 4-123) shows much of the reach is stable with some areas experiencing localized bank erosion (Figure 4-122). The reach is showing signs of stabilizing with the building of active floodplain berms (Figures 4-121 to 4-122).

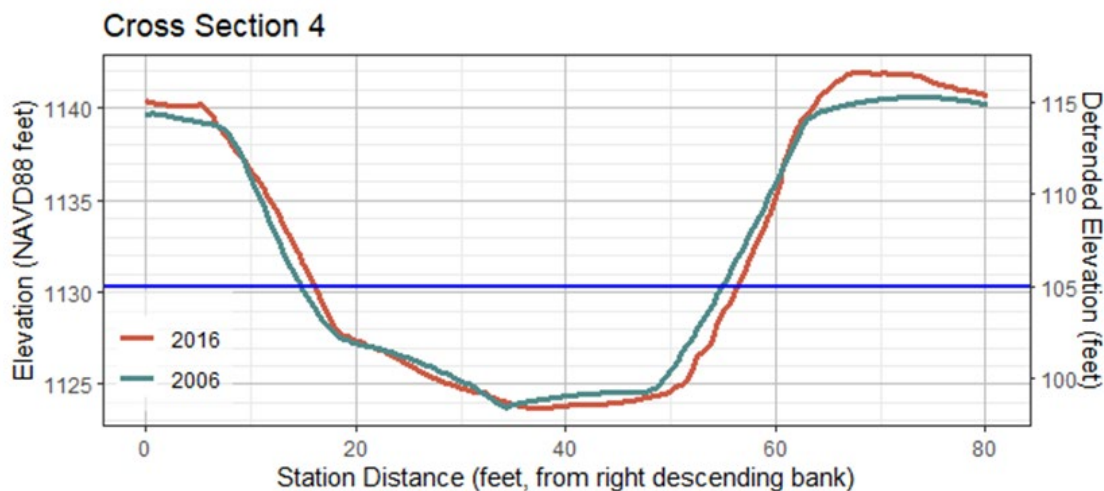


Figure 4-120: Reach 7 – Cross-section Depicting Relatively Stable Banks

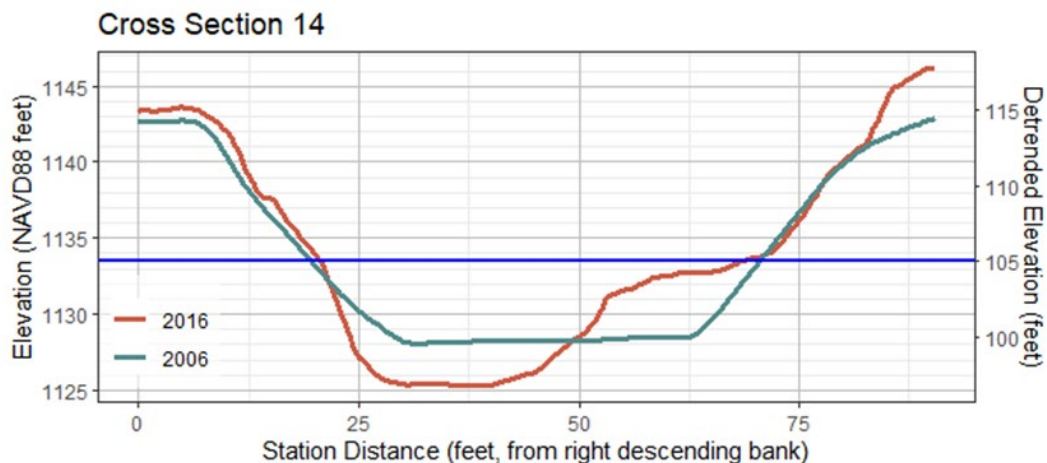


Figure 4-121: Reach 7 – Cross-section Showing Right Bank Berm Deposition

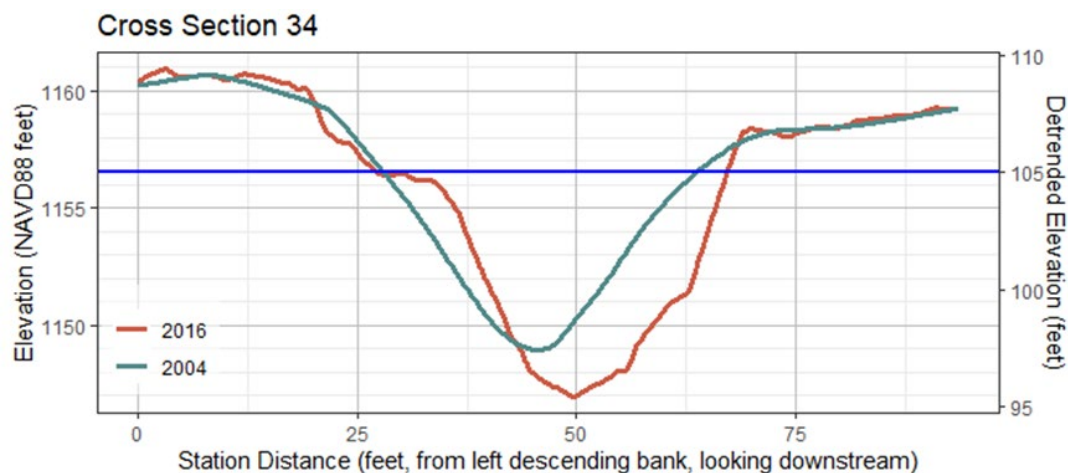


Figure 4-122: Reach 7 – Cross-section Depicting Right Bank Erosion

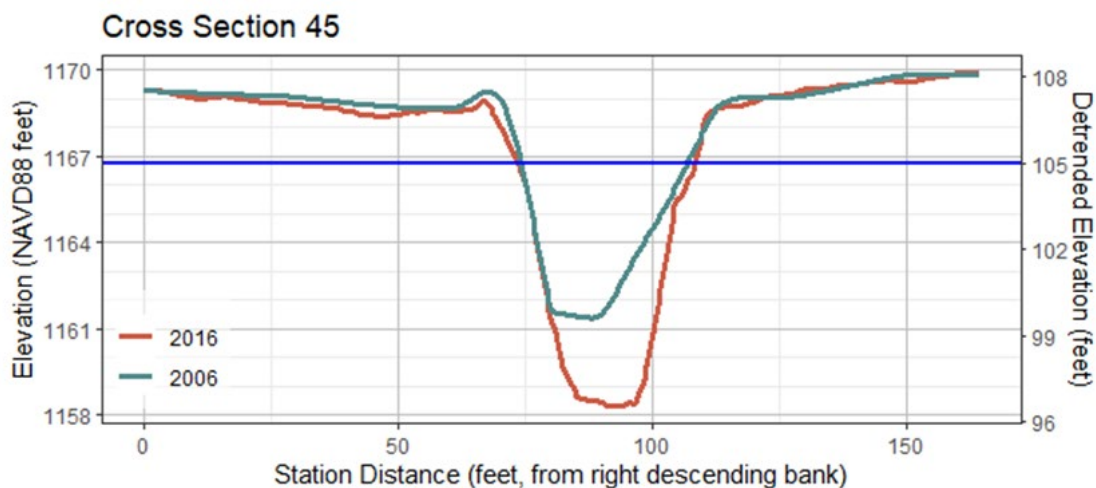


Figure 4-123: Reach 7 – Cross-section Showing Bed Changes Between 2004 and 2016

Reach 7 Summary:

Based on the FG Level 1 analysis:

- Based on the slope and cross-section analysis, the lower section of the reach appears to be in a CEM stage V. There is some uncertainty with the middle section of the reach where the channel appears to be running on resistant channel materials. Based on the cross-sections, this section of the reach is likely a late Stage IV/early Stage V. The upstream section of the reach is likely in a Stage V. This should be validated in the field.
- There is local streambank erosion occurring in the reach (Figure 4-122) Stabilization of bank erosion sites require local treatments. This local treatment option may need to be expanded upon once the middle section of the reach is investigated more. The slope is very steep compared to other reaches and there is no indication of any GCSs in the channel so there may be need for a more holistic approach to stabilization in the reach.
- The GCSs are providing needed bed stabilization and have also provided bank erosion control protection within the reach.
- Part of the South Papillion Creek restoration and stabilization plan will likely be enhancing the GCSs throughout the watershed; that will include closer examination of this reach and its stable trend.
- Level II analysis was completed on this reach and compiled in the next section.

Reach 7-FG Level II Analysis:

The geomorphic metrics for Reach 7 are plotted in Figure 4-124. The W/D metrics are spatially shown in Figure 4-125 and plotted in Figure 4-126.

- The W/D and ER metrics show locations where the channel is incised and has limited access to an active floodplain (Figure 4-124). The W/D ratios trend incised-to-stable in the downstream and upstream sections; over-widened channel sections occur between the farm culvert crossing and the S. 192nd Street culvert (cross-sections 10-32).
- Lower ERs should be targeted to investigate further as these are where the floodplain connections and access are low. The ERs downstream of the farm crossing culvert have a narrow range of values all less than 1.5. There is more variability in the upstream ERs ranging from 1.0 to 7.0, showing the variability and wider channel cross-sections (>ER).
- The GCSs are providing stability to the reach. The channel slope is steepest downstream of the farm crossing culvert at 0.0067 ft/ft and 0.009 ft/ft upstream.
- Sinuosity is most variable in the vicinity of the farm culvert crossing.
- High shear stress and USP values are associated with a low W/D in the channel section upstream of the S. 192nd Street culvert.
- The GCSs are providing streambed stability and many of the areas within the reach are in the process of stabilizing and building floodplain berms within the channel margins (Figures 4-120 and 4-121). There is some local bank erosion as the channel continues to adjust. The over-widened W/D areas within the reach are the most susceptible to bank erosion and requires field validation.

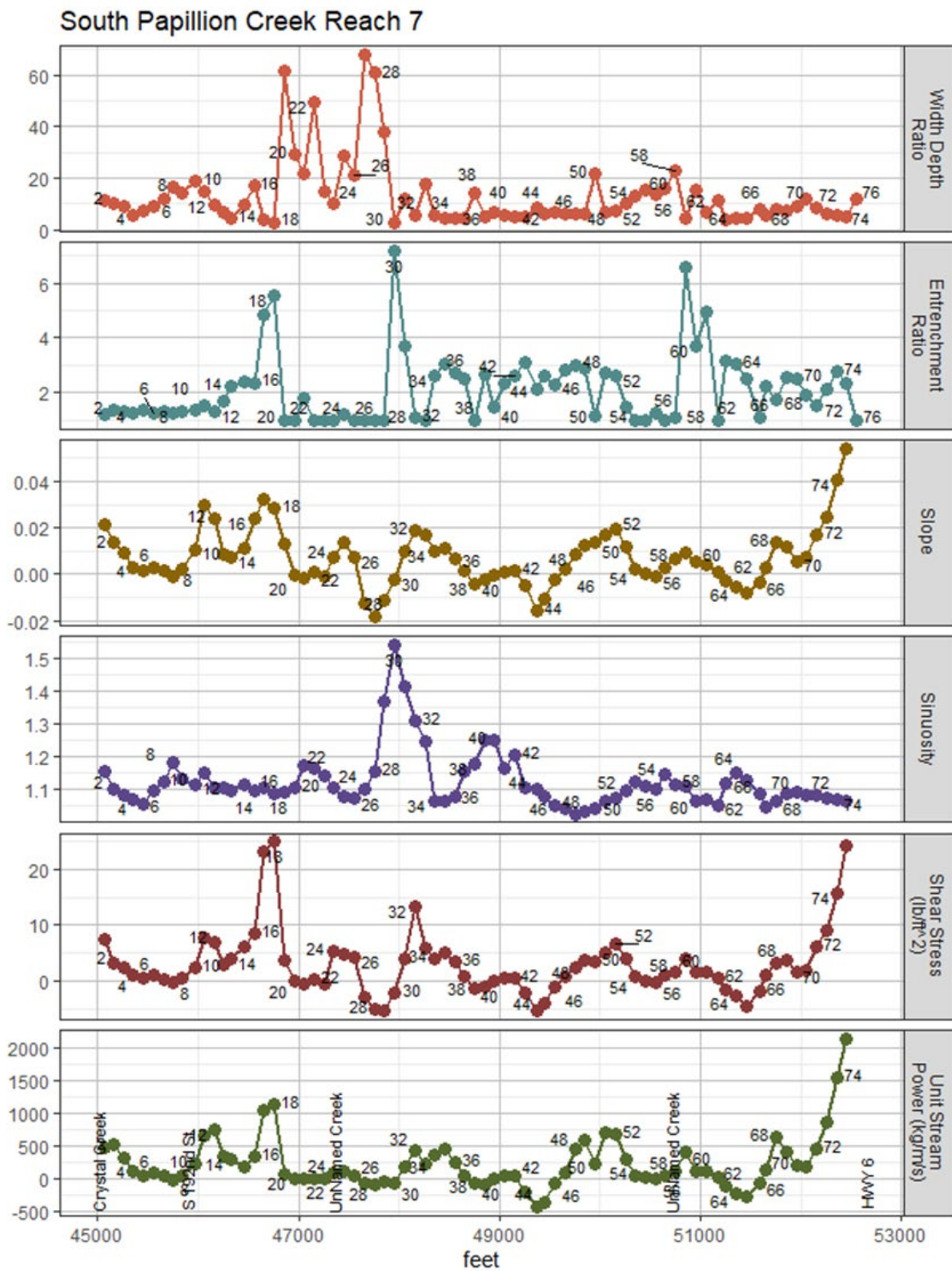


Figure 4-124: FG Level II – Geomorphic Metrics



Figure 4-125: FG Level II – Reach 7 W/D Metrics

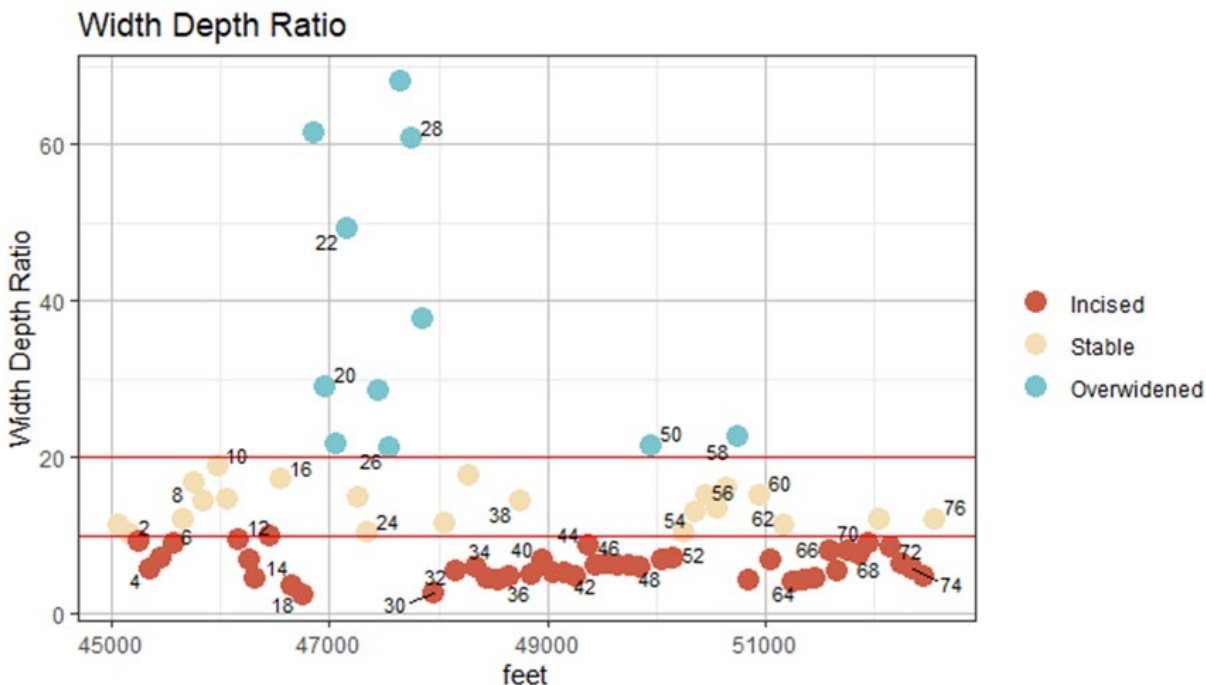


Figure 4-126: FG Level II – Reach 7 W/D Metrics

4.4.2.9 REACH 8: HIGHWAY 6 TO HARRISON STREET

Reach 8 - FG Level I Analysis:

The Reach 8 site map is illustrated in Figure 4-127 and the LiDAR water surface profiles are plotted in Figure 4-128. The reach has a meandering pattern in the downstream section, some of the meanders being very tortuous. The middle and upstream sections are mostly straight with some aspects of minor meandering. Bank heights range from approximately eight to 12 feet downstream of cross-section 40 to six-to-10 feet upstream. This change in bank heights is likely a remnant from channel incision working from downstream to the upstream then encountering the resistive materials that effectively stopped the channel degradation and widening.

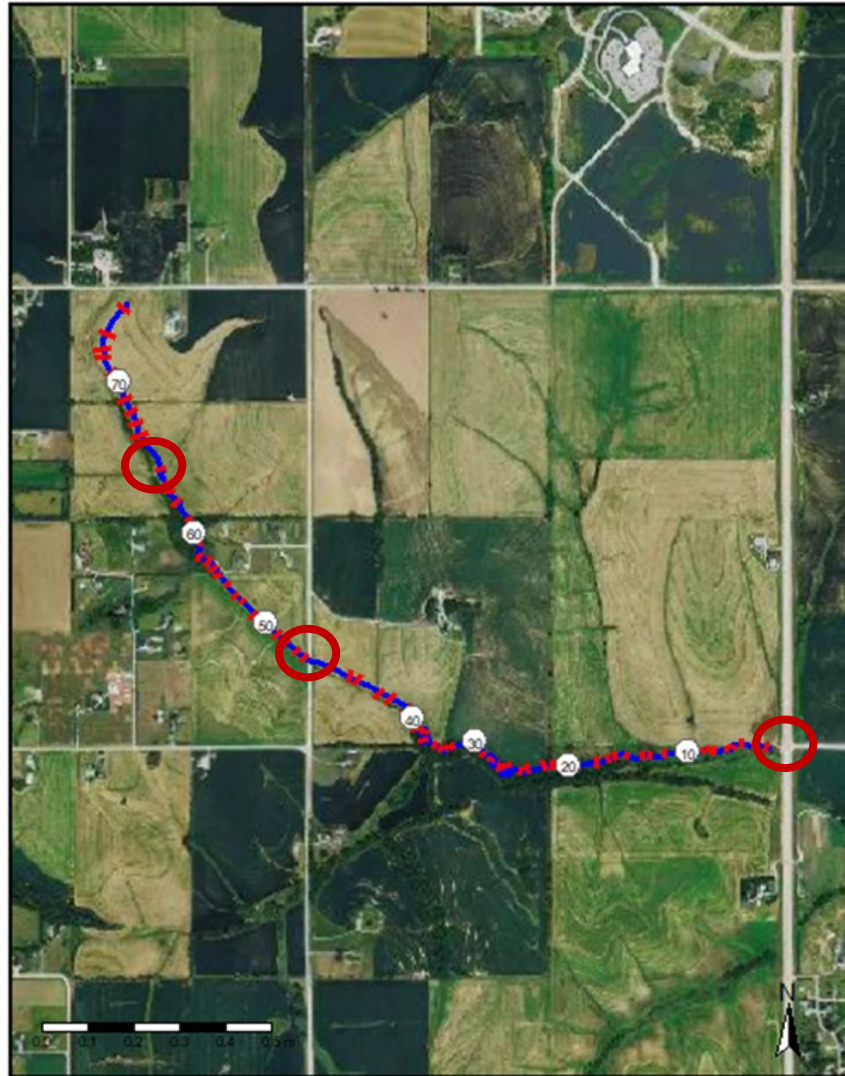


Figure 4-127: South Papillion Creek Reach 8 – Cross-section Location Map

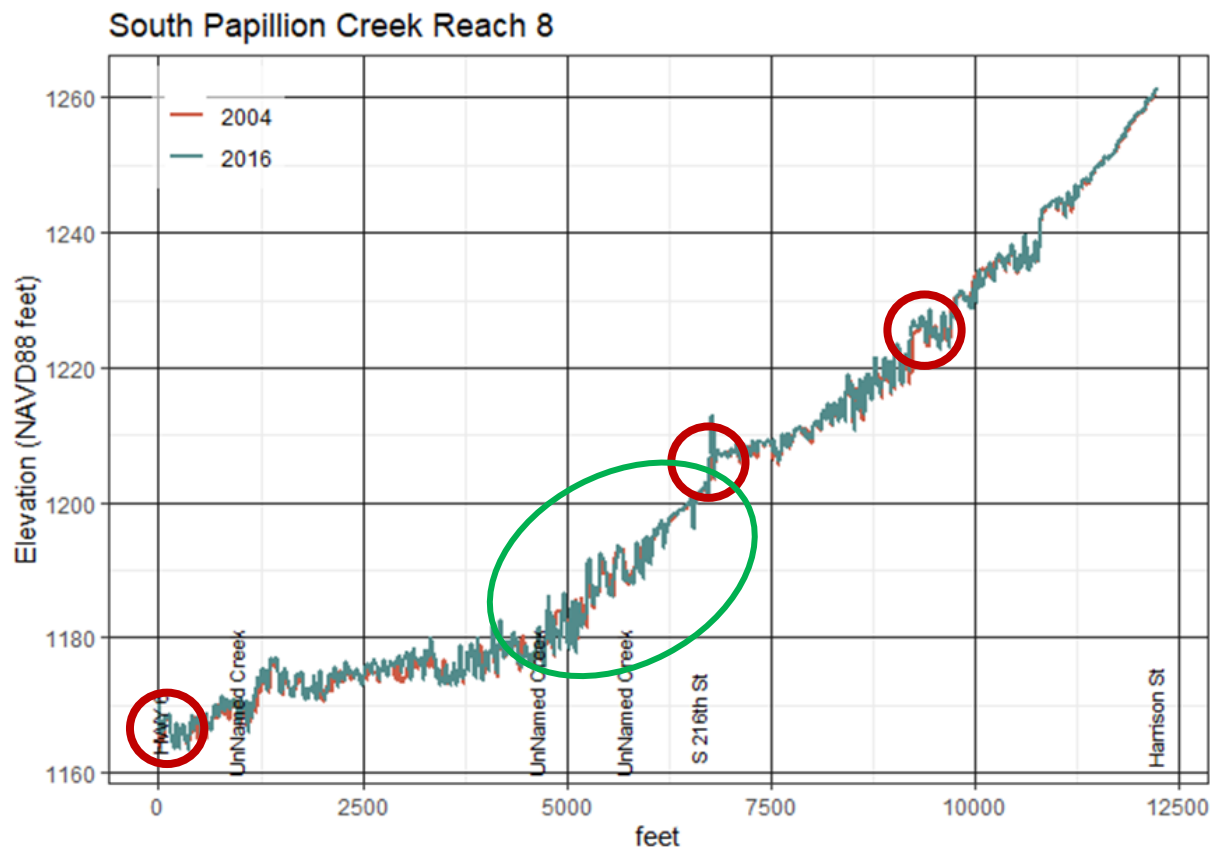


Figure 4-128: FG Level 1, Reach 8 – LiDAR Water Surface Profiles

Based on the slope profile trends, the streambed has maintained a similar profile throughout the lower reach up to approximate station 5,000, then the slope steepens drastically. There are a series of at least three GCSs in the reach (Figures 4-127 and 4-128, red circles). There appears to be some resistant bed/bank materials upstream of Highway 6 (Figure 4-128, green circle). This section of the reach requires further investigation as there is an extreme grade break in the profile. Channel stability should be assessed from the field to determine what is occurring at, below, and upstream of this transition.

The GCSs from downstream to upstream are the Highway 6 culvert, South 216th Street culvert, and a farm crossing culvert. There is approximately 35 feet of drop in the channel between the Highway 6 and South 216th Street culverts. The slope for that section of the reach is 0.0054 ft/ft. Upstream of the South 216th Street culvert, there is 54 feet of drop in the channel and the slope is 0.01 ft/ft.

The cross-sectional analysis (Figures 4-129 to 4-132) shows much of the reach appears to have channel degradation with some areas experiencing localized bank erosion (Figures 4-129 and 4-130). The main process appears to be channel incision with very little widening occurring (Figures 4-131 and 4-132). The lack of channel widening could be from encountering more erosion resistant materials in the bed and bank. This should be investigated further in coordination with reviewing the GCSs within the reach.

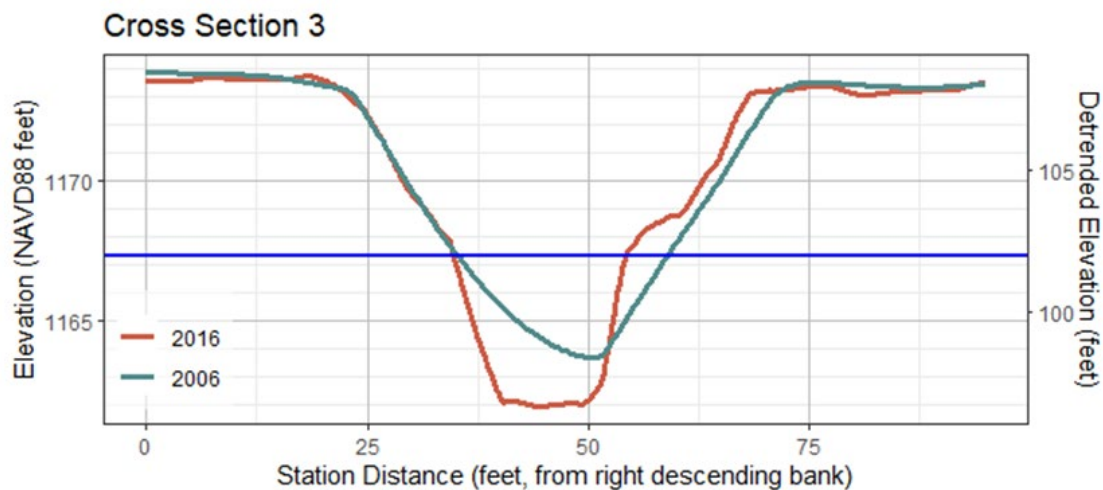


Figure 4-129: Reach 8 – Cross-section Depicting Relatively Stable Banks

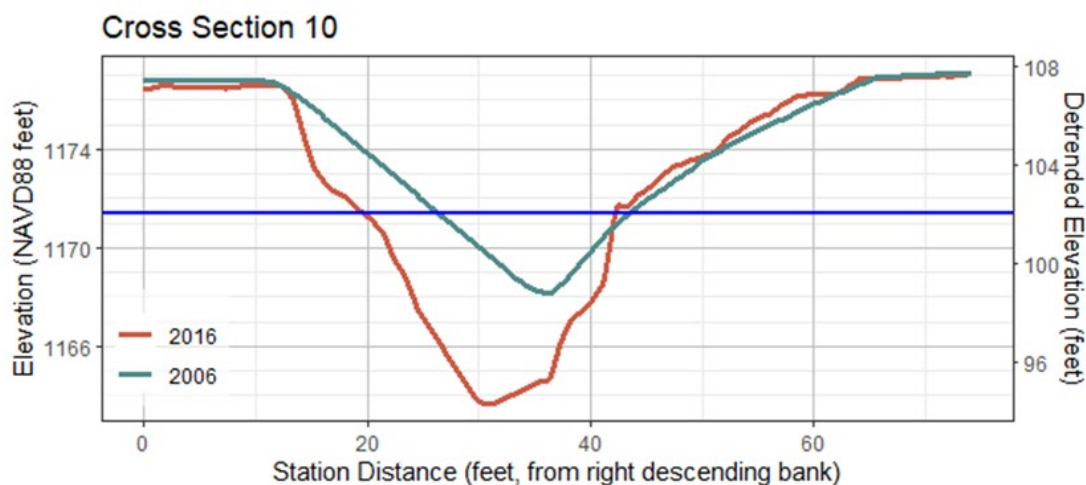


Figure 4-130: Reach 8 – Cross-section Illustrating Relatively Stable Banks

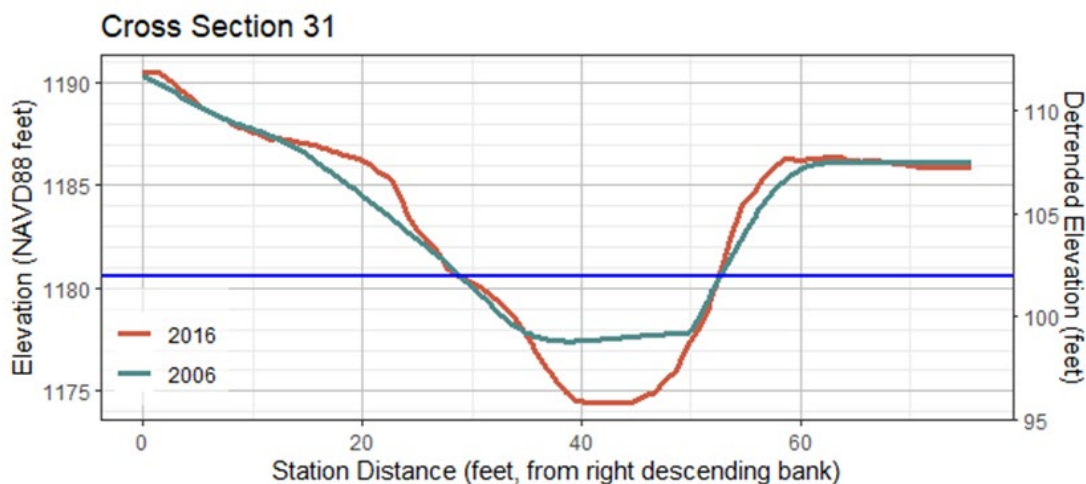


Figure 4-131: Reach 8 – Cross-section Illustrating Bed Changes Between 2004 and 2016

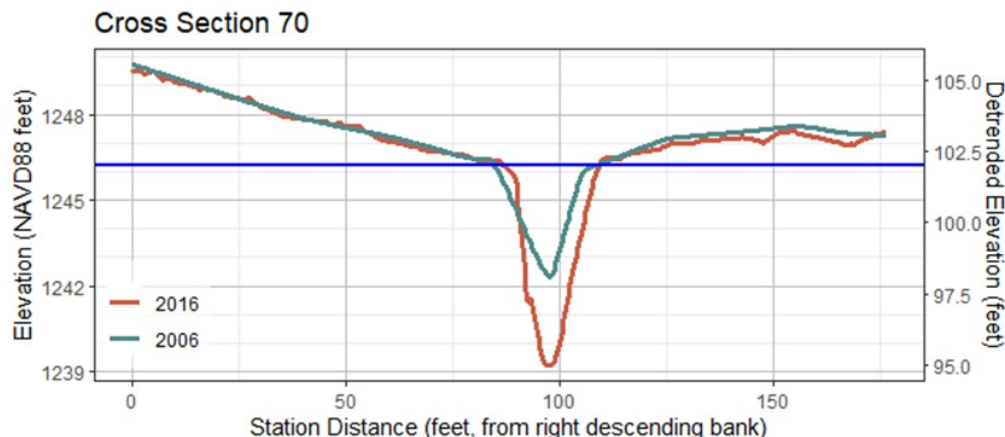


Figure 4-132: Reach 8 – Cross-section Illustrating Bed Changes Between 2004 and 2016

Reach 8 Summary:

Based on the FG Level 1 analysis:

- Based on the slope and cross-section analysis, the lower section of the reach (cross-sections 1-42) appears to be in a late Stage IV. The upstream section (cross-sections 43-74) is likely transitional from early CEM Stages to Stage VI at the upstream end. This should be validated in the field.
- The lower reach should be investigated further from approximately station 5,000 to the South 216th Street culvert to determine what channel materials are present and to check channel stability in the area.
- There is significant channel incision occurring in the reach (Figure 4-129 to 4-132). The three known GCSs are providing necessary bed stabilization and have also provided bank erosion control protection within the reach.
- Part of the South Papillion Creek restoration and stabilization plan should likely be enhancing the GCSs throughout the watershed; that will include closer examination of this reach and its stable trend.
- Level II analysis was completed on this reach and compiled in the next section.

Reach 8-FG Level II Analysis:

The geomorphic metrics for Reach 8 are plotted in Figure 4-133. The W/D metrics are spatially shown in Figure 4-134 and plotted in Figure 4-136.

- The W/D and ER metrics (Figure 4-133) trend low in the downstream section and are highly variable in the upstream section. The variability in the upstream section is likely due to sediment deposits within the channel providing the hummocky slope breaks. This appears to be related to the waterways that outlet into the stream channel through this area that drop sediment into the channel.
- Lower ERs should be targeted to investigate further as these are where the floodplain connections and access are low. The ERs downstream of the South 216th Street culvert have a narrow range of values mostly less than 1.5. There is more variability in the upstream ERs ranging from 1.5 to less-than-6, showing the variability and wider channel cross-sections (>ER).

- The GCSs are providing stability to the reach. The channel slope is steepest upstream of the South 216th Street culvert at 0.01 ft/ft and 0.0054 ft/ft downstream.
- Sinuosity is relatively low for most of the reach except for a small section in the middle of the reach where there are some meanders still present.
- Slope, shear stress and USP values all increase in the upstream direction as the watershed slope and LiDAR water surface slopes increase dramatically from the bottom to the top of this reach.
- The GCSs are providing streambed stability and locations in the downstream reach are in the process of stabilizing and building floodplain berms within the channel margins (Figures 4-133 to 4-135). The upstream reach appears to have some natural floodplain connections in some locations. The connection may be a sign of sediment deposition in the channel and should be verified with a site visit.

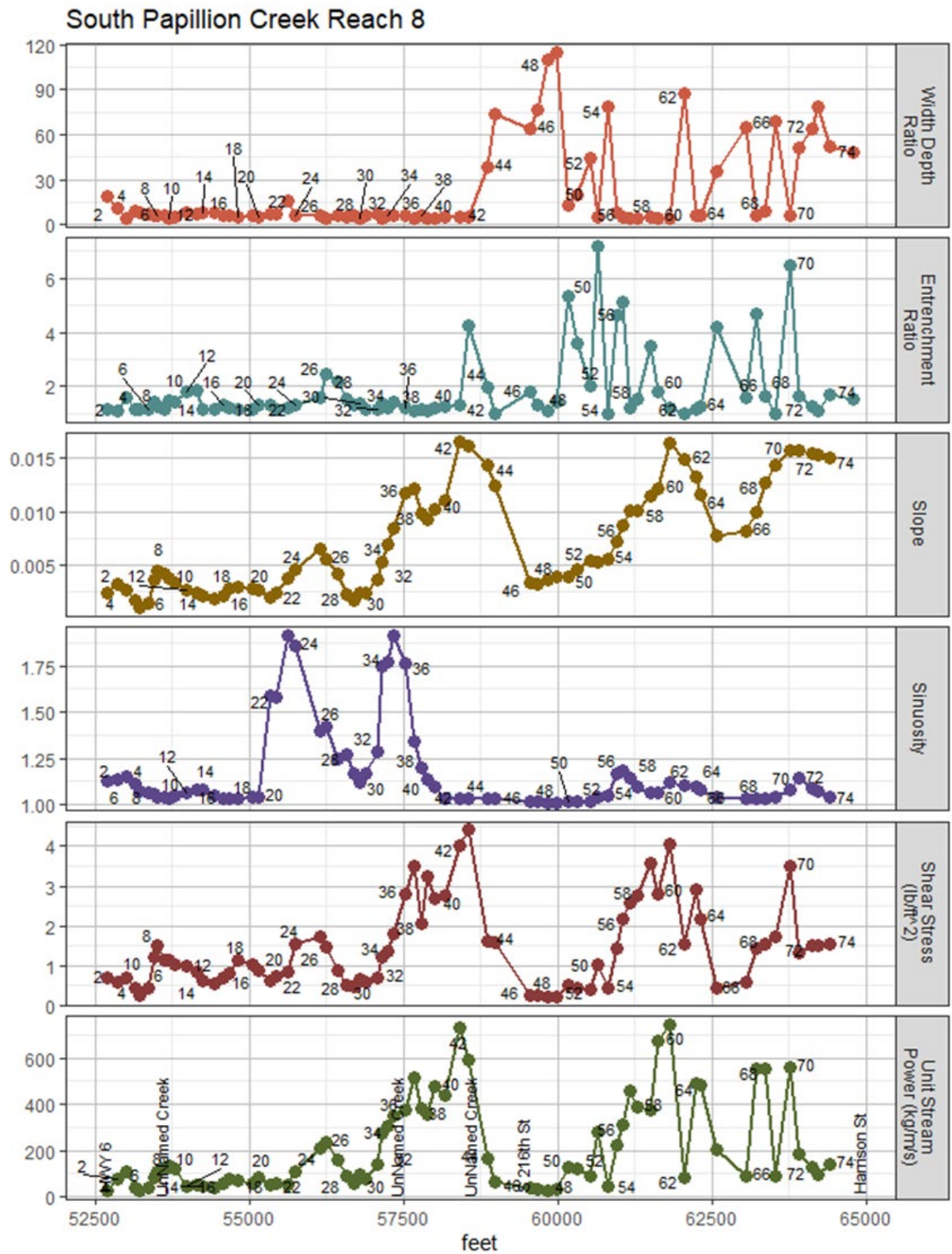


Figure 4-133: FG Level II – Geomorphic Metrics

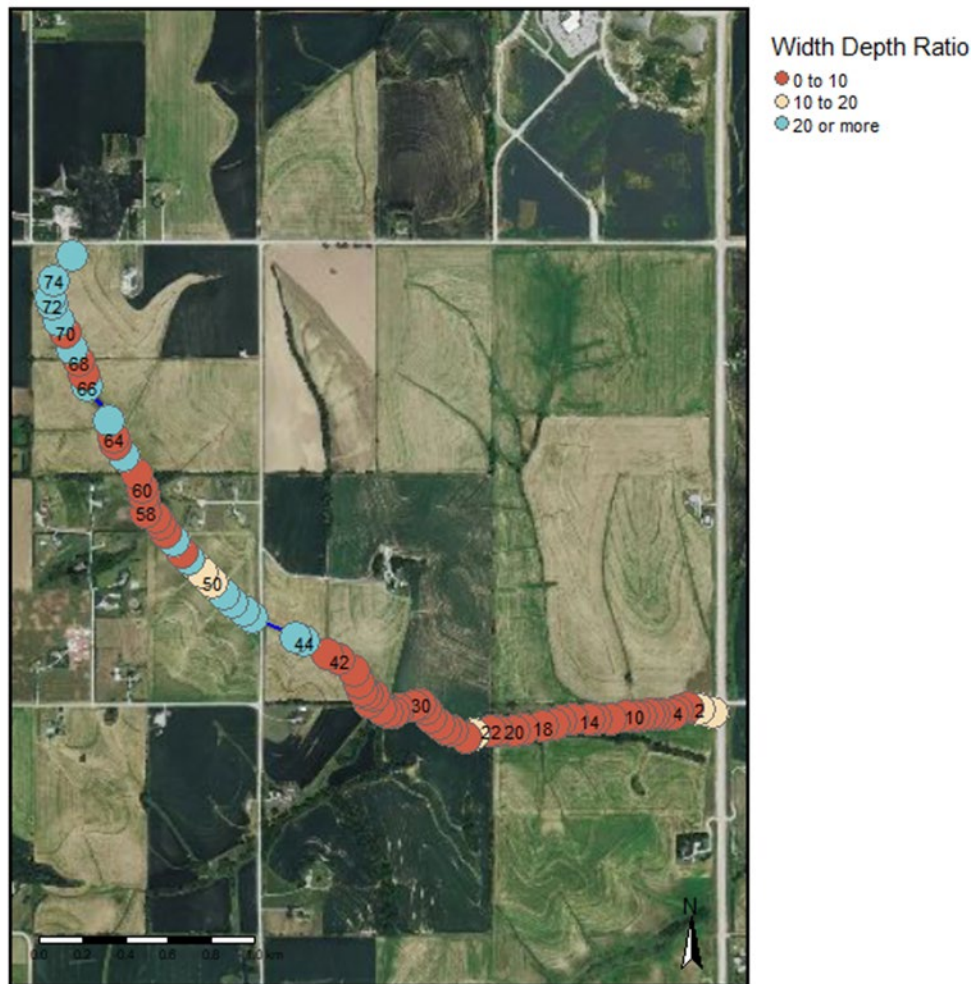


Figure 4-134: FG Level II – Reach 8 W/D Metrics

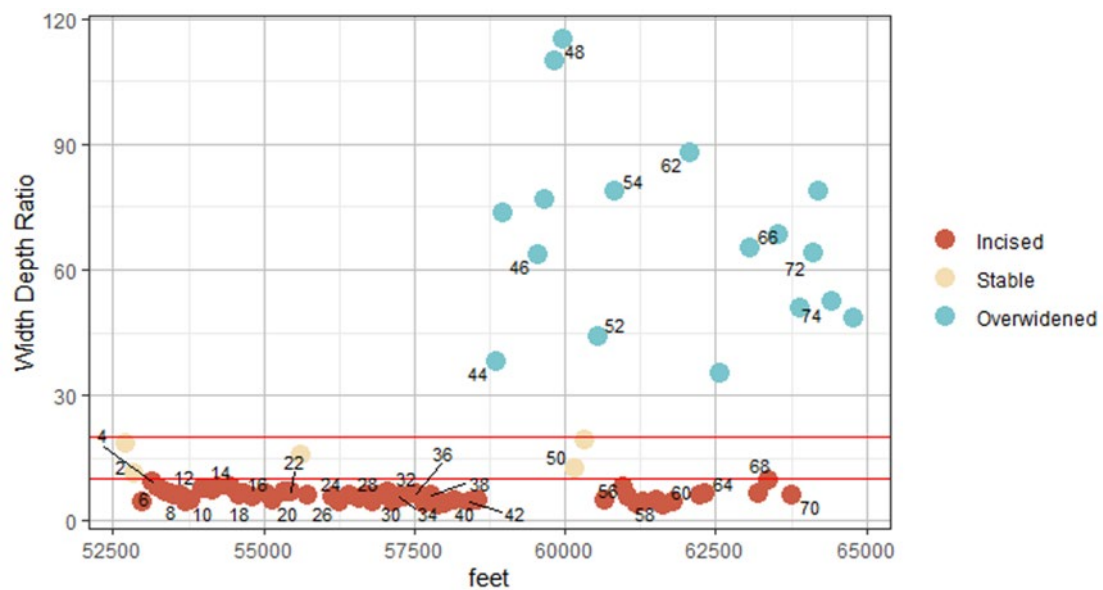


Figure 4-135: FG Level II – Reach 8 W/D Metrics

4.4.3 SOUTH PAPILLION CONCLUSIONS AND RECOMMENDATIONS

The South Papillion Creek has progressed through a series of channel degradational phases caused from land use changes throughout the watershed. The changes are continuing to occur as areas within the watershed are converted from agriculture to residential and commercial developments.

There have been widespread attempts to stabilize many sections of the creek using GCSs as illustrated in Figure 4-136. The figure provides locations where GCSs (red circles) are located within the FG study reaches. The locations were identified by analyzing the 2004 and 2016 LiDAR water surface profiles and review of aerial photographs.

The structures come in various forms; some are loose rock riffles, sheet piles with riprap, road culverts, and farm crossings. Also shown are the locations where there appears to be erosion-resistant materials in the stream (green circles). There were no GCSs identified in these locations and they should be evaluated with site visits. Finally, the orange circle in Reaches 2b and 3 may be defining a stable channel slope for which to consider future bed and bank stabilization design criteria.

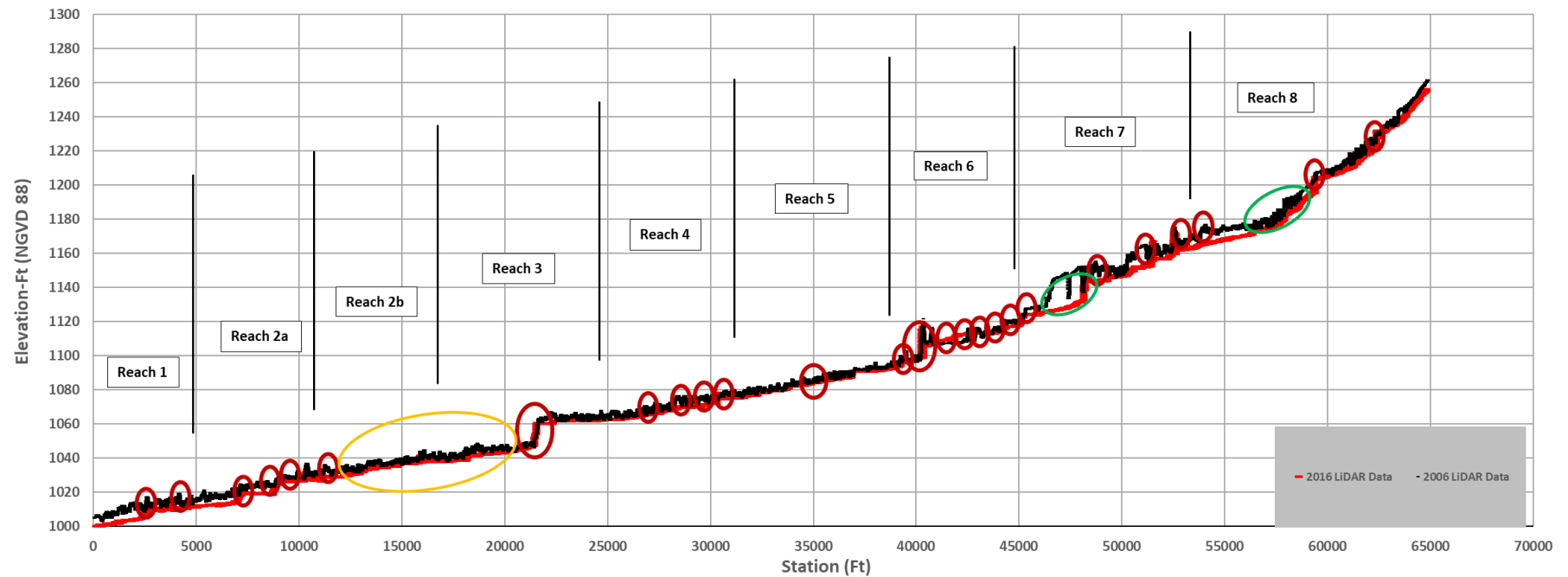


Figure 4-136: South Papillion Creek 2004/2016 LiDAR Water Surface Profiles with GCSs (red circles), Erosion-Resistant Materials (green circles), and Potential Equilibrium Slope (orange circle)

There are additional geomorphic analysis details for each study reach in the main sections of the report. This section is meant to provide the overarching recommendations based on the report analysis and assessment.

- Based on the FG Level 1 analysis of water surface slopes and reach cross-sections, the reaches are progressing through various stages of the CEM (Simon and Hupp, 1986), most identified as Stage IV and V. The reaches that are most susceptible to continued channel degradation are the areas in Figure 4-136 that appear to have erosion resistant materials without GCS. These areas should be investigated further to determine what materials are present and if additional GCSs are needed to prevent channel incision from working upstream. The generalized CEM trends were identified using the FG Level 1 CSA and are identified by reach. This assessment is based on 2016 data and requires field validation.

Channel Evolution Model (I-VI)

Reach 1: IV/V

Reach 2a: IV/V

Reach 2b: IV, V

Reach 3: V

Reach 4: V

Reach 5: V

Reach 6: IV/V/VI

Reach 7: (III?), IV/V

Reach 8: (III?), IV/V/VI

- Based on the FG Level 1 slope analysis, the 2016 water surface slopes are listed in Table 4-3. An arbitrary slope classification was developed using the slope ranges of <0.002 ft/ft as low, 0.002-0.004 ft/ft as medium, and > 0.004 ft/ft as high. From the slope classifications, steeper slopes are mostly in the upstream reaches; these reaches would be considered sediment supply reaches. Reaches 1, 2a, 3, 5, 6, 7, and 8 all have steeper average reach slopes because of the large elevation changes within the GCSs. The slope ranges in Reach 2b (0.0017 ft/ft) and Reach 4 (0.0024 ft/ft) should be investigated further to determine if it is representative of a stable equilibrium channel slope. The slopes provide an indication of which reaches are sediment sources, pathways, and sinks. Based on the slopes, reaches 6, 7, 8 and 3 have higher erosion potential based on the steeper slope classifications. Reaches 1, 2a, 4, and 5 are pathways with intermediate slopes. Reach 2b in addition to sub-reaches within 1, 2a, 3 and 5 are also potential locations for sediment sinks.

Table 4-3: South Papillion Creek-LiDAR Water Surface Slopes per Reach and Sub-Reach

Reach	Sub-Reach Slope	Reach Slope	Reach	Sub-Reach Slope	Reach Slope
Reach 1:			Reach 5:		
Downstream	0.0022		Downstream	0.0018	
Upstream	0.0010	0.0029	Upstream	0.0009	0.0025
Reach 2a:			Reach 6:		
Downstream	0.0014		Downstream	0.0039	
	0.00025	0.0035	Upstream	0.0026	0.0040
Upstream	0.0016		Reach 7:		
Reach 2b:			Downstream	0.009	
	0.0017	0.0017		0.0067	0.0052
			Upstream	0.0033	
Reach 3:			Reach 8:		
Downstream	0.0023		Downstream	0.0054	
Upstream	0.0009	0.0049	Upstream	0.01	0.0076
Reach 4:			Relative Slope Range:		
	0.0024	0.0024	Low:	<0.002	
			Med:	0.002-0.004	
			High:	>0.004	

- Most reaches are experiencing localized bank erosion. Local erosion control projects can be implemented in these cases if there is an additional survey in the reach to validate there are no continuing channel degradation issues that would affect the performance of bank stabilization.
- The existing GCSs are providing stability to the system as constructed; however, there may be some modifications to the structures that could assist the reaches in further stabilization. The best example of the channel stabilizing is in Reach 6 where a series of loose rock riffle structures was constructed, and the channel has rebuilt the floodplain berms and stabilized. The GCSs should be further investigated in the field to determine if maintenance is required for the structures to continue to function properly.
- Based on the FG Level II W/D assessment, many of the reaches are considered incised (W/D <10), with others on the lower end of the stable (W/D 10-20) less than 12, and very few sections that were considered over widened (W/D >20) (see main report for reach details).
- Based on the W/D metrics, construction of additional GCSs could raise the water surface profile and promote deposition and development of floodplain berms within the incised channel margins. The development of floodplains will reduce shear stress pressure on the existing entrenched streambanks.

Additional analysis of the spacing of the existing GCSs and assessment of stable channel slopes (Figure 4-136) could assist in further siting of additional GCSs. In all reaches, the stream

channel sections immediately upstream of GCSs were stable or in the process of stabilizing building floodplain berms.

- Spacing of GCSs may also reduce local bank erosion by providing stable channel slopes to the reaches. In addition, equalizing the energy slope and spreading the elevation change more naturally through reaches will provide additional stabilization benefits.
- Altering the large elevation drops will provide better aquatic habitat and provide fish passage if that is a goal of the restoration efforts.
- Geotechnical bank conditions will need to be investigated if GCS are constructed so banks are not destabilized.
- Any modification or additions to the GCSs would require hydraulic modeling to determine impacts to water surface profiles.
- Any modifications to existing structures should be carefully considered prior to final construction. Changing the inverts of the structures even if they were not meant to be GCSs will change the base level of the stream. Once this occurs channel degradation will likely move upstream.
- Based on the FG Level II ER assessment, most cross-sections of the reaches were mapped as moderately entrenched (ER 1.4-2.2) and entrenched (ER, 1-1.4). Low ERs tend to be highly erosive (high in-channel shear stress) as bankfull channel forming flows do not readily have access to a floodplain to dissipate and spread out flow energy. To reduce erosive high shear stress within the channel margins, stabilization methods that raise the ERs would provide the best option for stabilization. The sections within reaches that have the lower ERs should be targeted for potential GCSs and local bank protection.
- Based on aerial photo interpretation, there are areas within the upstream section of Reach 3, Reach 4, and Reach 7 that have tortuous channel meander patterns. These areas likely have R_c/BW ratios less than 2.0. Low R_c/BW ratios are outside the range of stable meandering channels and should be further investigated in the field to determine the severity of the erosion and appropriate treatment methods.
- Aerial photo investigation shows there are many additional areas within the small tributaries and agricultural waterway outlets within the Papillion Creek watershed that require stabilization. These areas should be identified and treated as part of a systems approach to stabilizing the watershed.

5 ADDITIONAL LEVEL 1 FLUVIAL GEOMORPH ANALYSIS

5.1 BIG PAPILLION CREEK

This report is a geomorphic assessment based on limited FG Level I analysis and field visits. Many of the Papillion Creek watersheds have similar hydrology, geology, geomorphic characteristics, and land-use. These assumptions provide the basis for comparison of limited watershed data in this report.

Big Papillion Creek is a large watershed (approximately 232 square miles) within the overall Papillion Creek watershed located west of Omaha, NE (Figure 5-1). It merges with West Papillion Creek (approximately 133 square miles) about 900 feet downstream of South 36th Street and generally flows from northwest to southeast. The reaches in this study are largely developed residential and industrial areas with some small pockets of agricultural land mostly in Reaches 7 and 8. The upstream end of the study occurs at Dutch Hall Road (Washington County line). The watershed is still 110 square miles upstream of Reach 8 and is mostly agricultural.

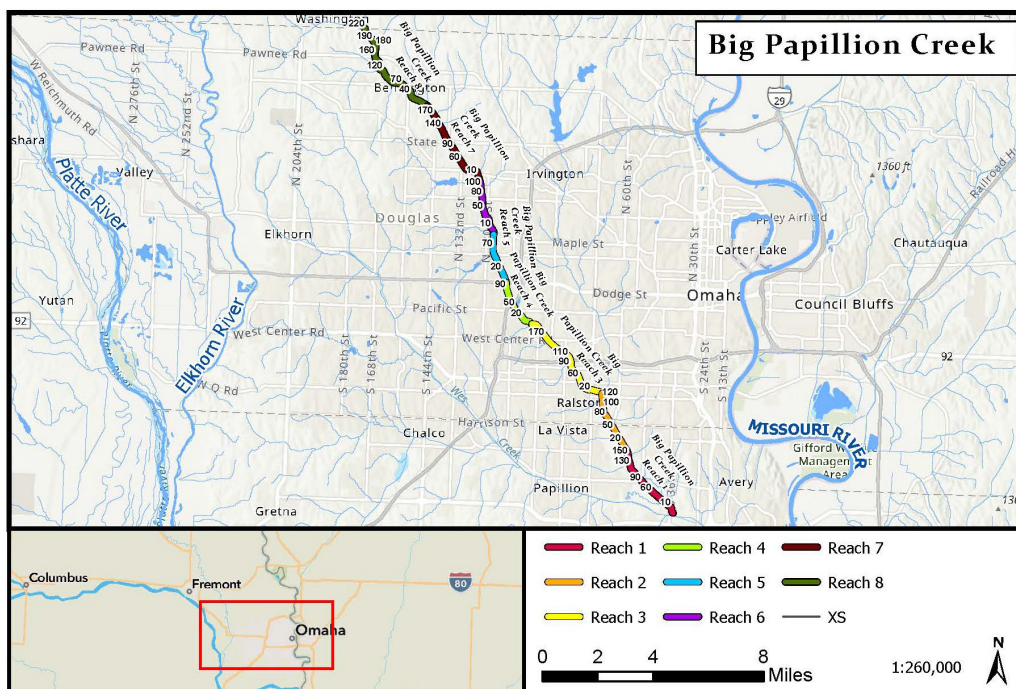


Figure 5-1: Big Papillion Creek FG Level I Reaches

FG Study Reaches and General Assessment:

There are many sections of the creek that have some form of revetment, riprap or other materials present in the channel bed or banks. In most cases, these materials are providing bed or bank stability. It is not known whether these structures and revetments were designed, or materials were placed in stream to protect utility crossings. In many locations, material has launched and formed GCSs, stabilizing the channel bed in these locations. Upstream a GCS at South 36th Street (Reach 1), floodplain berms developed (Figure 5-2). Compared to an incised channel (high banks with no floodplain), the berms provide access to the frequent flood events

dissipating flow energy across a wide cross-sectional area. This is a common feature in the urbanized Papillion Creek watersheds seen during the limited site visits.

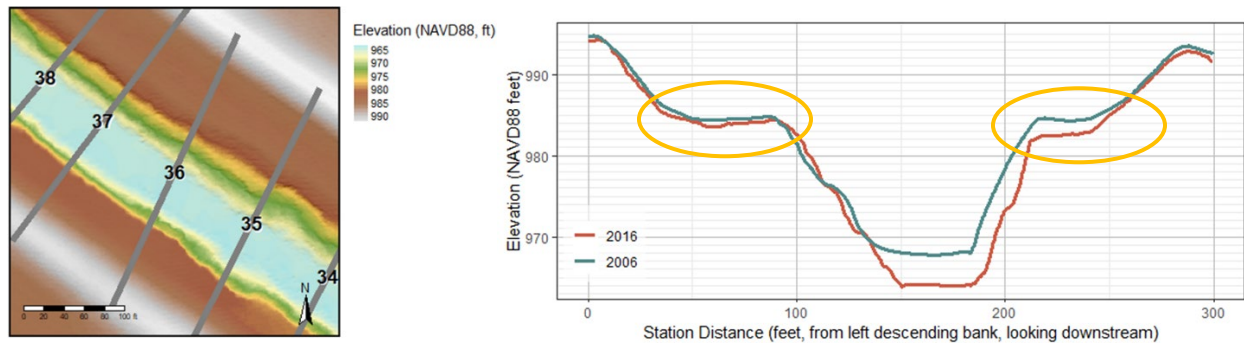


Figure 5-2: Floodplain Berms (orange circles) Developed Upstream of GCS – Big Papillion Creek

The next section provides the overall profile and individual Reach information developed for this study. The FG study reaches are defined in Figure 5-3 with individual FG Reach profile plots (2004 and 2016 LiDAR) in each section. Some of these locations were field verified but others were not due to time restrictions on fieldwork. Each reach has bulleted descriptions based on geomorphic information collected from the site visits and FG Level I analysis.

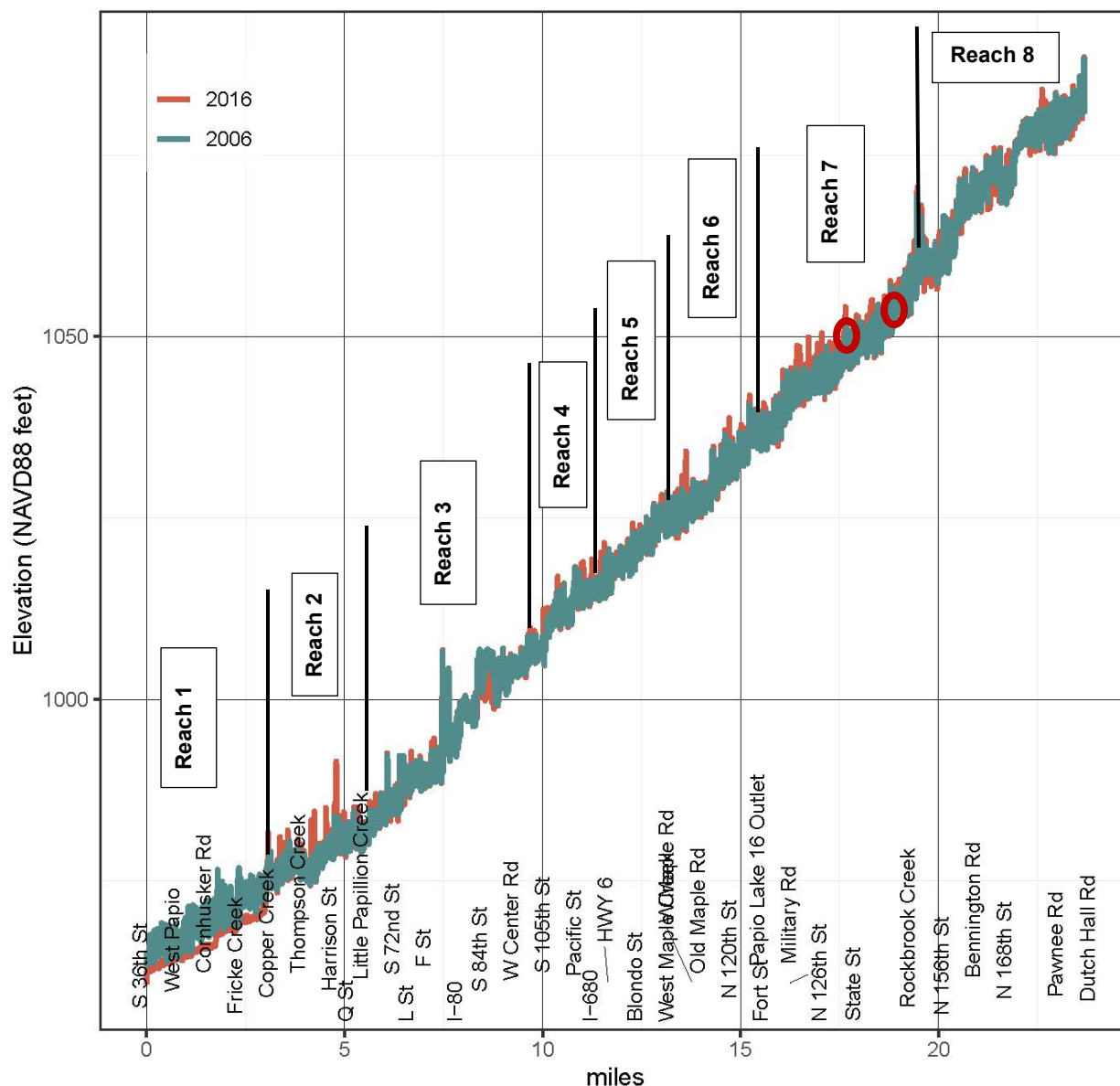


Figure 5-3: Big Papillion Creek FG LiDAR Water Surface Profiles

Note: GCS locations are labeled in Reach 1-8, Figures 5-4 through 5-11.

5.1.1 REACH 1

Reach 1 starts at the confluence with West Papillion Creek and is highly modified with levees (confining the river floodplain), greenspace, and trails that separate the agricultural and residential activity from the stream channel. Based on aerial photo investigations, the agricultural areas are developing and will soon be replaced by residential areas. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at two main bridge locations and other locations between. The largest GCS is located at Cornhusker Road approximately 9,000 feet upstream of the confluence with West Papillion Creek. The GCS is part of an over-steepened section with other GCSs located upstream and downstream with an approximate elevation drop of four feet (Figure 5-4).

- Based on aerial photo interpretation, the section upstream of Cornhusker Road, especially between Fricke and Copper Creeks, is over-steepened and has significant materials deposited in the channel providing bed stability. The existing structures within this area of Reach 1 should be investigated further to determine channel and bank stability.
- There is a substantial portion of the reach containing bank erosion control revetments, the likely source of bed stabilizing materials (Figure 5-4).
- There are areas within the reach that have active bank erosion and others that have been stabilized with revetment. This reach would be considered a sediment pathway and source.
- There are many locations within Reach 1 that would have access to an active floodplain if levees could be setback to provide more room for flood flows. This is still possible in areas where agriculture is present.
- Establishment of floodplain access areas to dissipate and store floodwater would be a great alternative to establish where applicable to the upstream reaches.

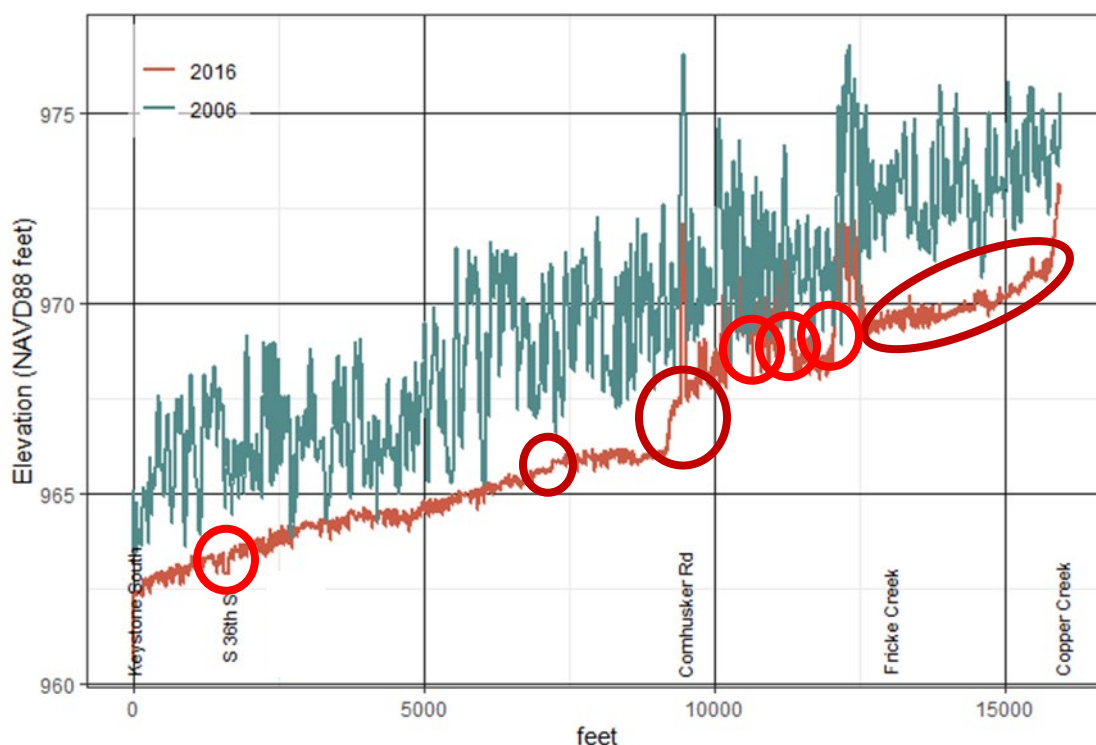


Figure 5-4: Big Papillion Creek FG – Reach 1

Note: GCSs (red circles) or erosion resistant bed materials present.

5.1.2 REACH 2

Reach 2 is a highly modified reach, similar to Reach 1 but with more industrial areas. It has levees, limited width floodplain/greenspace and recreational trails that limit the floodplain access. The list below describes the limited FG and field assessments for the reach.

- GCSs are spaced relatively evenly throughout (Figure 5-5). The structures are likely reworked revetment material or placed to protect utility crossings.
- Based on the FG cross-sectional analysis, there are areas where floodplain berms are building within the confined (by levees) floodplain. There are other areas where there has been substantial channel erosion. This reach is a mix of sediment source and some minimum sediment sink locations.
- The reach could be enhanced for flood water storage by increasing floodplain connection and access through series of levee setbacks. There are still some areas of agriculture that could be targeted. If sediment delivery to downstream reaches is a priority, then installation of additional bank erosion revetments is recommended.

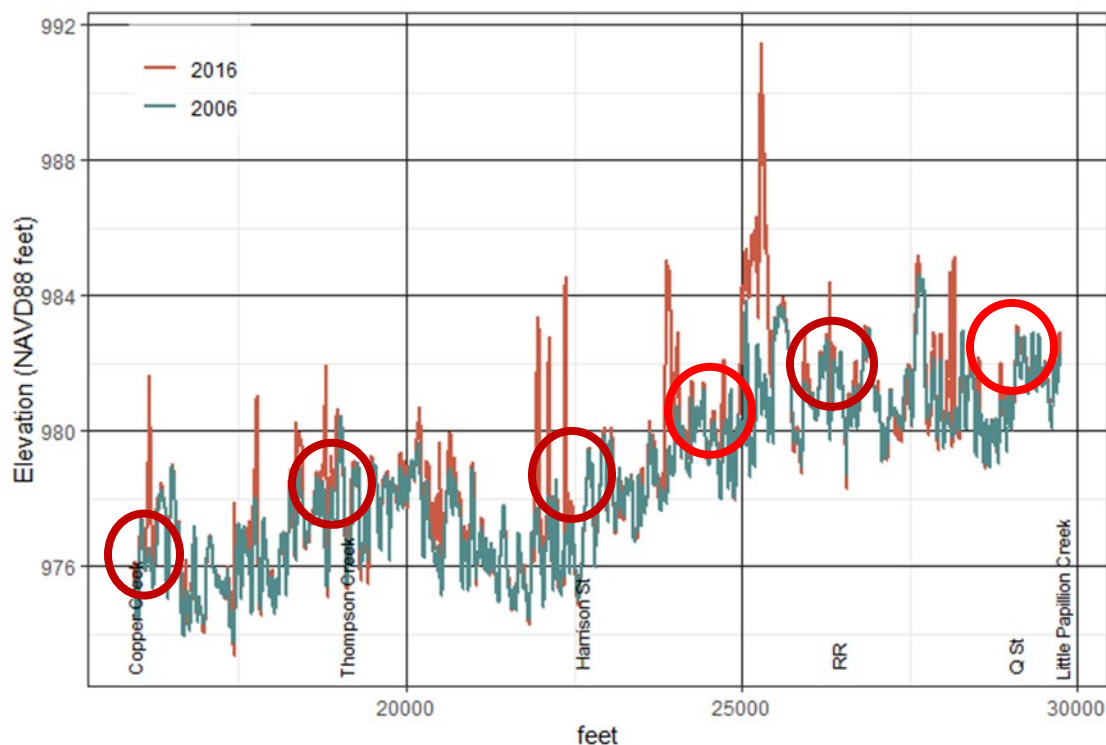


Figure 5-5: Big Papillion Creek FG – Reach 2

Note: GCSs (red circles) or erosion resistant bed materials present.

5.1.3 REACH 3

Reach 3 has limited greenspace with more encroachment and no adjacent agricultural land-use. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at bridge locations and throughout the reach (Figure 5-6).
- Based on the number of GCSs within this reach, each location should be investigated further to determine stability of structure and potential need for enhancements. There are a lot of bank revetments within this reach and likely a lot of launched riprap in the channel. The GCS may be a result of protection for utility crossings. If so, records of these structure locations could be used to further map channel stability.
- Based on the FG cross-section analysis, there is bank erosion in many sections of the reach. Additional bank protection revetments and developing a better understanding of the channel bed stability would be recommended. This reach would be considered a sediment source and areas with little or no erosion a sediment pathway.
- There are no locations available within the reach to expand access to floodplain areas behind the existing levees.

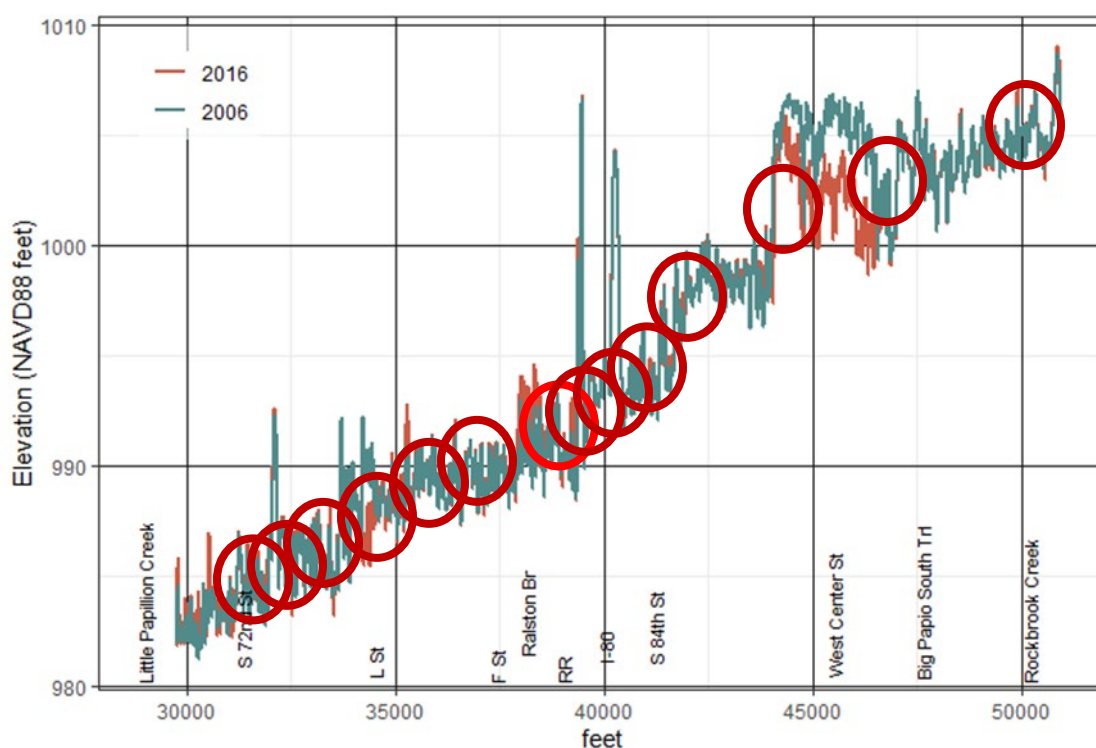


Figure 5-6: Big Papillion Creek FG – Reach 3

Note: GCSs (red circles) or erosion resistant bed materials present.

5.1.4 REACH 4

Reach 4 has a highly confined channel and small floodplain between levees, with limited greenspace and pedestrian trails. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at bridge locations and other locations within the reach likely from launching revetment materials (Figure 5-7).
- The largest GCS (series) is located downstream of South 105th Street and runs upstream to the Pacific Street vicinity. The approximate elevation drop is four feet (Figure 5-7).
- Like Reach 3, there are many locations with limited floodplain berms based on a smaller greenspace width and bank revetments locking the banks in place and not allowing natural alluvial processes to occur. Based on the FG cross-section analysis, there is bank erosion in many sections of the reach. Additional bank protection revetments and developing a better understanding of the channel bed stability would be recommended. This reach would be considered a sediment source and areas with little or no erosion a sediment pathway.
- There are no locations available within the reach to expand access to floodplain areas behind the existing levees.

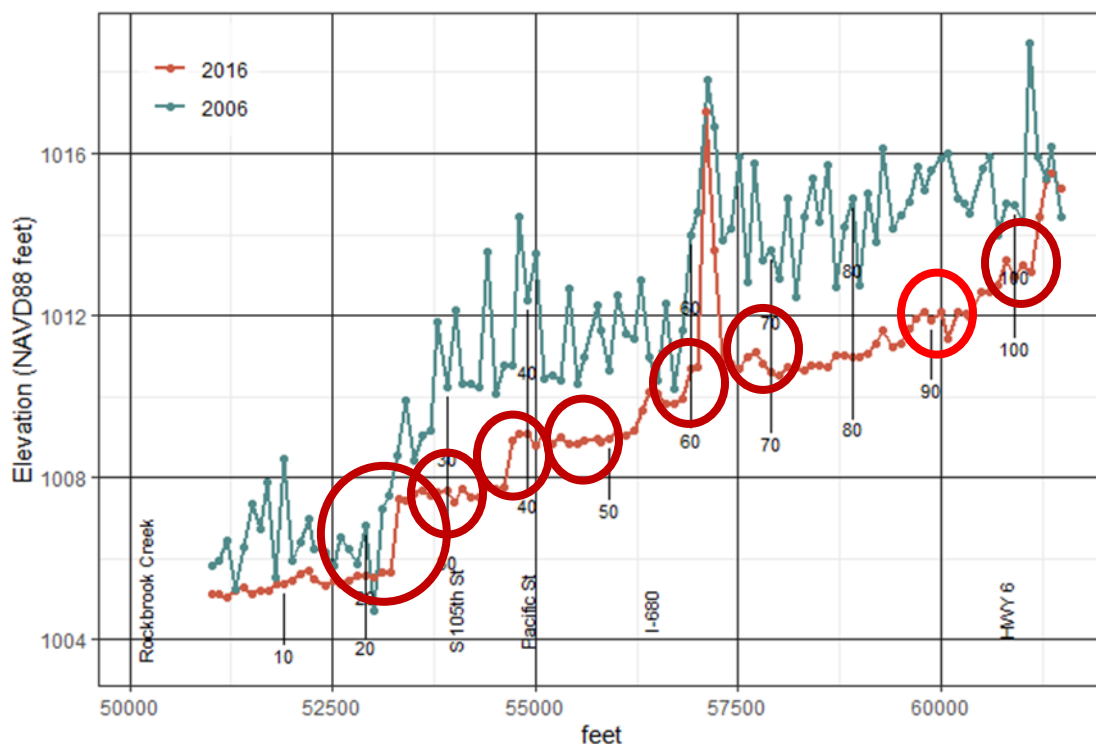


Figure 5-7: Big Papillion Creek FG – Reach 4

Note: GCSs (red circles) or erosion resistant bed materials present.

5.1.5 REACH 5

Reach 5 is similar Reach 4 in floodplain development and urbanization but has more bank erosion throughout. The levees and recreational trails stop at the upstream end of this reach. The list below describes the limited FG and field assessments for the reach.

- GCSs are present throughout the reach with the largest at the Blondo Street Bridge (Figure 5-8).
- There are additional GCSs or other resistant bed materials located within the reach based on the 2016 LiDAR and aerial photo interpretation. Specific GCS locations should be field-verified (Figure 5-8).
- The reach has a substantial amount of bank sloughing and erosion. Some of the erosion is threatening pipe outlets, pedestrian trails, and possibly the levee system.
- Based on the limited FG analysis, this reach would be considered partially a sediment source and pathway.
- There are no locations available within the reach to expand access to floodplain areas behind existing levees.

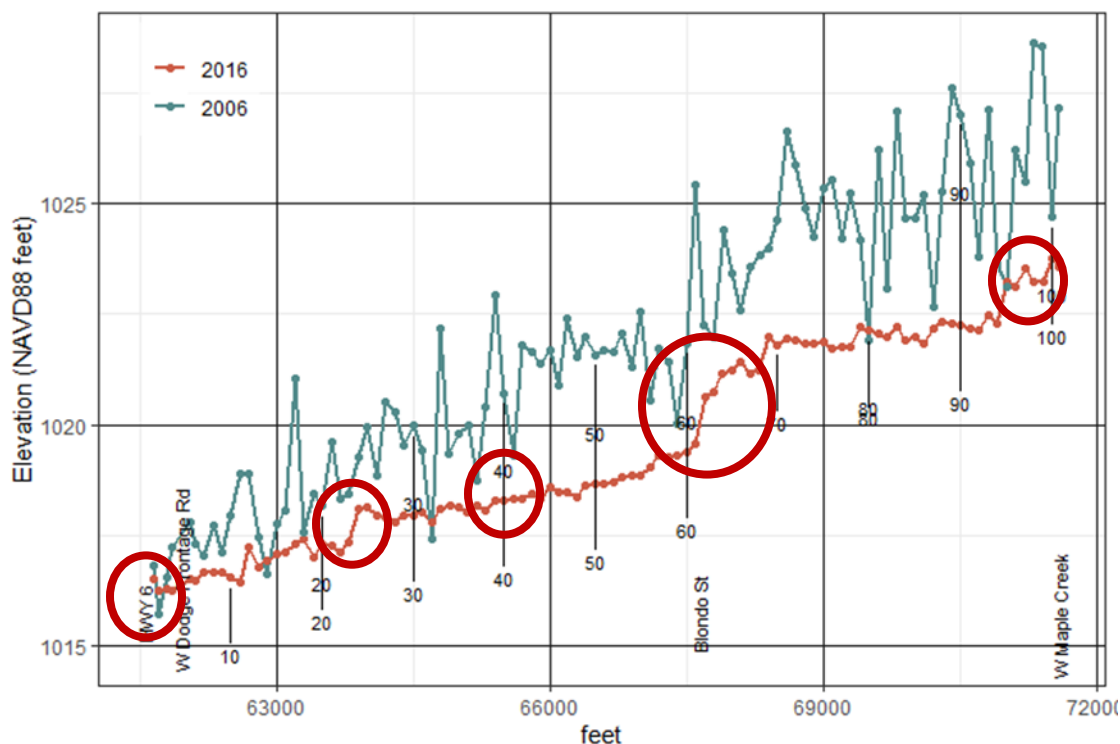


Figure 5-8: Big Papillion Creek FG – Reach 5

Note: GCSs (red circles) or erosion resistant bed materials present.

5.1.6 REACH 6

Reach 6 is primarily urbanized with the upstream area ending at the Standing Bear Reservoir outlet. There are a limited number of agricultural fields in the upper area of the reach that will likely be developed. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at two main bridge locations and other locations between. The largest series of GCSs are located at North 120th Street Bridge. The series of GCSs are a part of an over-steepened section with an approximate elevation drop of five feet (Figure 5-9).
- Based on aerial photo interpretation, the section upstream of North 120th Street, is over-steepened and has significant materials deposited in channel providing bed stability. The existing structures within this area should be investigated further to determine channel and bank stability.
- There is a substantial portion of the reach that has bank erosion control revetments present, and they are likely the source of bed stabilizing materials (Figure 5-9).
- The reach has a watershed size of approximately 136 square-miles, and the channel has been highly modified for industrial and residential stormwater and flood risk management.
- FG cross-sectional analysis comparisons show bank erosion and lateral channel movement in this reach. Based on the limited FG analysis, this reach would be considered a sediment source.
- Land-use transitions moving upstream range from highly urbanized to agricultural. Targeting areas for additional greenspace and streambank erosion (additional geomorphic study required to determine severity) within this reach will provide sediment reduction benefits to the downstream reaches.
- Based on the FG cross-section analysis, there are areas where floodplain berms are building within the incised channel margins. There are other areas where there has been substantial channel erosion. This reach is a mix of sediment source and sink.

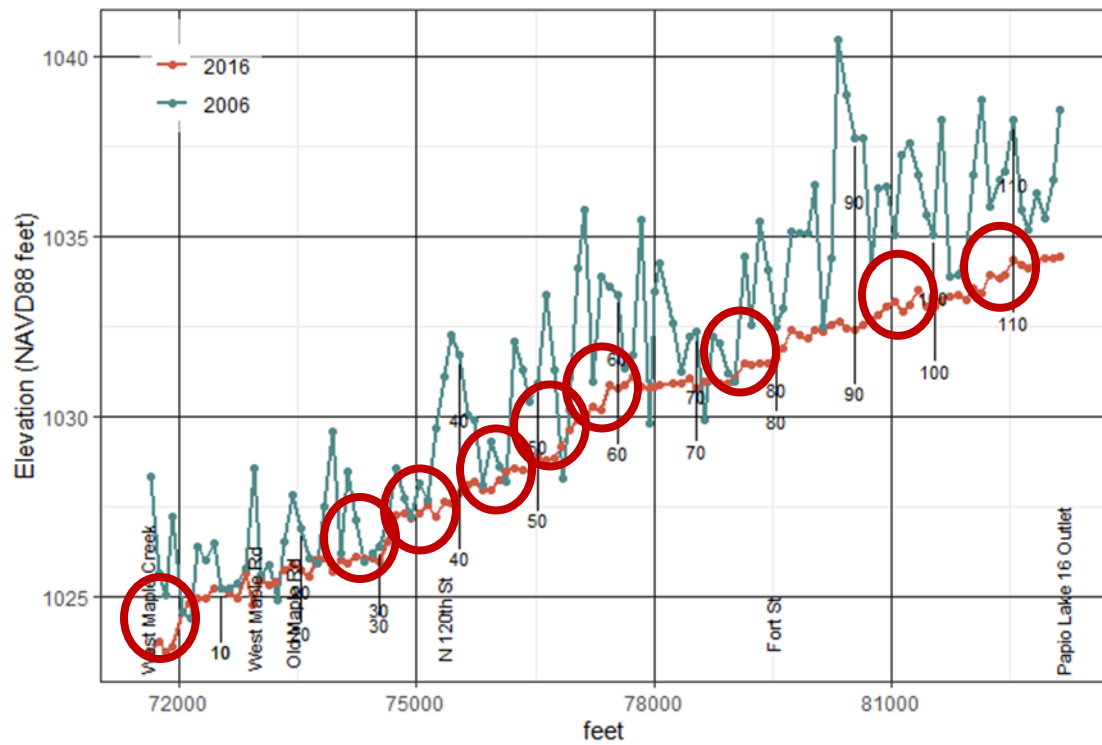


Figure 5-9: Big Papillion Creek FG – Reach 6

Note: GCSs (red circles) or erosion resistant bed materials present.

5.1.7 REACH 7

Reach 7 is primarily agricultural with some residential areas building in the downstream area. This reach will likely continue to urbanize in the upstream direction. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at bridge locations and two other locations (Figure 5-10).
- Comparisons of the FG LiDAR profiles (Figure 5-10) illustrate relatively similar profiles. This reach appears to have a stable bed.
- There are resistant bed materials located within the reach based on the 2016 LiDAR and aerial photo interpretation (Figure 5-10). What makes up these areas is unknown and should be determined through additional field investigations.
- The reach is approximately 121 square-miles and is channelized for the entire reach.
- FG cross-sectional analysis comparisons show the lateral channel movement in many locations but also sediment being deposited in other locations. Based on the limited FG analysis, this reach would be considered partially a sediment source and sink.
- The reach has few urban area developments so access to an active floodplain is likely in most of the reach. It is unknown if frequent storm events and resulting stream flows access floodplain areas. Because of this reach being agricultural, if there is currently no access for floodplain storage; there are opportunities to enhance flood storage to the downstream reaches and Big Papillion Creek watershed.
- Land-use in this reach is likely to see more pressure to urbanize, so enhanced zoning rules with limiting restrictions on land-use and impingements upon the channel are good ideas.
- Concentrating upland runoff reduction practices would assist in this reach to reduce sediment delivery from overland and tributary streams.

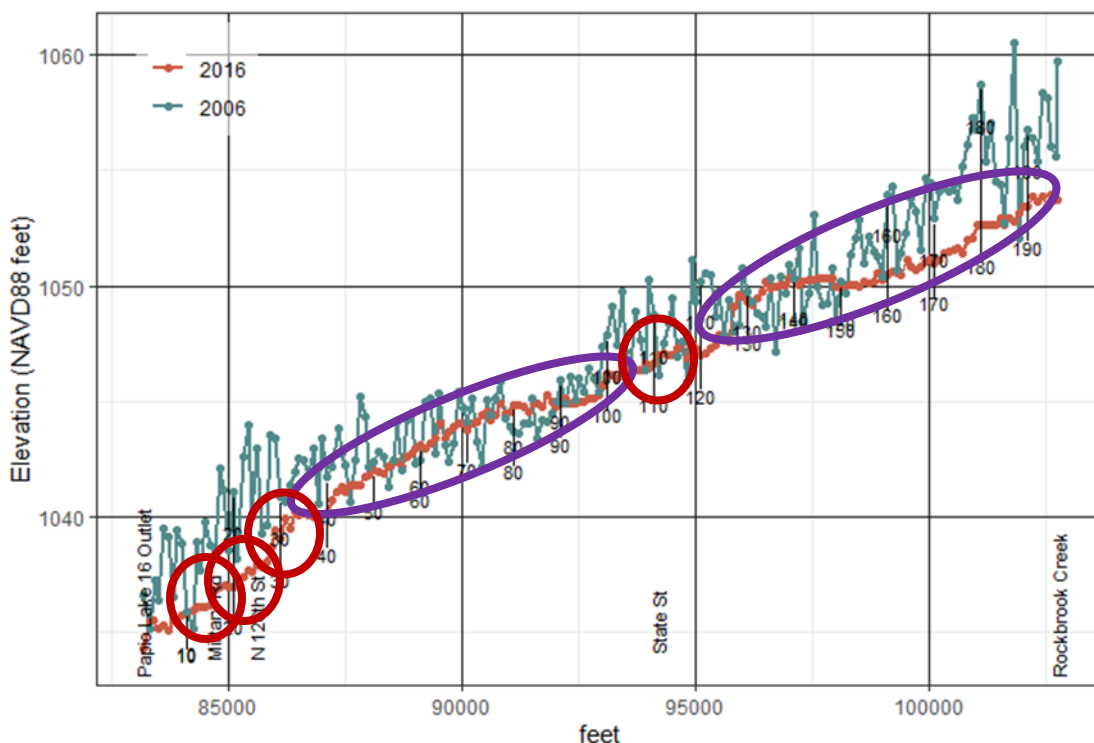


Figure 5-10: Big Papillion Creek FG – Reach 7

Note: GCSs (red circles) field verified, unknown erosion resistant bed materials (Purple circles) either formed from revetment materials or, likely, glacial till.

5.1.8 REACH 8

Reach 8 is primarily agricultural but does contain the Bennington and Bennington Lake developments. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at bridge locations and one other location (Figure 5-11). The largest GCS is located at North 156th Street Bridge and upstream to Bennington Road. The GCSs are part of an over-steepened section with an approximate elevation drop of seven feet (Figure 5-11).
- There is revetment at bridge locations but it's not evident in other areas as compared to the downstream reaches 1-5. There are resistant bed materials located within the reach based on the 2016 LiDAR and aerial photo interpretation. Specific GCS locations need to be verified in the field (Figure 5-11).
- The reach is approximately 110 square-miles, and the channel has been highly modified for agriculture and the lake in the upstream area of the reach.
- FG cross-sectional analysis comparisons show lateral channel movement upstream and deposition downstream. Based on the limited FG analysis, this reach would be considered partially a sediment source and sink.
- Land-use in this reach is likely to see more pressure to urbanize, so enhanced zoning rules with limiting restrictions on land-use and impingements upon the channel are good ideas.

- Concentrating upland runoff reduction practices would assist in this reach to reduce sediment delivery from overland and tributary streams.

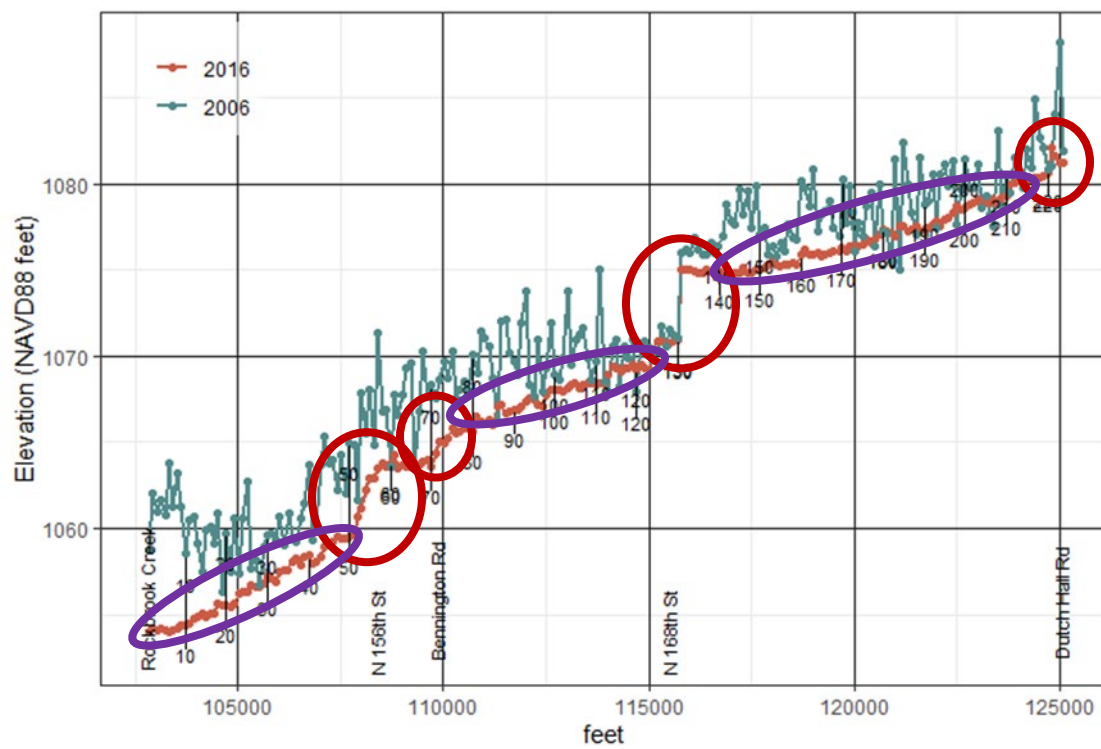


Figure 5-11: Big Papillion Creek FG – Reach 8

Note: GCSs (red circles) field verified, unknown erosion resistant bed materials (Purple circles) either formed from revetment materials, culverts or -likely glacial till.

Big Papillion Creek-Study Recommendations:

This report is based on a limited scope FG Level I CSA. It is recommended to complete more geomorphic analysis including FG level II and III assessments along with additional field assessments. The study recommendations are listed below. This section is meant to provide the overarching recommendations for priorities based on the limited FG Level I analysis and assessment. The Priorities are not in order of relevance.

- **Priority #1:** Use existing GCS locations to continue to stabilize the channel. The structures whether designed or not are the basis for existing channel stability in the system.
- **Priority #2:** Assess existing structures and other areas within the reaches that are providing channel and bank stability.
- **Priority #3:** Reaches 7 and 8 should be investigated to determine if resistive bed materials or natural channel characteristics are providing stability to the reaches.
- **Priority #4:** Where possible, increased floodplain connections should be re-established in Reaches defined in the report. Options could include additional GCS construction to re-establish floodplain berms, levee setbacks or cutting floodplain berms into the existing bank lines or a combination of all of these options. If any work is done, hydraulic analysis will need to be completed to assess potential impacts to flood flow and increasing flood stages.
- **Priority #5:** Target upland areas for water and sediment retention structures where applicable in Reaches 7 and 8.
- **Priority #6:** Complete additional geomorphic analysis upstream of the Washington County line and Big Papillion Creek tributaries to determine critical areas for restoration and stabilization focus.

5.2 LITTLE PAPILLION CREEK

This report is a geomorphic assessment based on limited FG Level I analysis and field site visits. This report follows the Measures and Alternatives Matrix report completed for the Papillion Creek watershed. Many of the Papillion Creek watersheds have similar hydrology, geology, geomorphic characteristics, and land-use. These assumptions provide the basis for comparison of limited watershed data in this report.

Little Papillion Creek is a major tributary watershed (approximately 59 square miles) to Big Papillion Creek, located in northwestern Omaha, NE (Figure 5-12). Little Papillion Creek flows from north to south almost parallel to State Route 133 (upstream reaches) and 72nd Street (downstream reaches). The watershed is mostly agricultural upstream of Glenn Lake Cunningham and fully developed downstream where the FG reaches are established for this study. The lake has approximately 21 square-miles upstream and 38 square-miles downstream of the spillway. Downstream of the lake, FG reaches are entirely urbanized with residential and commercial areas bordering much of the system.

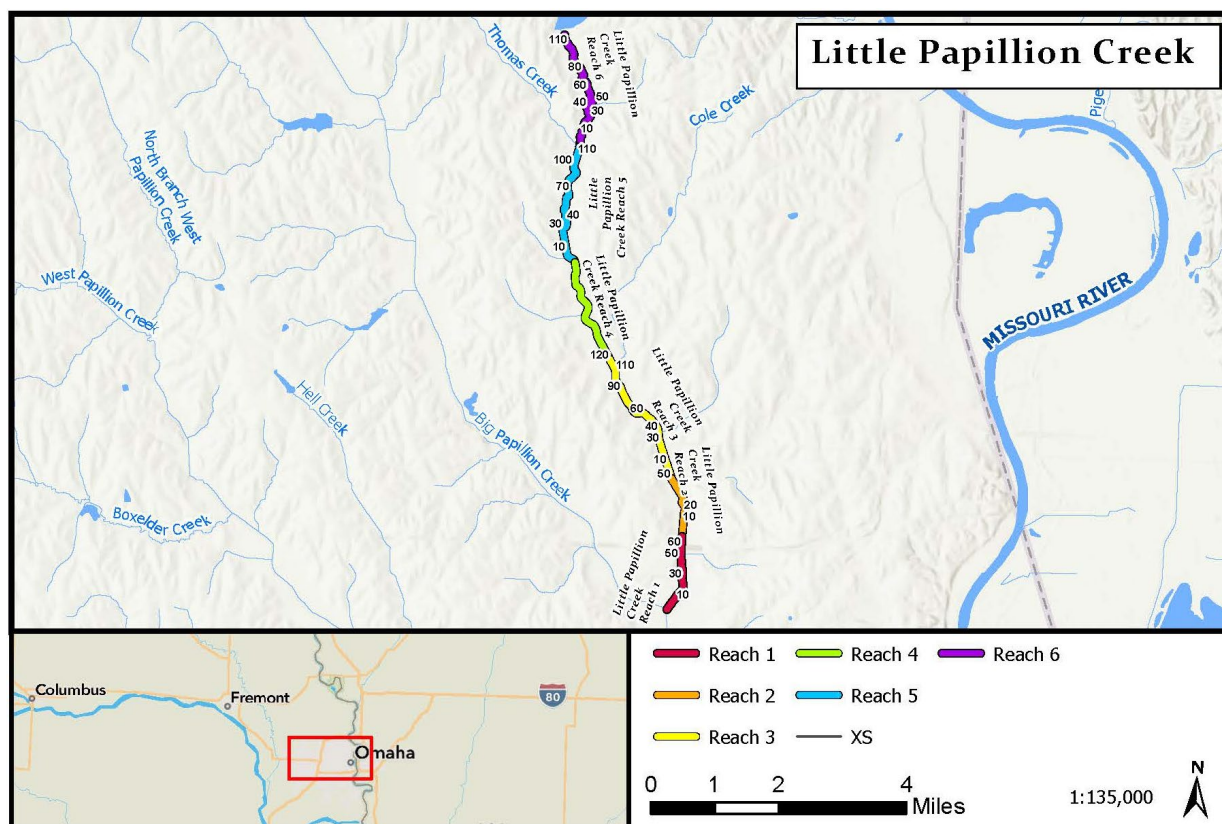


Figure 5-12: Little Papillion Creek FG Level I Reaches

FG Study Reaches and General Assessment:

There are many sections of the creek that have some form of revetment, riprap or other materials present in the channel bed or banks. In most cases, these materials are providing bed or bank stability. It is not known whether these structures and revetments were designed, or materials were placed in stream to protect utility crossings. Some of the material has undoubtedly launched and formed GCSs, stabilizing the channel bed in these locations. Upstream of a GCS in Reach 1, floodplain berms (Figure 5-13) have developed. Compared to

an incised channel (high banks with no floodplain), the berms provide access to the frequent flood events dissipating flow energy across a wide cross-sectional area. It was noted during the site visit, that these floodplain berms developed upstream of GCSs. This is a common feature in the urbanized Papillion Creek watersheds seen during the limited site visits. The next section provides the overall profile and individual Reach information developed for this study. The FG study reaches are defined in Figure 5-14 with individual FG Reach profile plots (2004 and 2016 LiDAR) in each individual reach writeup. Some of these locations were field-verified but many were not due to time restrictions on fieldwork. Each reach has bulleted descriptions based on geomorphic information collected from the field site visits and FG Level I analysis.

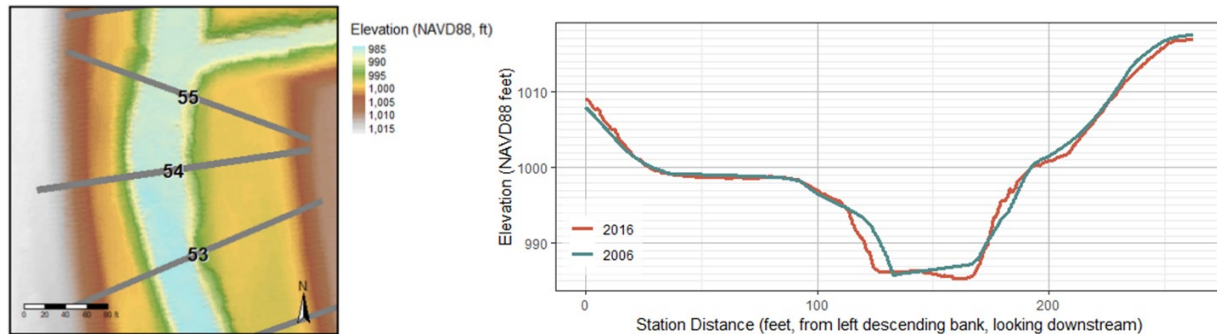


Figure 5-13: Floodplain Berms Developed Upstream of GCS-Little Papillion Creek

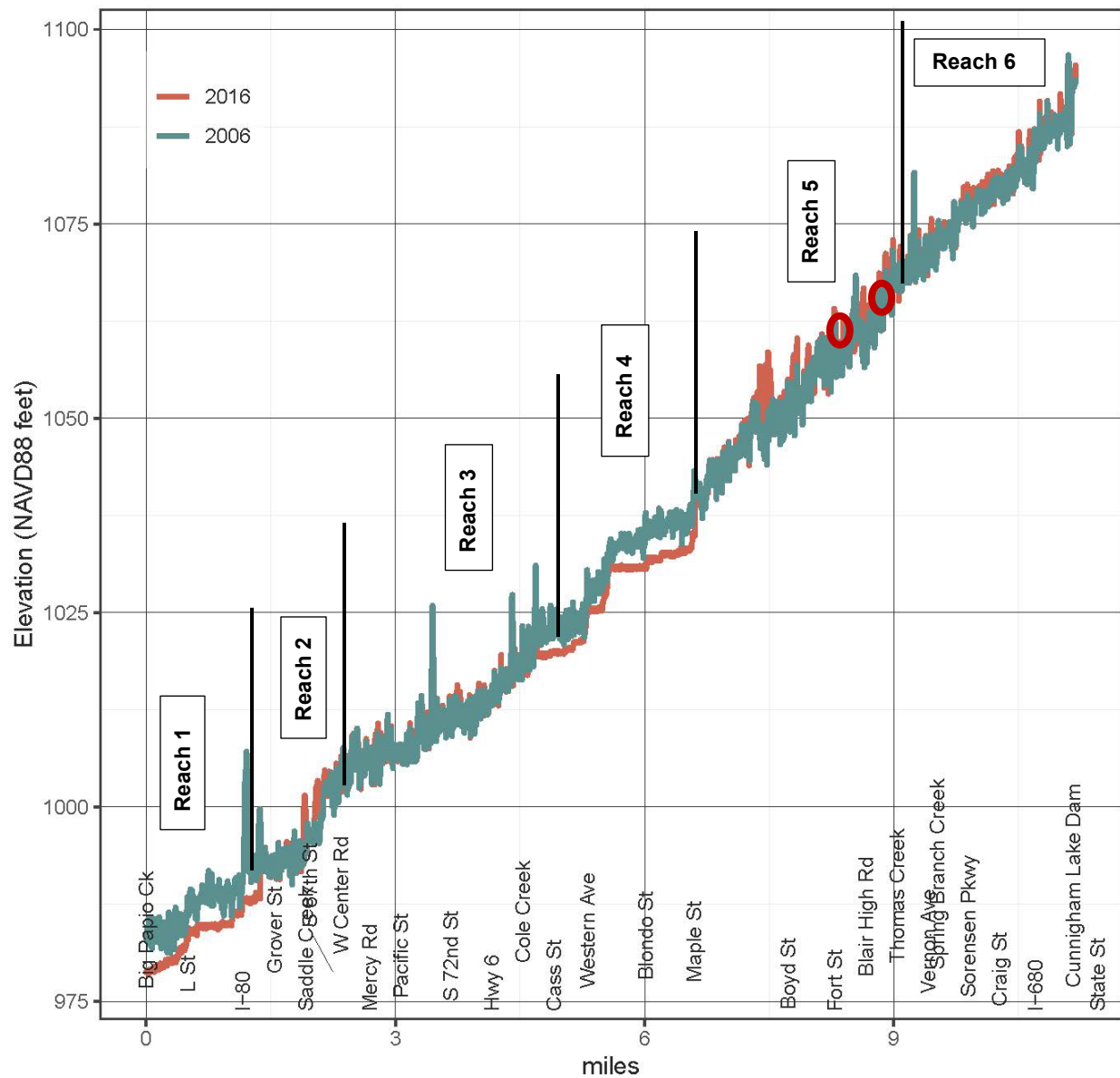


Figure 5-14: Little Papillion Creek FG LiDAR Water Surface Profiles

Note: GCS locations are labeled in Reach 1-6, Figures 5-15 to 5-20.

5.2.1 REACH 1

Reach 1 is a highly modified reach; however, there is greenspace and trails that separate the immediate industrial and residential activity from the stream channel. The list below describes the limited FG and field assessment for the reach.

- GCSs are present at three main bridge locations. The largest GCS is located at L Street approximately 2500 feet upstream of the confluence with Big Papillion Creek. The GCS is part of an over-steepened section with two other GCSs located upstream and downstream with an approximate elevation drop of five feet (Figure 5-15).
- Existing GCS locations should be investigated further to determine stability of structure and potential need for enhancements.
- There are locations within Reach 1 that have access to an active floodplain, which decrease channel velocities and channel boundary shear stress and erosion potential. There are two main floodplain access areas within the reach, one upstream of the confluence with Big Papillion Creek and the other upstream of the GCSs associated with L Street. This reach would be considered a sediment pathway.
- Establishment of floodplain access areas to dissipate and store floodwater would be a great alternative to establish where applicable to the upstream reaches.
- There are additional GCS and other resistant bed materials located within the reach based on the 2016 LiDAR and aerial photo interpretation. Specific GCS locations need to be verified in the field (Figure 5-15).

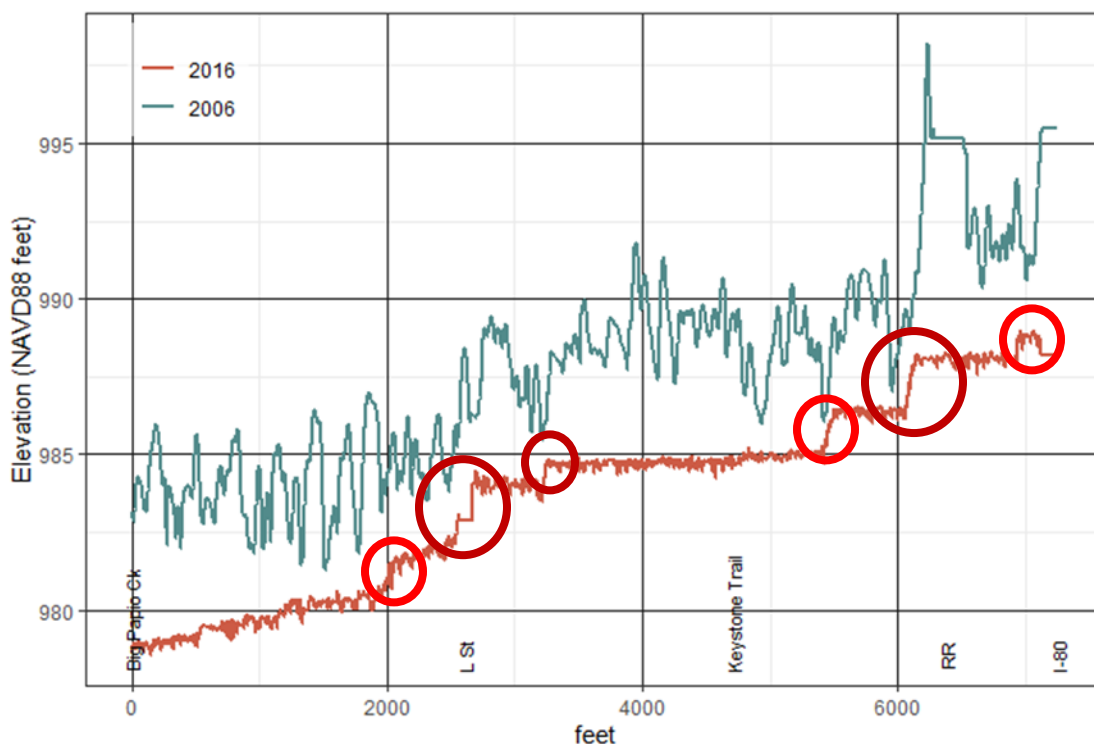


Figure 5-15: Little Papillion Creek FG Reach 1

Note: GCSs (red circles) or erosion resistant bed materials present.

5.2.2 REACH 2

Reach 2 is a highly modified reach; however, it is similar to Reach 2 as there are greenspace and trails that separate the immediate industrial and residential activity from the stream channel. The list below describes the limited FG and field assessments for the reach.

- GCSs are present in the upper half of the reach as there appears to be multiple bank erosion control revetments present through a meandering section of the creek downstream of Saddle Creek outlet (Figure 5-16). There are two more GCSs located upstream of South 67th Street Bridge and West Center Road that may have been created when the bridges were constructed.
- The lower area of the reach has little or no access to an active floodplain, however upstream of the GCSs there are floodplain berms that have formed that illustrate a channel stabilization trend. This reach would be considered a sediment pathway.
- The reach could be enhanced by establishing increased floodplain connections to the lower area of the reach. Options could include additional GCS construction to re-establish floodplain berms or cutting floodplain berms into the existing bank lines or a combination of both. If any work is done, hydraulic analysis would need to be completed to assess potential impacts to flood flow and increasing flood stages.

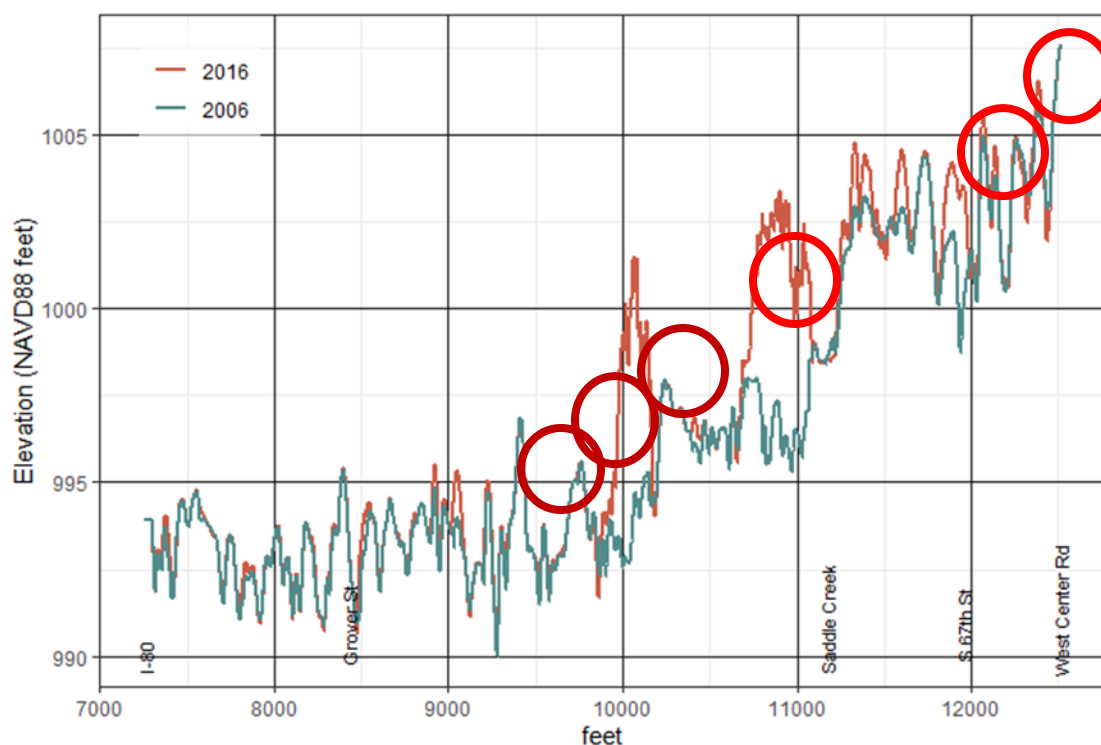


Figure 5-16: Little Papillion Creek FG – Reach 1

Note: GCSs (red circles) or erosion resistant bed materials present.

5.2.3 REACH 3

Reach 3 is similar to Reach 1 and 2 with limited greenspace throughout. The list below describes the limited FG and field assessments.

- GCSs are present at bridge locations and throughout the reach (Figure 5-17).
- Based on the number of GCSs within this reach, each location should be investigated further to determine stability of structure and potential need for enhancements. This may be a reach to further study to determine if some form of natural riffle pool development has occurred. There are a lot of bank revetments within this reach and likely a lot of launched riprap in the channel.
- There are many locations where limited floodplain berms have developed. This is likely limited based on a smaller greenspace width and bank revetments locking the banks in place and not allowing natural alluvial processes to occur. This reach would be considered a sediment pathway.
- Similar to Reach 2, exploring options to widen the greenspace and provide more floodplain access would be desirable.

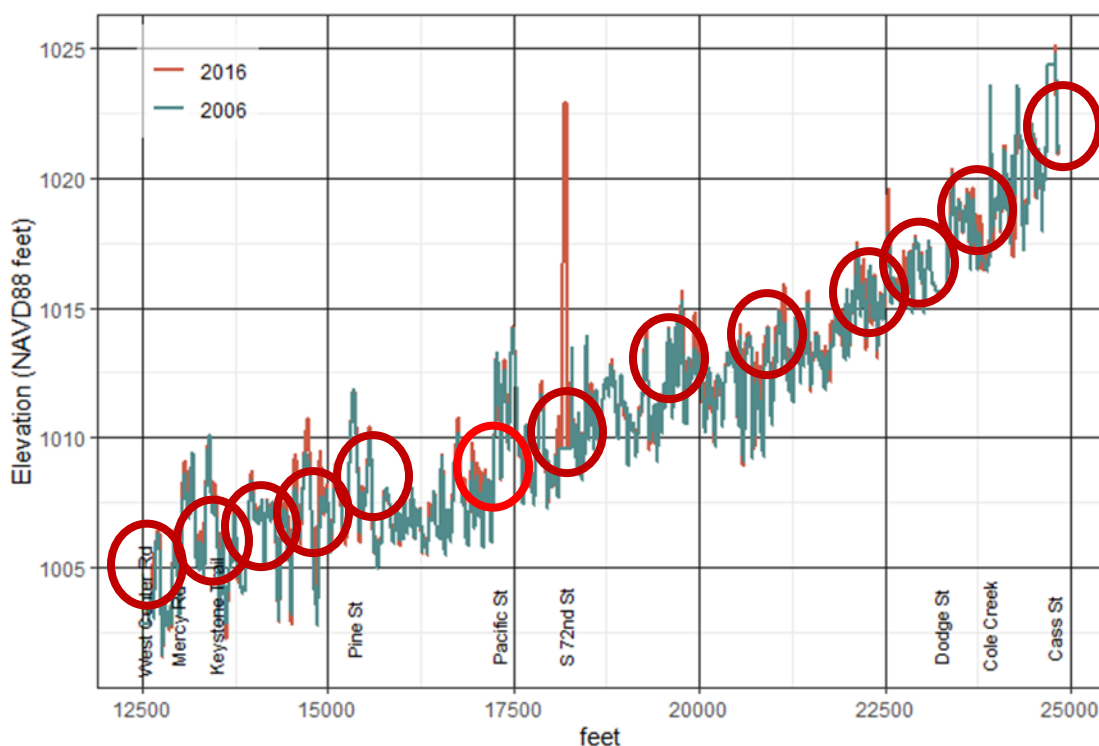


Figure 5-17: Little Papillion Creek FG – Reach 1

Note: GCSs (red circles) or erosion resistant bed materials present.

5.2.4 REACH 4

Reach 4 is like the downstream reaches with limited greenspace and pedestrian trails. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at bridge locations and six other locations within the reach (Figure 5-18). The small upstream elevation increases in the FG 2016 LiDAR profile show locations where GCSs or some form of erosion-resistant bed material may be present. These are likely from launched revetment materials within the reach.
- The largest GCS (series) is located at Western Avenue and upstream to Seward Street. The GCS is part of an over-steepened section with other GCSs located upstream and downstream. The approximate elevation drop is 10 feet (Figure 5-18). This area should be investigated further due to the excessive channel slope change and designs should be reviewed to determine if channel stability will continue.
- Like Reach 3, there are many locations with limited floodplain berms based on a smaller greenspace width and bank revetments locking the banks in place and not allowing natural alluvial processes to occur. This reach would be considered a sediment pathway.
- Like Reaches 2 and 3, exploring options to widen the greenspace and provide more floodplain access would be desirable.

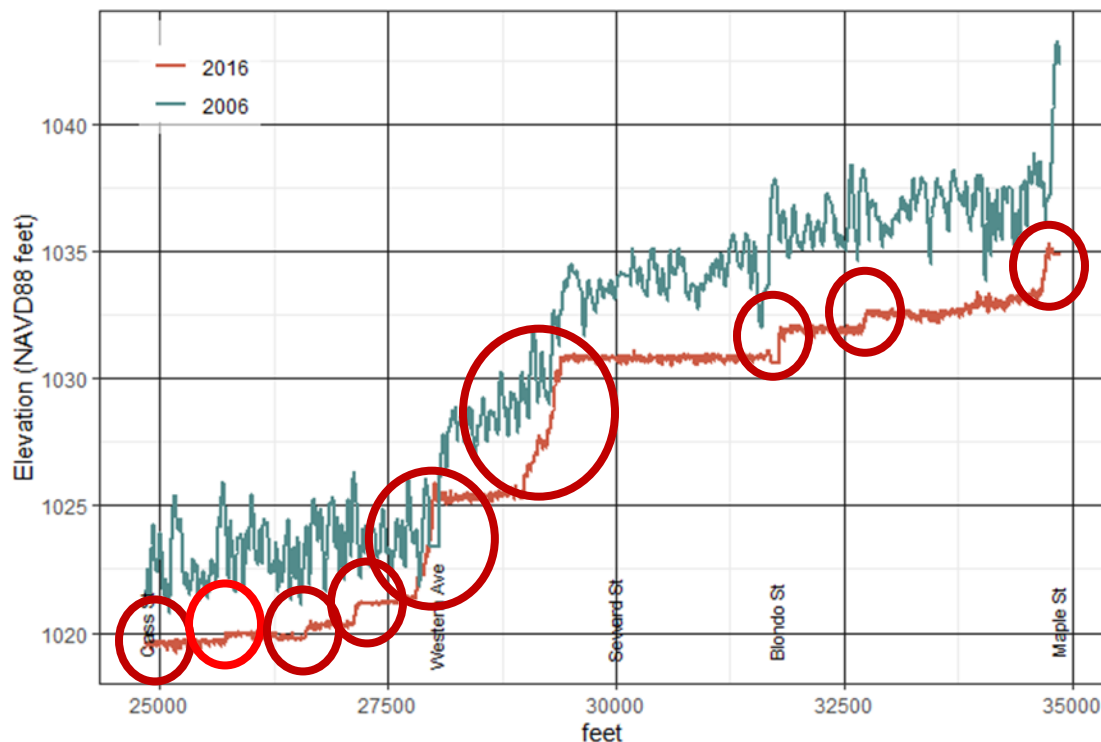


Figure 5-18: Little Papillion Creek FG – Reach 1

Note: GCSs (red circles) or erosion resistant bed materials present.

5.2.5 REACH 5

Reach 5 is split into three main areas. The downstream area is like Reach 4, the middle area is Keystone Park with riparian vegetation that continues upstream to the upstream area that has industrial development on the right bank and agricultural land use on the left bank. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at four main bridge locations (Figure 5-19).
- Comparisons of the FG LiDAR (Figure 5-19) illustrate relatively similar profiles. This reach appears to have a stable bed.
- There is an additional GCS and other resistant bed materials located within the reach based on the 2016 LiDAR and aerial photo interpretation (Purple Circles in Figure 5-19). Specific GCS locations need to be verified in the field.
- The reach has greenspace, bank revetments and GCSs downstream of Keystone Park. This is likely stabilizing the natural meandering channel through the park. The riparian areas should be further assessed with field investigations to determine channel stability. These areas should be targeted to prevent future encroachment on the greenspace.
- Based on the limited FG analysis, this reach would be partially considered a sediment source/pathway.
- Land-use in this area is mostly urban with some agricultural in the upstream area so there are some limited opportunities to provide flood storage and erosion control.

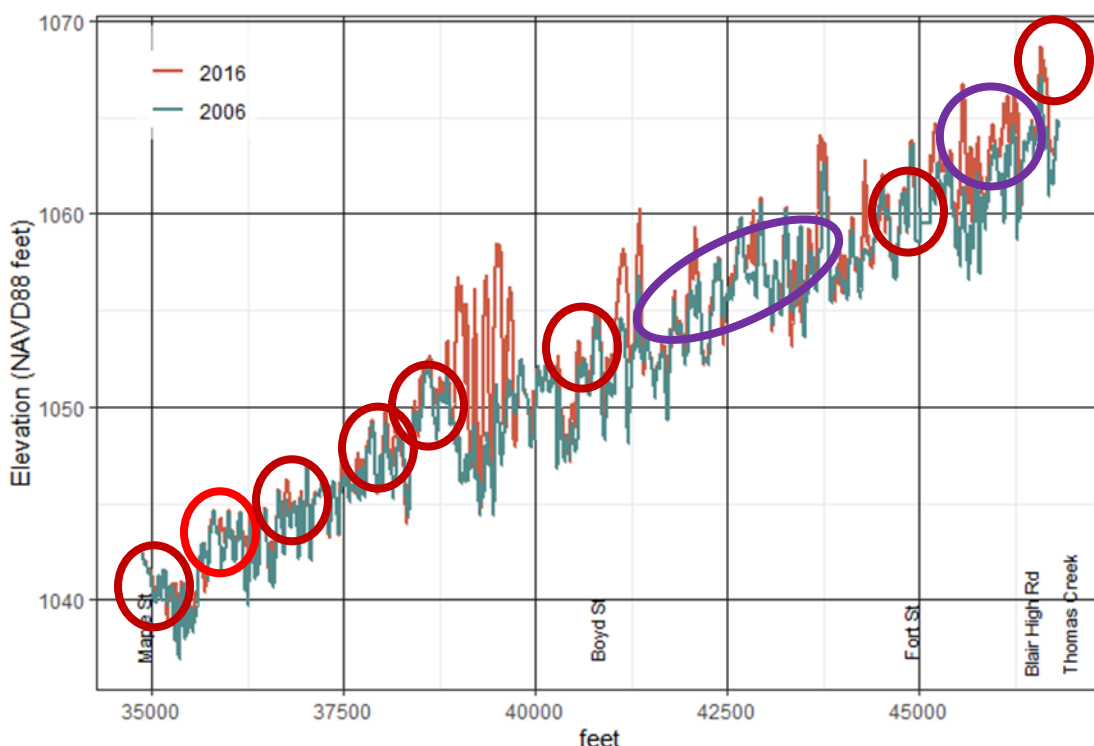


Figure 5-19: Little Papillion Creek FG – Reach 5

Note: GCSs (red circles) field verified, unknown erosion resistant bed materials (Purple circles) either formed from revetment materials, culverts or -likely glacial till.

5.2.6 REACH 6

Reach 6 is primarily urbanized with the upstream area of the watershed being Glenn Cunningham Lake. There are a limited number of agricultural fields in this reach with some larger riparian corridor. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at bridge locations and two other locations (Figure 5-20).
- Comparisons of the FG LiDAR (Figure 5-20) illustrate relatively similar profiles. This reach appears to have a stable bed.
- There are resistant bed materials located within the reach based on the 2016 LiDAR and aerial photo interpretation. Specific GCS locations need to be verified in the field (Figure 5-20).
- The reach is approximately 21 square-miles, and the channel has been highly modified for industrial, agricultural and lake uses in the upstream area of the reach.
- FG cross-sectional analysis comparisons show the most lateral channel movement in this reach. Based on the limited FG analysis, this reach would be partially considered a sediment source.
- Land-use in this area has transitioned from mostly agricultural to highly urbanized. Targeting areas for additional greenspace and streambank erosion (additional geomorphic study required to determine severity) within this reach will provide sediment reduction benefits to the downstream reaches.

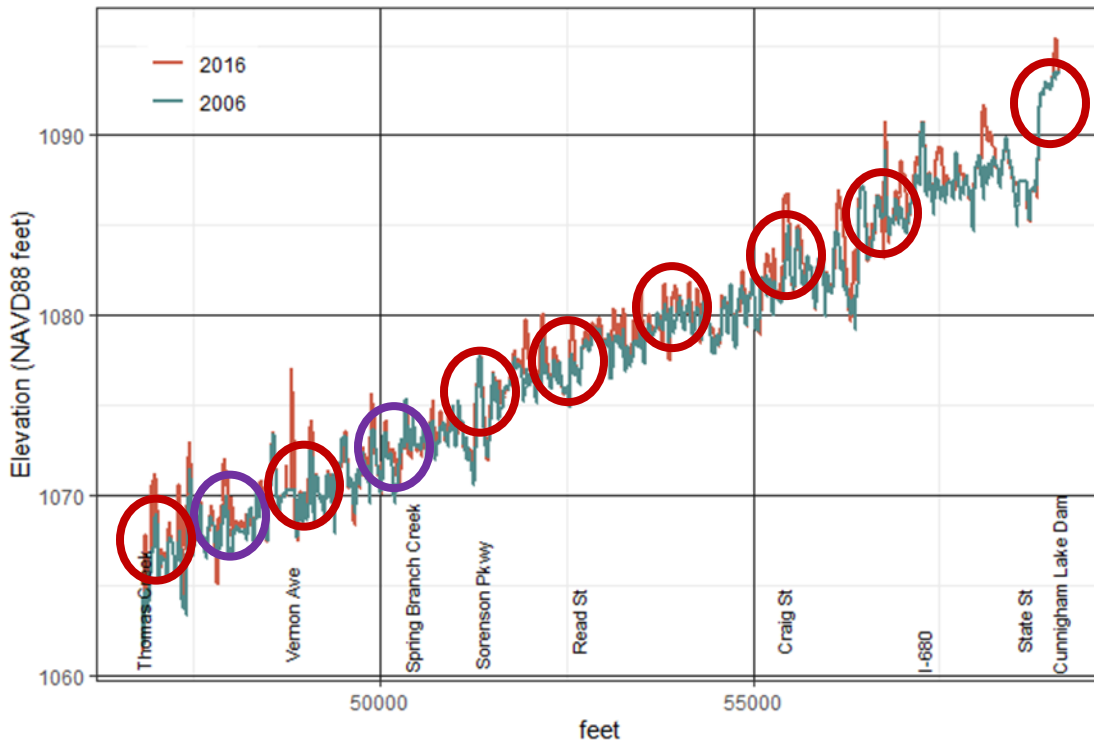


Figure 5-20: Little Papillion Creek FG – Reach 6

Note: GCSs (red circles) field verified, unknown erosion resistant bed materials (Purple circles) either formed from revetment materials, culverts or, likely, glacial till.

Little Papillion Creek-Study Recommendations:

This report is based on a limited scope FG Level I CSA. It is recommended to complete more geomorphic analysis including FG level II and III assessments along with additional field assessments. The study recommendations are listed below. This section is meant to provide the overarching recommendations for priorities based on the limited FG Level I analysis and assessment. The Priorities are not in order of relevance.

- **Priority #1:** Use existing GCS locations to continue to stabilize the channel.
- **Priority #2:** Assess existing structures and other areas within the reaches that are providing channel stability.
- **Priority #3:** Reach 3 should be investigated further due to the excessive channel slope change and any existing revetment designs should be reviewed to determine if channel stability will continue.
- **Priority #4:** Where possible, increased floodplain connections should be re-established in reaches defined in the report. Options could include additional GCS construction to re-establish floodplain berms or cut floodplain berms into the existing bank lines or a combination of both. If any work is done, hydraulic analysis would need to be completed to assess potential impacts to flood flow and increasing flood stages.
- **Priority #5:** If erosion control and sediment reduction is a goal, further study of Reach 6 should be completed to better define channel stability.
- **Priority #6:** Target upland areas for water and sediment retention structures where applicable in Reaches 5 and 6.
- **Priority #7:** Complete additional geomorphic analysis to determine additional areas for restoration and stabilization.

5.3 HELL CREEK

This report is a geomorphic assessment based on limited FG Level I analysis and field visits. This report follows the Measures and Alternatives Matrix report completed for the Papillion Creek watershed. Many of the Papillion Creek watersheds have similar hydrology, geology, geomorphic characteristics, and land-use. These assumptions provide the basis for comparison of limited watershed data in this report.

Hell Creek is an urbanized tributary watershed (approximately six square-miles) to West Papillion Creek, located in the western suburbs of Omaha (Figure 5-21). Hell Creek flows from northwest to southeast, somewhat parallel to 144th Street, before it empties into West Papillion Creek. South Papillion Creek merges with West Papillion Creek near the mouth of Hell Creek (Figure 5-21). The watershed is fully urbanized upstream of Boys Town Reservoir #1 and downstream where three FG reaches were established for this study. The reservoir has less than one square-mile of upstream watershed and consists of underground piping for removing residential storm water. Downstream of the lake, FG reaches are entirely urbanized with residential and commercial areas bordering much of the system.

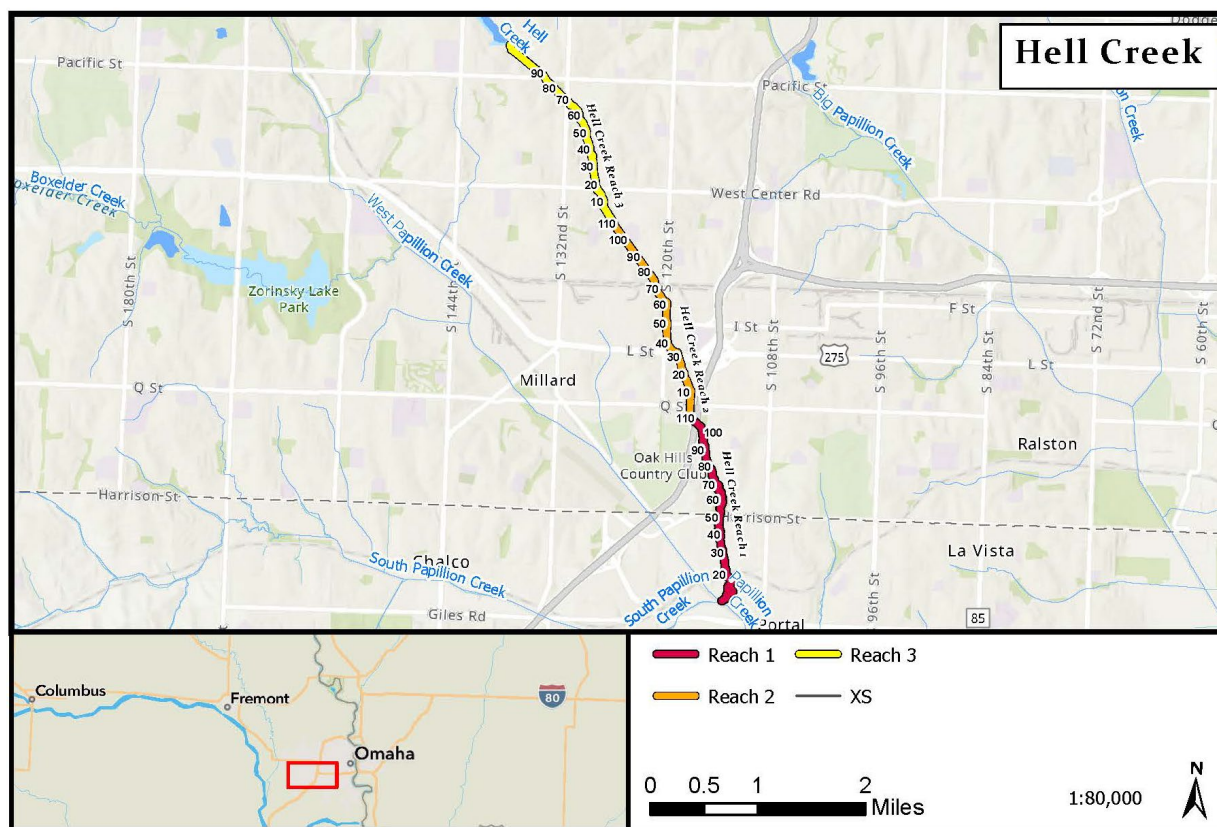


Figure 5-21: Hell Creek FG Level I Reaches

FG Study Reaches and General Assessment:

There are many sections of the creek that have some form of revetment, riprap or other materials present in the channel bed or banks. In most cases, these materials are providing bed or bank stability. It is not known whether these structures and revetments were designed, or materials were placed in stream to protect utility crossings. Some of the material has undoubtedly launched and formed Grade Control Structures (GCS) stabilizing the channel bed

in these locations. One example of a constructed concrete grade control is in Reach 1 at the confluence with West Papillion Creek (Figure 5-22). This is a common feature in the urbanized Papillion Creek watersheds seen during the limited site visits. The next section provides the overall profile and individual Reach information developed for this study. The FG study reaches are defined in Figure 5-23 with individual FG Reach profile plots (2004 and 2016 LiDAR) in each individual reach writeup. Some of these locations were field verified but many were not due to time restrictions on fieldwork. Each reach has bulleted descriptions based on geomorphic information collected from the field site visits and FG Level I analysis.



Figure 5-22: Concrete GCS at the Mouth of Hell Creek

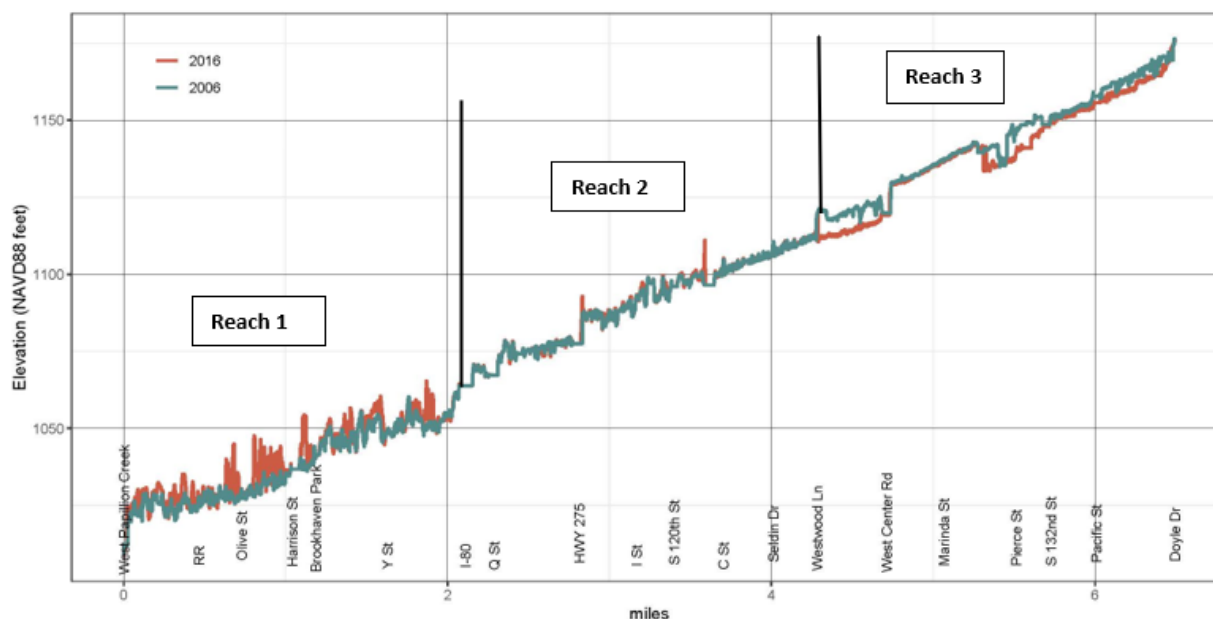


Figure 5-23: Hell Creek FG LiDAR Water Surface Profiles

Note: GCS locations are labeled in Reach 1-3 Figures 5-24 through 5-26.

5.3.1 REACH 1

Reach 1 has a riparian corridor with recreational trails that separate the immediate industrial and residential activity from the stream channel. The lower quarter mile of stream (upstream of the GCS located at the mouth) has a tortuous meandering channel with significant bank erosion; this area is likely some of the original pre-settlement channel. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at four main bridge locations (Railroad Crossing, Olive Street, Harrison Street, I-80 culverts) and a low-water crossing in Brookhaven Park. The largest series of GCSs and elevation drops in the reach are located approximately 350 feet downstream of Harrison Street, continuing upstream approximately 700 feet at a concrete and riprap structure in Brookhaven Park. The upstream structure is part of a sewer outfall inlet structure from the east. The approximate elevation drops are 15 feet (Figure 5-24).
- Additional study should be completed to assess the existing GCS locations to determine stability of structure and potential need for enhancements.
- There are additional GCSs located within the reach based on the 2016 LiDAR and aerial photo interpretation. Specific GCS locations need to be verified in the field (Figure 5-24).
- There are very few locations within Reach 1 that have access to an active floodplain which is typical of urban incised channels. One location is immediately upstream of the confluence of Hell Creek and West Papillion Creek. Upstream of the concrete GCS there is a wide terrace (previous floodplain) that could potentially provide floodplain access and storm water storage. This would need to be studied in much more detail to determine what benefits would be gained for the downstream West Papillion Creek reaches.
- This reach would be considered a sediment source as there is bank line erosion in many locations, some threatening the existing pedestrian trails.
- Establishment of floodplain access areas to dissipate and store floodwater would be a great alternative to establish, where applicable for the upstream reaches.

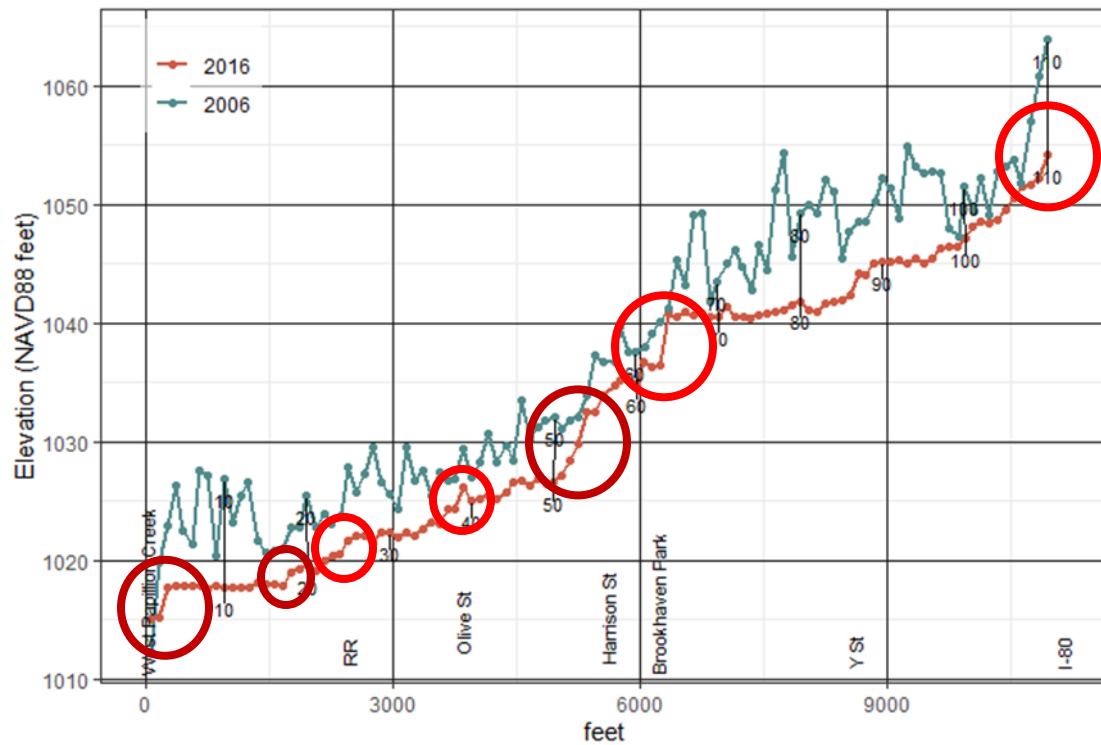


Figure 5-24: Hell Creek FG LiDAR Water Surface Reach 1 Profiles

Note: GCSs (red circles) or erosion resistant bed materials present.

5.3.2 REACH 2

Reach 2 has a highly modified channel with all but the lower quarter mile completely channelized. The list below describes the limited FG and field assessment for the reach.

- GCSs are present at all bridge crossings, with some very large culverts also present at I-80 and Highway 275 (Figure 5-25). There is a large concrete GCS located at the upstream terminus of the reach under Westwood Lane. From Westwood Lane downstream to the Railroad crossing culverts, the stream channel was concrete lined until approximately 2015-2016. The concrete lining was removed, and riprap was used to stabilize the reaches through what appears to be a series of loose rock riffle GCSs and riprap bank revetments. This area, while not in a state of natural stream conditions, appears to be naturalized (limited) and should be monitored and potentially used as a template for implementation in other watersheds where applicable conditions exist.
- Based on the FG profiles, there has been little or no change to the channel gradient and while there are some major elevation drops within the reach, they are largely controlled by rigid materials (culverts and revetments).
- Based on FG cross-sections, there has been little bank erosion. This reach would be considered a sediment pathway.

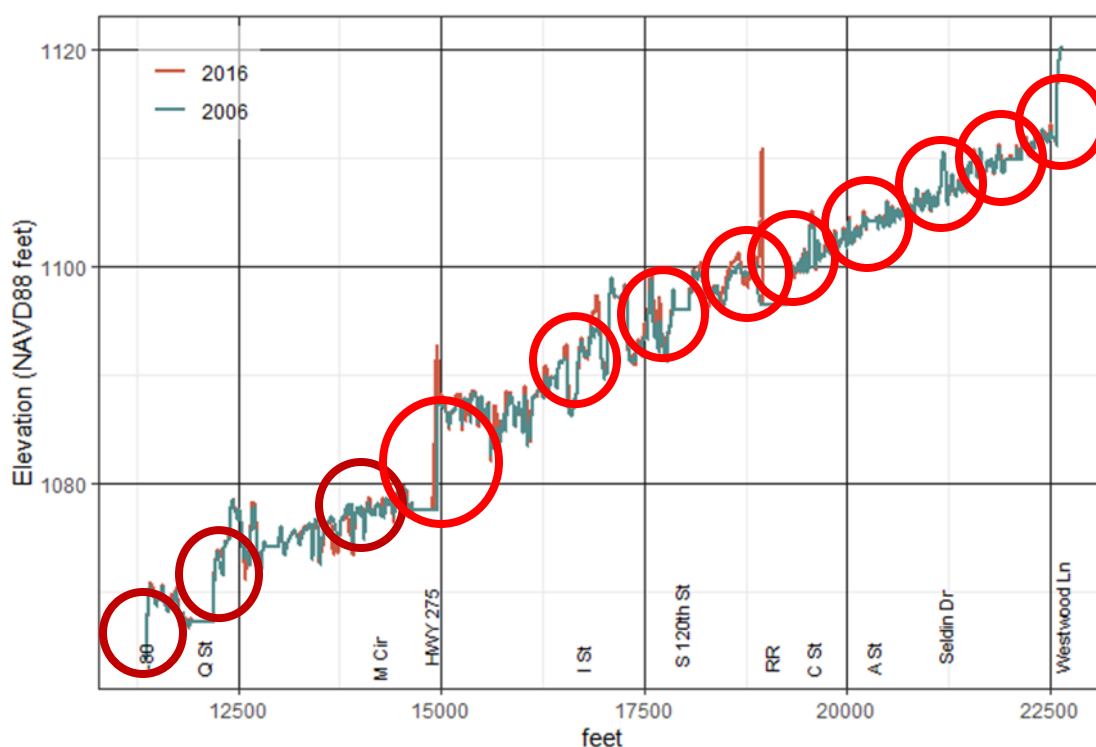


Figure 5-25: Hell Creek FG LiDAR Water Surface Reach 2 Profiles

Note: GCSs (red circles) or erosion resistant bed materials present.

5.3.3 REACH 3

Reach 3 is like Reach 1 and 2, being highly modified, but has more greenspace throughout. The downstream area has Westwood Golf Course, middle area has residential neighborhoods and the upstream is a detention basin with some riparian corridor, pedestrian trails, Trendwood Park, and Boys Town Reservoir #1 at the upstream end. The list below describes the limited FG and field assessment for the reach.

- GCSs are present at some bridge locations and throughout the reach (Figure 5-26).
- Hell Creek is piped underground from Faith Place Road to West Center Road.
- The channel downstream of West Center Road has degraded through the Westwood Golf Course reach. The channel degradation may be a result of changes to the Westwood Lane GCS or continued channel adjustments from past system-wide instability.
- Based on the FG profiles, the area upstream of Westwood Lane and Faith Place Road are water detention basins. The basin upstream of Faith Place Road was recently excavated and constructed between 2006 and 2016.
- This reach of the watershed is largely developed and managed for stormwater storage. There is minor erosion on some sections of banks, but no major issues, based on the FG cross-section analysis. This reach would be considered a sediment pathway.
- It appears that all the widening and channel alteration options for greenspace and potential for providing more floodplain access have been developed for this reach.

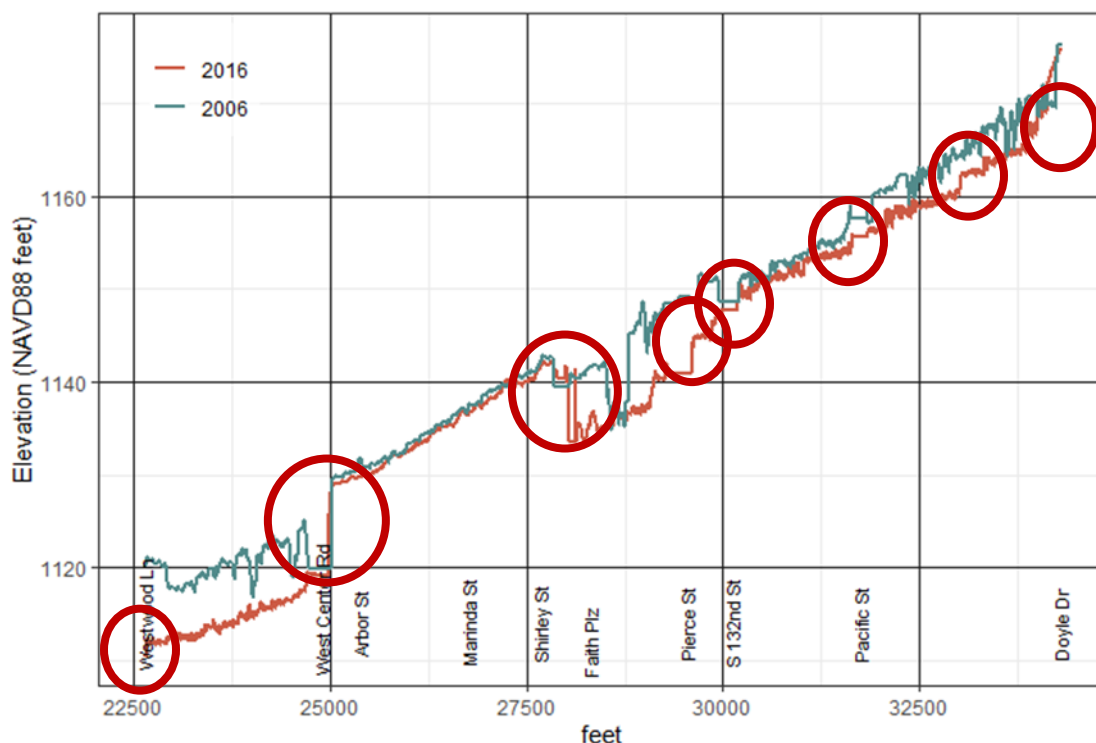


Figure 5-26: Hell Creek FG LiDAR Water Surface Reach 3 Profiles

Note: GCSs (red circles) or erosion resistant bed materials present.

Hell Creek-Study Recommendations:

This report is based on a limited scope FG Level I CSA. It is recommended to complete more geomorphic analysis including FG level II and III assessments along with additional field assessments. The study recommendations are listed below. This section is meant to provide the overarching recommendations for priorities based on the limited FG Level I analysis and assessment. The Priorities are not in order of relevance.

- **Priority #1:** Use existing GCS locations to continue to stabilize the channel.
- **Priority #2:** Assess existing structures and revetments within the reaches that are providing channel bed and bank stability.
- **Priority #3:** If erosion control and sediment reduction is a goal for the system, specifically the downstream reaches of West Papillion Creek, additional study of Reach 1 should be completed to better define streambank stability and priority location for restoration. The reach is considered a sediment source with streambank erosion in many locations, some threatening the existing pedestrian trails. Alternatives for bank stabilization measures should be considered for this reach.
- **Priority #4:** Target upland areas for water and sediment retention structures where applicable in all reaches.
- **Priority #5:** Complete additional geomorphic analysis to determine additional areas for restoration and stabilization priorities.

5.4 THOMAS CREEK

This report is a geomorphic assessment based on limited FG Level I analysis and field visits. This report follows the Measures and Alternatives Matrix report completed for South Papillion Creek. Many of the Papillion Creek watersheds have similar hydrology, geology, geomorphic characteristics, and land-use. These assumptions provide the basis for comparing limited watershed information to provide this report.

Thomas Creek is a small tributary watershed to Little Papillion Creek, located in northwestern Omaha. Thomas Creek flows from north to south almost parallel to State Route 133. Approximately 75 percent of the watershed is agricultural with the top of the watershed located on the Blair Municipal Airport. The lower section of the creek is urbanized in vicinity of the State Route 133 and Interstate 680 intersection, just before Thomas Creek merges with Little Papillion Creek, just downstream of Glenn Cunningham Lake.

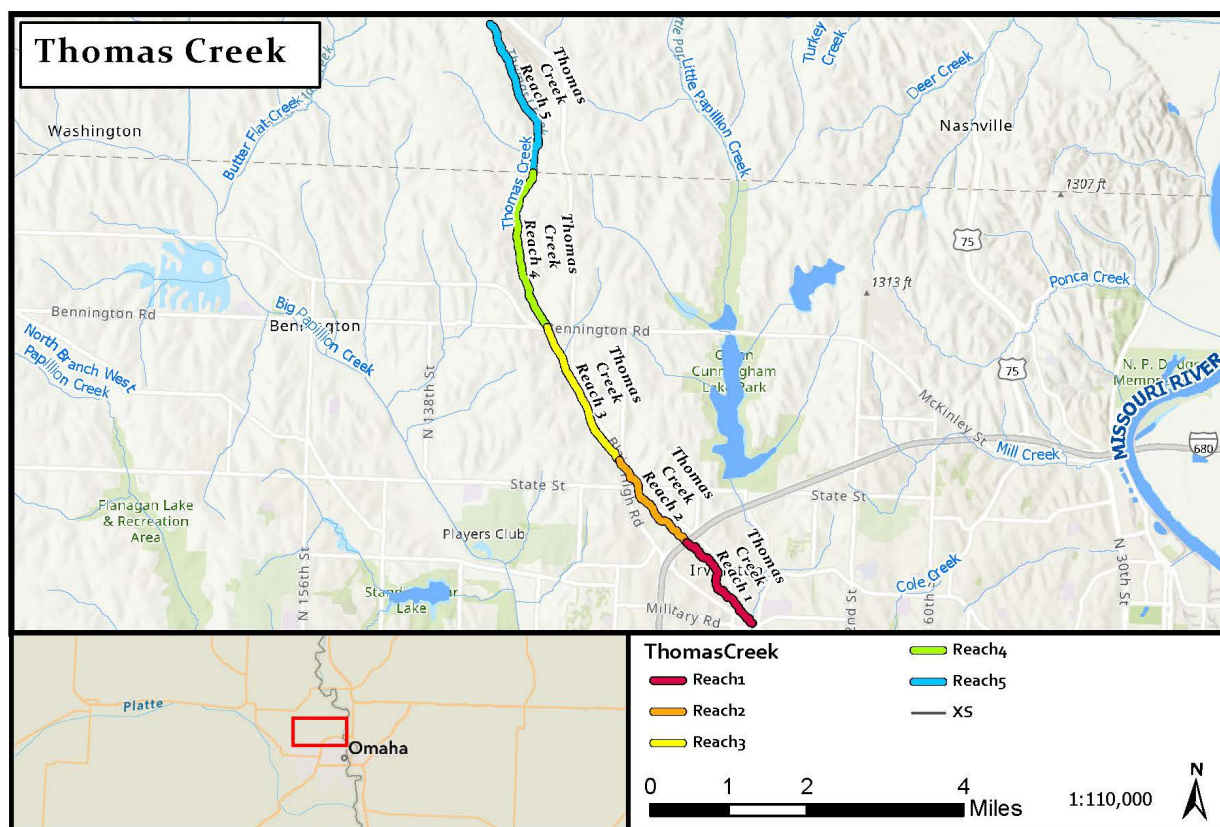


Figure 5-27: Thomas Creek FG Level I Reaches

FG Study Reaches and General Assessment:

There are many sections of the creek that have riprap or other materials present that are providing bed or bank stability. It is not known whether these structures and revetments were designed, or materials were placed in stream, or they have launched and formed GCSs as illustrated in Figure 5-28. This figure illustrates the rock riprap GCS located in the center of the channel providing bed stability (upstream bank stability) between the Blair High Road Bridges marking the transition between Reach 2 and 3. This is a common feature in all the Papillion Creek watersheds seen during the limited site visits completed for this study.

The next section provides the overall profile and individual Reach information developed for this study. Figure 5-29 provides locations where GCSs (red circles) were located during the site visit. The individual FG profile plots (2004 and 2016 LiDAR) provide an estimate of where additional GCSs are located within the Reaches. Some of these locations were field verified but many were not due to time restrictions on fieldwork. Each reach has bulleted descriptions based on geomorphic information collected from the field site visits and FG Level I analysis.



Figure 5-28: Grade Control Structure Located Under Blair High Road Bridge – Thomas Creek

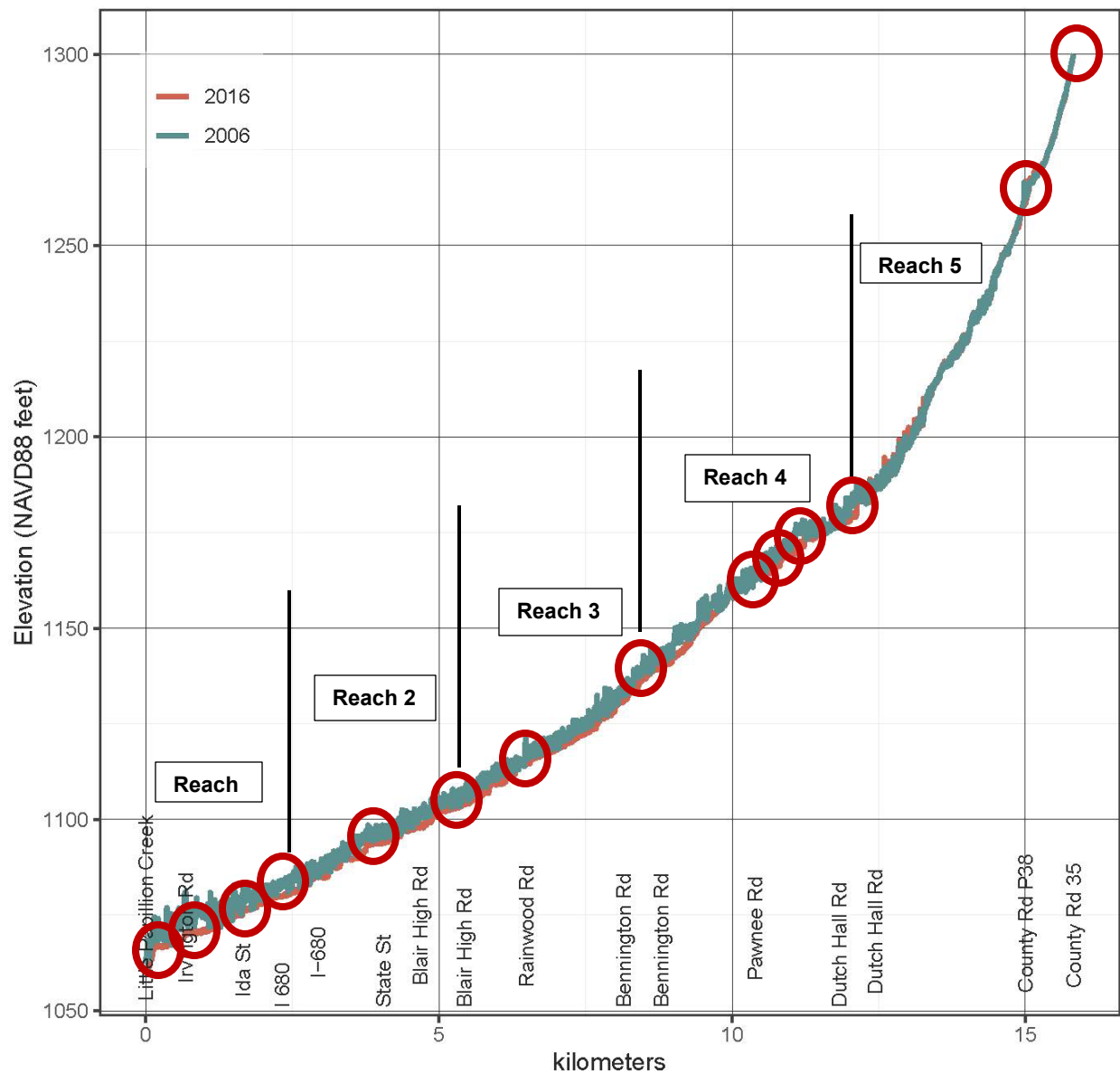


Figure 5-29: Thomas Creek FG LiDAR Water Surface Profiles with GCSs (red circles)

5.4.1 REACH 1

Reach 1 is highly modified with industrial activity impacting stream channel characteristics and limiting natural processes. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at three main bridge locations possibly from encroachment and infilling of the floodplain and channel margins from land-use practices. The largest GCS is located at the mouth of Thomas Creek where it meets Little Papillion Creek. The GCS is located upstream of station 0+00 and has approximately seven feet of elevation drop (Figure 5-30).
- Existing GCS locations should be investigated further to determine stability of structure and potential need for enhancements.
- There is little or no access to an active floodplain in Reach 1, which increases channel velocities and channel boundary shear stress, increasing runoff rates from this reach. This reach would be considered a sediment pathway.
- The reach could be enhanced with limiting restrictions on land-use and impingements upon the channel. Land-use in this area is unlikely to change so there is little value in concentrating restoration funding in this reach.
- There are additional GCSs and other resistant bed materials located within the reach, based on the 2016 LiDAR and aerial photo interpretation. Specific GCS locations need to be verified in the field (Figure 5-30).

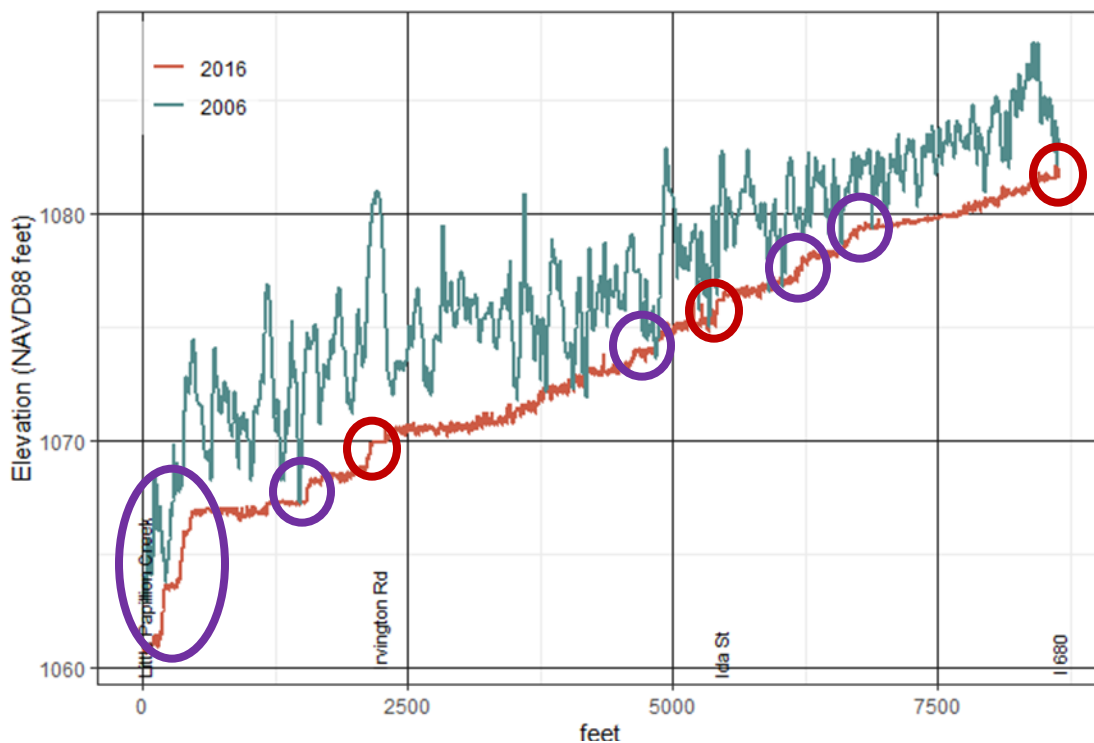


Figure 5-30: Thomas Creek FG – Reach 1

Note: GCSs (red circles) field verified, unknown erosion resistant bed materials (purple circles) either formed from revetment materials, culverts or likely, glacial till.

5.4.2 REACH 2

Reach 2 has some urbanized areas within the lower half and agricultural areas in the upstream areas. The reach is starting to urbanize and will likely continue putting more pressure on the stream corridor. The list below describes the limited FG and field assessments for the reach.

- GCSs are present throughout the reach possibly from encroachment and infilling of the floodplain and channel margins from land-use practices (Figure 5-31). The Blair High Road Bridge has a GCS under the upstream bridge that appears to have been constructed during construction of the bridges (Figure 5-31).
- Existing GCS locations should be investigated further to determine stability of structure and potential need for enhancements.
- There are additional GCSs and other resistant bed materials located within the reach, based on the 2016 LiDAR and aerial photo interpretation. Specific GCS locations need to be verified in the field (Figure 5-31).
- The lower area of the reach has little or no access to an active floodplain due to a residential neighborhood on the left bank and an industrial area on the right. There is an opportunity to provide floodplain access thereby providing for flood storage in the upstream area of the reach. This would need to be weighed against the pressure for development and the increase to channel velocities and increasing runoff rates to the downstream Reach 1 and South Papillion Creek areas. This reach would be considered a sediment pathway.
- The reach could be enhanced with limiting restrictions on land-use and impingements upon the channel. Land-use in this area is unlikely to change so there is little value in concentrating restoration funding in this reach could be most effective in the upstream area of the reach.

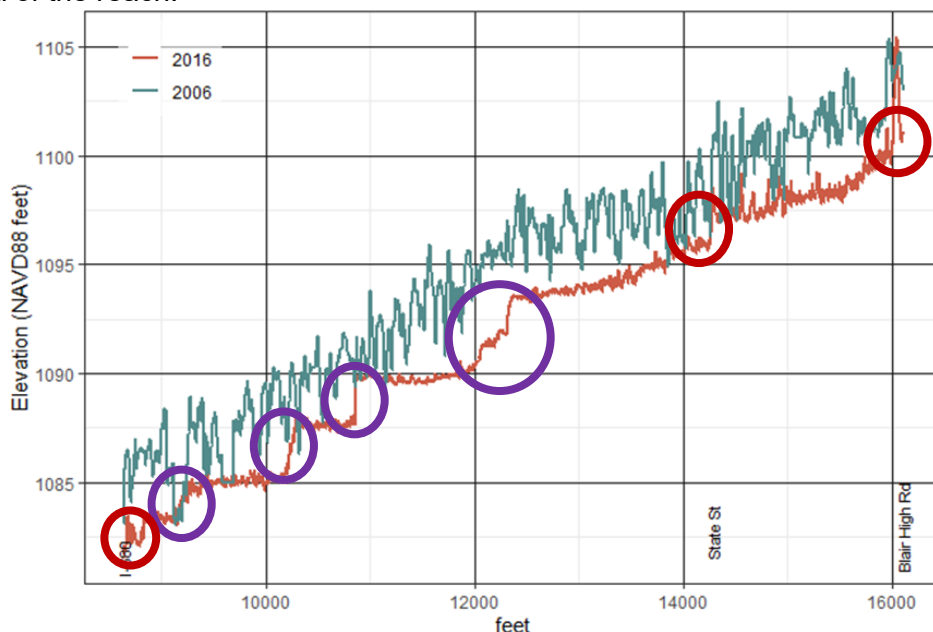


Figure 5-31: Thomas Creek FG – Reach 2

Note: GCSs (red circles) field verified, unknown erosion resistant bed materials (purple circles) either formed from revetment materials, culverts or likely, glacial till.

5.4.3 REACH 3

Reach 3 is primarily agricultural with limited industrial activity in the middle of the reach. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at three main bridge locations (Figure 5-32).
- Existing GCS locations should be investigated further to determine stability of structure and potential need for enhancements.
- There are additional GCS and other resistant bed materials located within the reach based on the 2016 LiDAR and aerial photo interpretation. Specific GCS locations need to be verified in the field (Figure 5-32).
- The reach has little-to-no urban area developments so access to an active floodplain is possible, but it is unknown if the frequent storm and resulting flow events access the floodplain areas within the reach. Because of the limited urbanized areas, there is an opportunity to provide floodplain access thereby providing for flood storage to the downstream reaches and South Papillion Creek watershed. This reach would be considered a sediment pathway.
- Land-use in this area is mostly agricultural so there is high value in concentrating restoration funding in this reach.

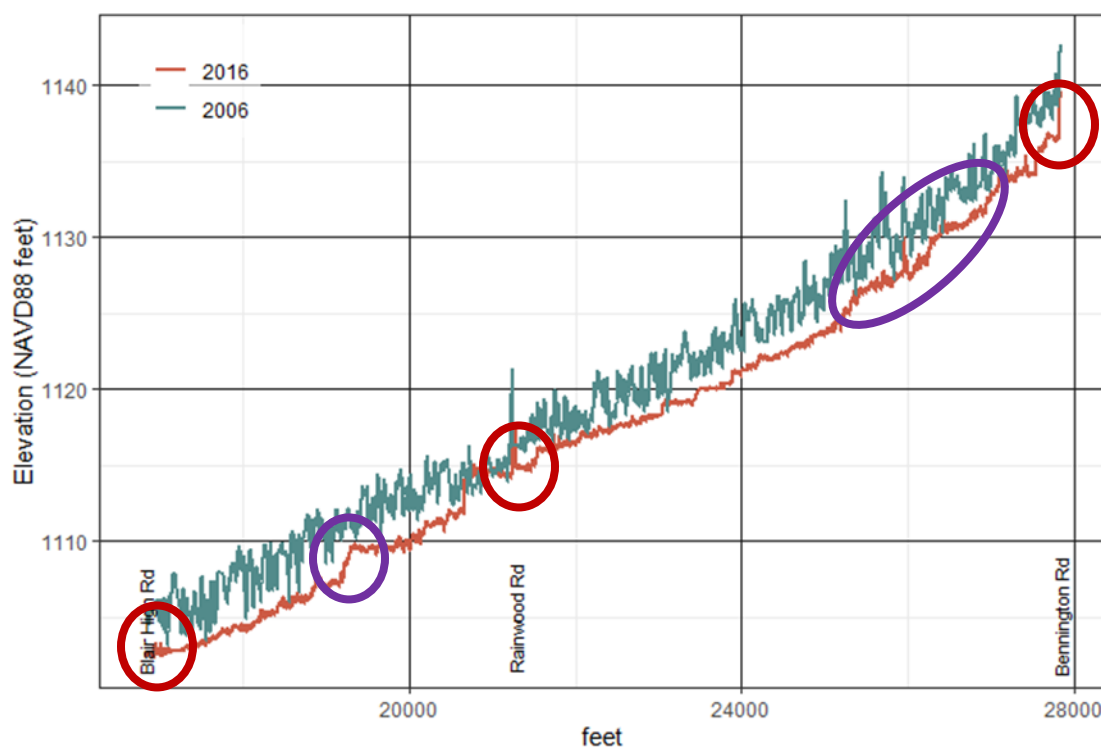


Figure 5-32: Thomas Creek FG – Reach 3

Note: GCSs (red circles) field verified, unknown erosion resistant bed materials (Purple circles) either formed from revetment materials, culverts or likely glacial till.

5.4.4 REACH 4

Reach 4 is primarily agricultural with most of Thomas Creek being a relatively straight channel. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at two main bridge locations and three driveway crossings in the upstream area of the reach (Figure 5-33). The driveway crossings are bridges, likely with riprap or some other erosion-resistant materials providing bed stability to the upstream channel.
- Comparisons of the FG LiDAR profiles (Figure 5-33) illustrate a likely channel degradation pattern upstream of Bennington Road and again upstream of Pawnee Road.
- Existing GCS locations should be investigated further to determine stability of structure and potential need for enhancements.
- There are additional GCSs and other resistant bed materials located within the reach based on the 2016 LiDAR and aerial photo interpretation. Specific GCS locations need to be verified in the field (Figure 5-33).
- The reach has no urban area developments so access to an active floodplain is likely in most of the reach. It is unknown if frequent storm events and resulting stream flows access floodplain areas. Because of this reach being agricultural, if there is currently no access for floodplain storage, there are opportunities to enhance flood storage to the downstream reaches and South Papillion Creek watershed. Based on the limited FG analysis, this reach would be considered a sediment source.
- Land-use in this area is mostly agricultural so there is high value in concentrating restoration funding in this reach where applicable.

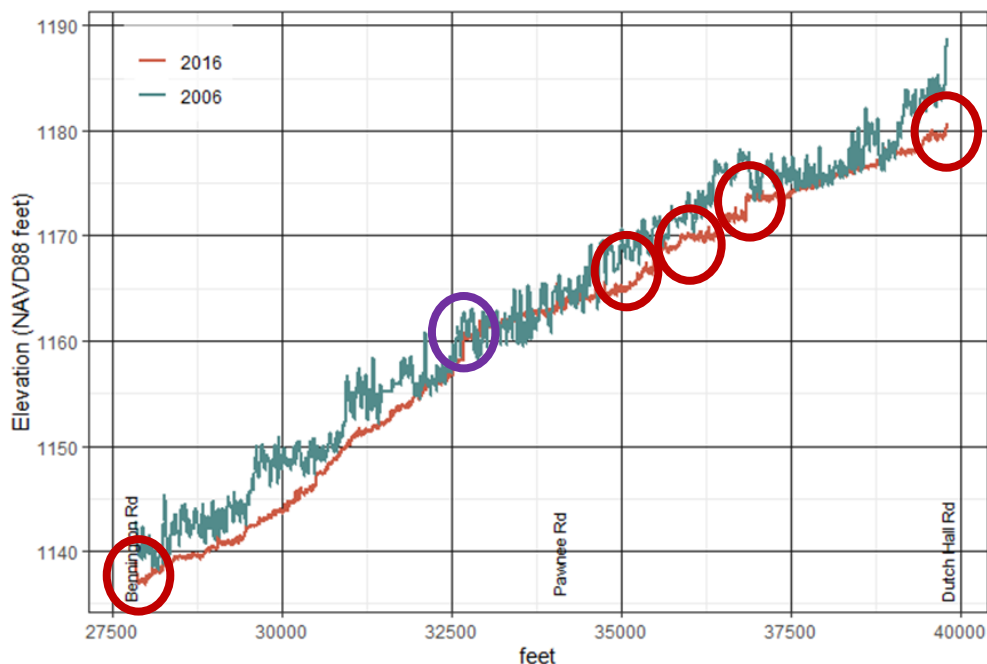


Figure 5-33: Thomas Creek FG – Reach 4

Note: GCSs (red circles) field verified, unknown erosion resistant bed materials (Purple circles) either formed from revetment materials, culverts or likely, glacial till.

5.4.5 REACH 5

Reach 5 is primarily agricultural with the upstream area of the watershed occupied by the Blair Municipal Airport. The list below describes the limited FG and field assessments for the reach.

- GCSs are present at three main bridge locations (Figure 5-34).
- Comparisons of the FG LiDAR profiles (Figure 5-34) illustrate relatively similar profiles. This reach appears to have a stable bed.
- Existing GCS locations should be investigated further to determine stability of structure and potential need for enhancements.
- There is an additional GCS and other resistant bed materials located within the reach based on the 2016 LiDAR and aerial photo interpretation. Specific GCS locations need to be verified in the field (Figure 5-34).
- The reach is less than three square-miles, so Thomas Creek is not a large channel in this reach. However, the channel has been highly modified for agricultural and airport uses in the upstream area of the reach.
- There are opportunities to enhance flood storage in this reach and reduce runoff from the airport to the downstream reaches and South Papillion Creek watershed. Based on the limited FG analysis, this reach would be considered partially a sediment source/pathway.
- Land-use in this area is mostly agricultural so there is high value in concentrating restoration funding in this reach where applicable.

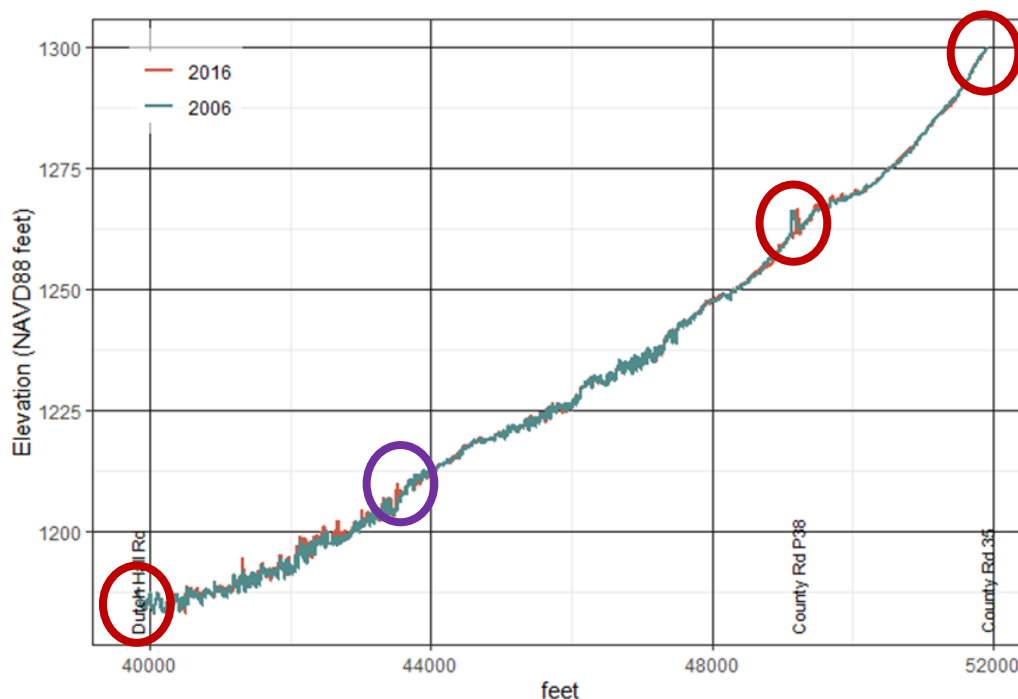


Figure 5-34: Thomas Creek FG – Reach 5

Note: GCSs (red circles) field verified, unknown erosion resistant bed materials (purple circles) either formed from revetment materials, culverts or likely, glacial till.

Thomas Creek-Study Recommendations:

This report is based on a limited scope FG Level I CSA. It is recommended to complete more geomorphic analysis including FG level II and III assessments along with additional field assessments. The study recommendations are listed below for Thomas Creek. This section is meant to provide the overarching recommendations for priorities based on the limited FG Level I analysis and assessment.

- **Priority #1:** Use existing GCS locations to continue to stabilize the channel.
- **Priority #2:** Assess existing structures and other areas within the reaches that are providing channel stability.
- **Priority #3:** Target upland areas for water and sediment retention structures.
- **Priority #4:** Complete additional geomorphic analysis to determine additional areas for restoration and stabilization.

5.5 SUMMARY OF FG LEVEL 1 ASSESSMENTS

FG Level I CSA analysis and reports were completed for Thomas and Hell Creeks, and Big and Little Papillion Creeks. The watersheds varied greatly in size but have common characteristics in physical geomorphic conditions and location. Based on a limited scope FG Level I CSA, the following is a summary of the findings:

- Use existing GCS locations to continue to stabilize the channel. Assess existing structures and other areas within the reaches that are providing channel stability for further study.
- Target upland areas for water and sediment retention structures and other Best Management Practices (BMPs) to assist in slowing, storing and releasing stormwater runoff.
- Where possible, increased floodplain connections should be re-established in reaches defined in the reports. Options could include additional GCS construction to re-establish floodplain berms or cutting floodplain berms into the existing bank lines or a combination of both. If any work is done, hydraulic analysis would need to be completed to assess potential impacts to flood flow and potentially increasing flood stages.
- Completing additional geomorphic analysis upstream of the Washington County line and Big Papillion Creek tributaries would determine critical areas for restoration and stabilization focus.
- It is recommended to complete more geomorphic analysis including FG level II and III assessments along with additional field assessments.

6 COLE CREEK SOLUTIONS MATRIX AND DESIGN CONCEPTS

This section contains measures to consider for Site Specific Bank Stabilization of FG Reach 1: Mouth of Cole Creek to Blondo Street Bridge (including Engineering with Nature (EWN) measures).

6.1 PRELIMINARY STRUCTURAL AND NON-STRUCTURAL MEASURES

Five bank protection structural measures and two bed stabilizing measures were considered to stabilize the FG Reach 1. In addition, EWN measures are listed as key enhancements to the structural measures. EWN measures are a mixture of hard (riprap) and soft (vegetation) techniques that improve natural physical stream processes. EWN promotes a suite of stabilization and restoration options, typically with some form of vegetation or ecological enhancements.

Buyouts are considered the only nonstructural measure and are not part of this assessment. They are described below. These measures were developed into alternatives, based on preliminary information and best professional engineering judgement.

Please note, the No Action alternative is always considered in USACE analysis.

6.1.1 STRUCTURAL MEASURES

Sheet Pile Wall:

Sheet piling is an earth retention and excavation support technique that retains soils, using steel sheet sections with interlocking edges. Sheet piles are installed in sequence to a design depth along the planned excavation perimeter alignment. They are typically driven into the earth with a vibrator hammer. The interlocked sheet piles form a wall for permanent or temporary lateral earth support with reduced groundwater inflow. Anchors can be included to provide additional lateral support if required. This measure would also include removing all debris and vegetation in the excavated area and placing material in a state-approved landfill.



Figure 6-1: Example – Metal Sheet-pile Wall

Retaining Wall:

This measure could use prefabricated retaining wall blocks (Figure 6-2), proprietary methods such as GEOWEB (Figure 6-3) or a landscape rock wall (Figure 6-4). This measure would require excavating into the channel bottom to a depth below the calculated scour depth. Removal of debris and vegetation in the excavated area would be required. The bank would be excavated and graded, and the wall would be placed along the stream bank starting at the river's edge and progressing up the bank.



Figure 6-2: Example – Vertical Stabilization Option (Redi-Rock)

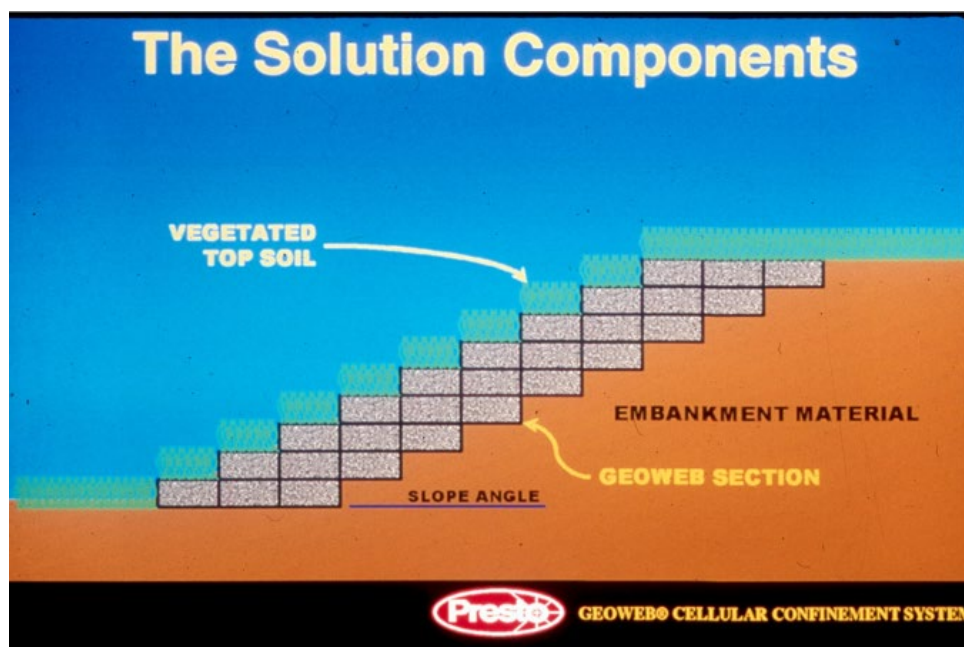


Figure 6-3: Example – Vertical Stabilization Option Using GEOWEB



Figure 6-4: Example – Vertical Stabilization Using Landscape Boulders

Riprap Blanket-Bank Lining with Riprap Stone Protection:

Riprap stone protection is a method of armoring the streambank from erosion through the placement of well-graded stone (Figure 6-5). The length of the protection depends on the extent of erosion. A toe is typically excavated to the depth of the scour. Revetment top and end protections are constructed to prevent erosion caused by wave action, floating debris, and water surface irregularities. This measure would also include shaping the bank and removing all debris and vegetation in the excavated area and moving this material to an offsite location. The riprap blanket normally extends to protect at the two-year (50 percent AEP) level plus two feet of freeboard.

In the case of the Cole Creek reach below Hillside Drive, this would only cover the bottom third to half of the left bank. Above the blanket, bank shaping to a shallower 3:1 slope would be required for stability. The bank above the riprap blanket should be planted with soil stabilizing native species.

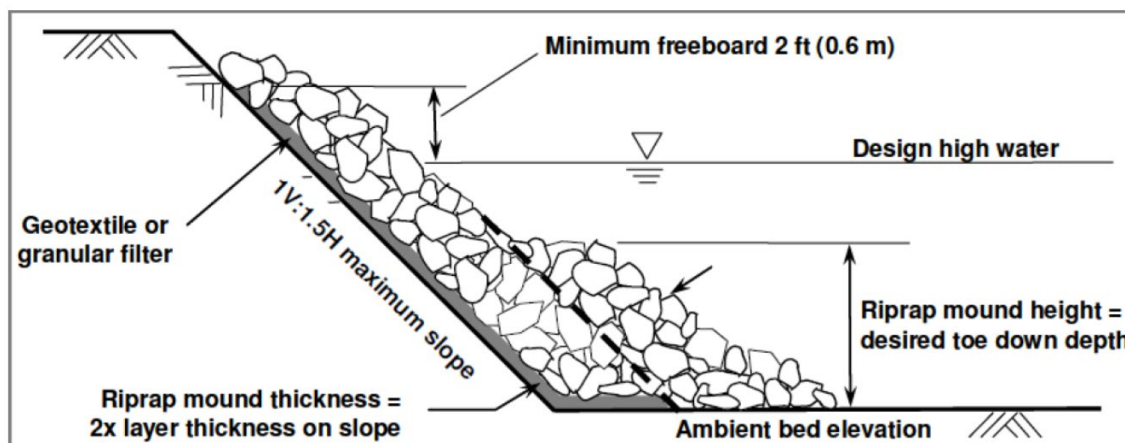


Figure 6-5: Riprap Blanket on Eroding Slope

Engineering with Nature Measures**EWN-Longitudinal Peaked Stone Toe Protection (LPSTP):**

This method only protects the toe of the slope, leaving the mid and upper banks for vegetation plantings or other methods, if there is anticipated erosion from higher flows (Figures 6-6 to 6-9). The toe protection provides revetment structure that can launch when scour occurs at the toe and re-lock in place within the scour locations, providing a stable foundation. This requires well-graded riprap to provide the launching and relocking capabilities. Numerous other measures tolerate minor scour and are not designed to adjust leading to foundational failures.



Figure 6-6: EWN LPSTP Pre-project Conditions – Bank Erosion on Left Bank Threatening Residence, Bettendorf, Iowa



Figure 6-7: EWN LPSTP Project with Erosion Control Matting on Mid- and Upper Banks



Figure 6-8: EWN LPSTP Project Two Years After Construction

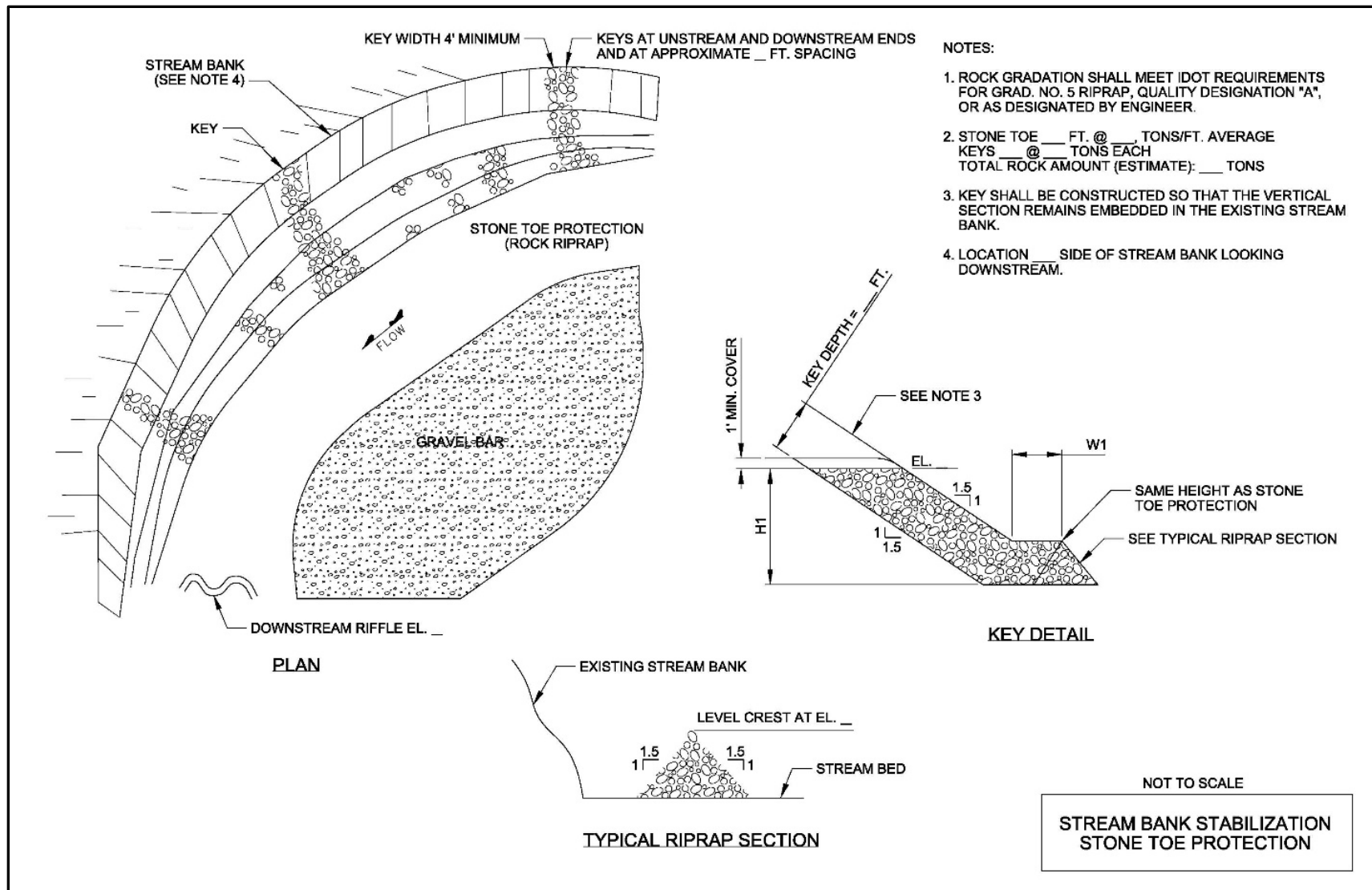


Figure 6-9: Longitudinal Peaked Stone-Toe Protection (LPSTP) Typical Section

EWN-Longitudinal Fill Stone Toe Protection (LFSTP):

This is like LPSTP but has a level crest elevation for more rock quantities to account for additional scour (Figures 6-10 to 6-11).

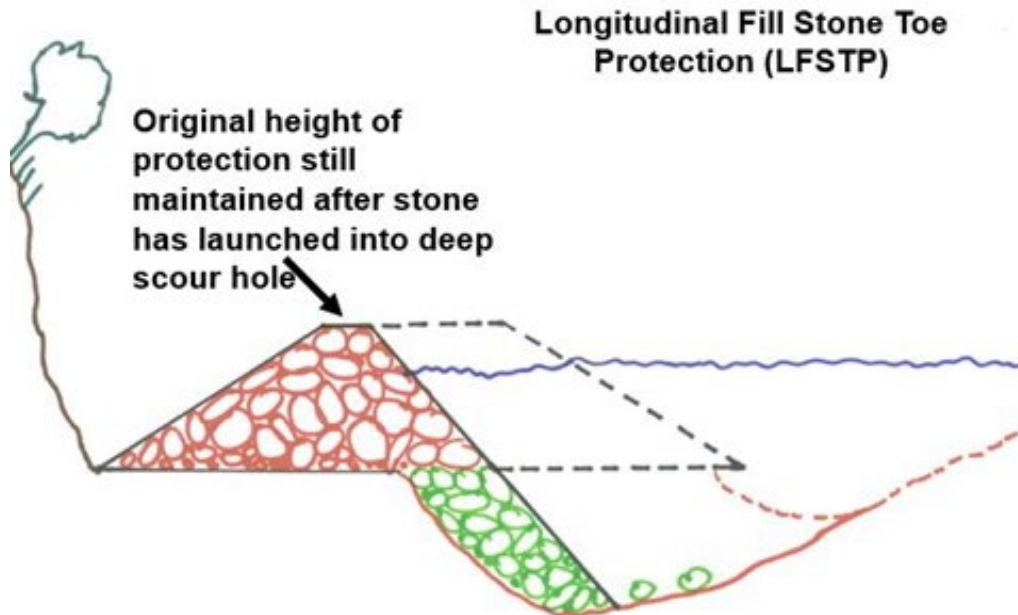


Figure 6-10: EWN LFSTP Cross-section Typical Section (dotted line) Illustrating Scour After Erosion of Toe



Figure 6-11: Brazos River, TX EWN LFSTP Project

EWN-Loose Rock Riffle Grade Control Structures:

This method provides bed stabilization through a series of structures that equalize the channel grade over the entire reach, and promote stabilization of the eroding bank line toe (Figures 6-12 to 6-14). This practice should be considered in combination with toe protection when stabilizing an incised channel. Benefits of loose rock riffle grade control structures include potential for re-establishing connections to previous floodplains (dissipation of flow energy and recycling of nutrients), floodplain berms building within the active channel, stabilization of bank lines upstream of structures, biological and ecological enhancements adding stable channel substrate for macro-invertebrate habitat, aeration of water over structures increasing dissolved oxygen levels and others.



Figure 6-12: Sinsinawa River, IL EWN Loose Rock Riffle Grade Control Project

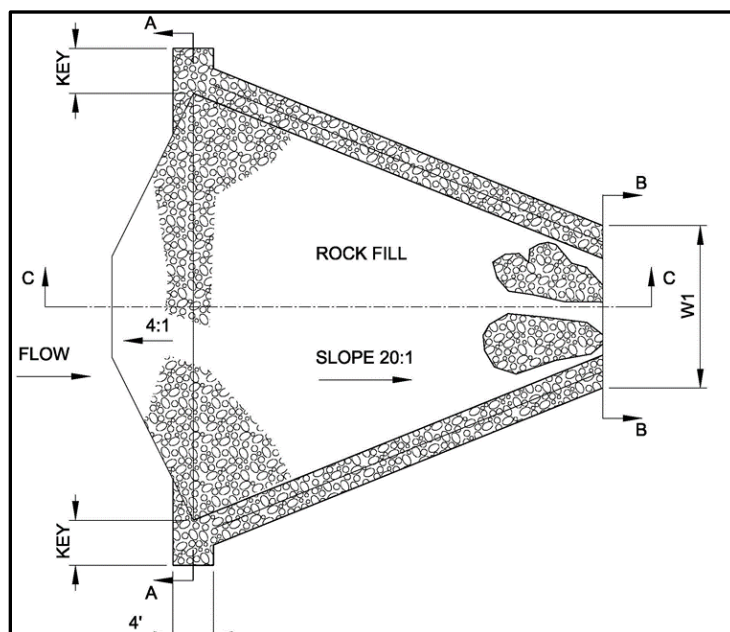


Figure 6-13: Typical Rock Riffle Design Details – Planview

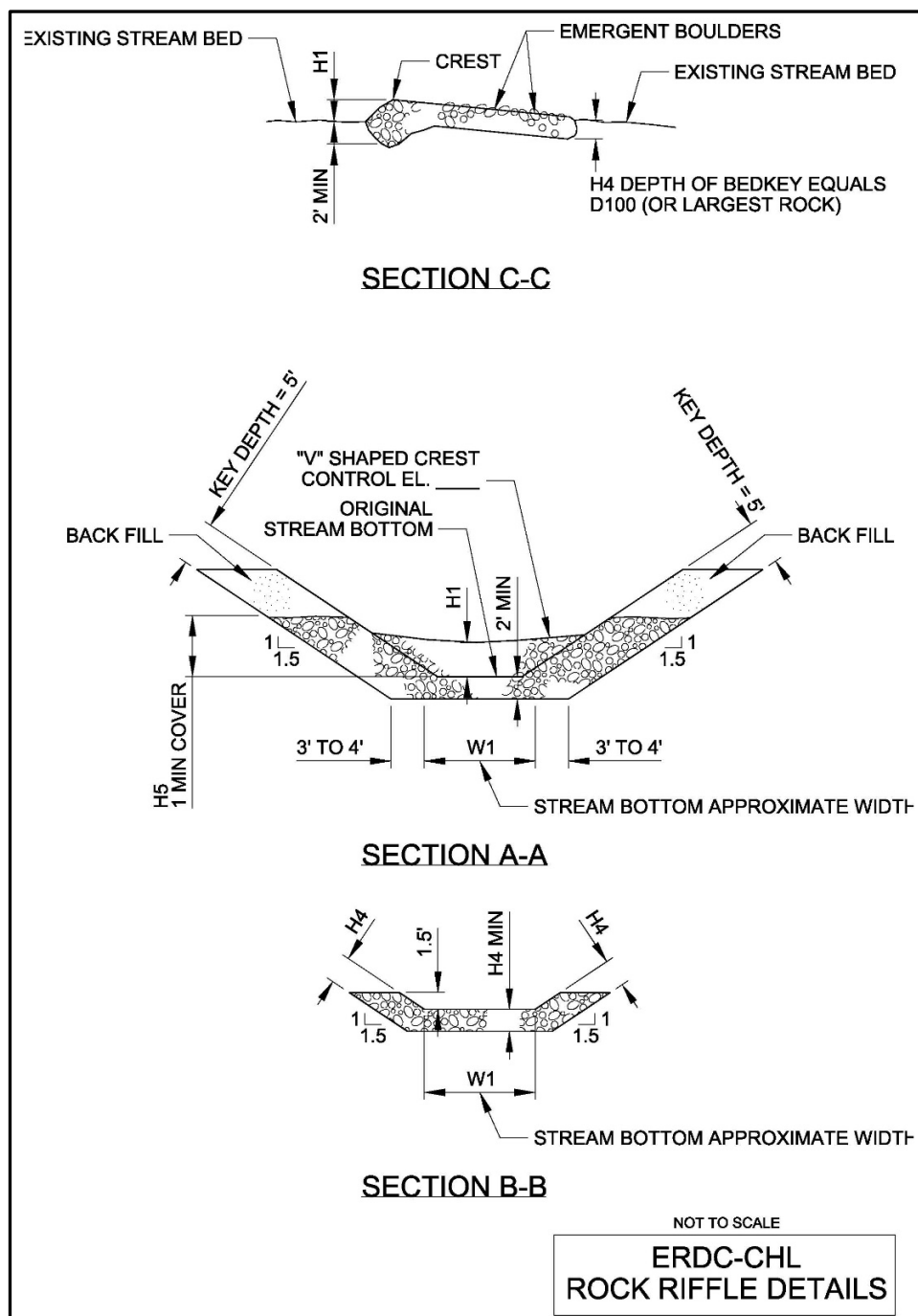


Figure 6-14: Typical Rock Riffle Design Details – Cross-section Views

6.1.2 NONSTRUCTURAL MEASURES

Property Buyouts:

This measure would involve buying out properties adjacent to Cole Creek. This would remove private property from continued erosion control problems and provide more room for stabilizing the stream corridor. This is a stand-alone plan and would not require additional measures.

EWN Enhancement Measures:

- For the Cole Creek location, EWN enhancements may include willow posts, wattling bundles, rootwads, revegetation with shrubs, critical area seed mixes, hydroseeding & mulching and other bio-engineering options. The zoned cross-section map (Figure 6-15) provides details on recommended seeding areas for successful establishment of riparian vegetation types.

Zone 1 seeding should consist of hydrophytic (wetland) herbaceous vegetation, such as bulrush or cattail, native to the region.

Zone 2 seeding and planting should consist of hydrophytic vegetation, including herbaceous grasses (e.g., prairie cordgrass), forbs, shrubs, and trees (e.g., willows and dogwood), native to the region.

Zone 3 seeding and planting should consist of a mixture of upland and hydrophytic vegetation, including herbaceous grasses and forbs (bluestems, switchgrass, clover, etc.), shrubs and trees (cottonwood, boxelder, etc.), native to the region. A useful reference for identifying regional vegetation communities and native species of Nebraska is *Terrestrial Ecological Systems and Natural Communities of Nebraska* (Rolfmeier S.B. and G. Steinauer. 2010). The lower zones require a form of toe protection; in this case within an incised Cole Creek channel, recommendations would be to provide a hard toe combining these EWN enhancements with a structural EWN measure such as LPSTP.

- Examples of EWN Enhancements that can be supplemented with structural components are provided in Figures 6-15 through 6-18.
- EWN measures may be limited based on changing channel boundary conditions. Flood stages are modeled to establish existing conditions so that alternatives have a baseline hydraulic condition to be measured against. If any measures and subsequent alternatives have negative impacts to the flood stages, then those will be screened out. This may occur with increased vegetation on channel margins, especially in urban and flood control areas.

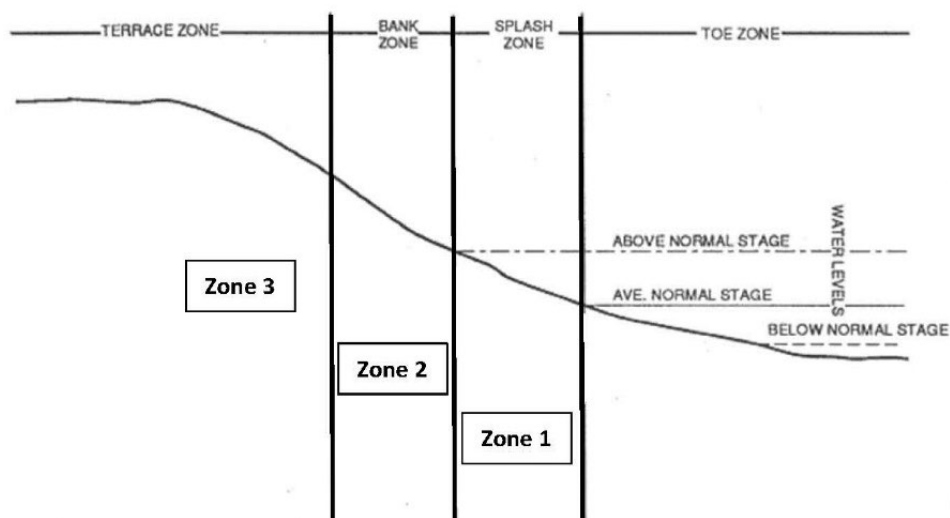


Figure 6-15: Recommended Planting Zones

Source: modified from USACE 1998.

Schematics Of Brush Mattress And Wattling

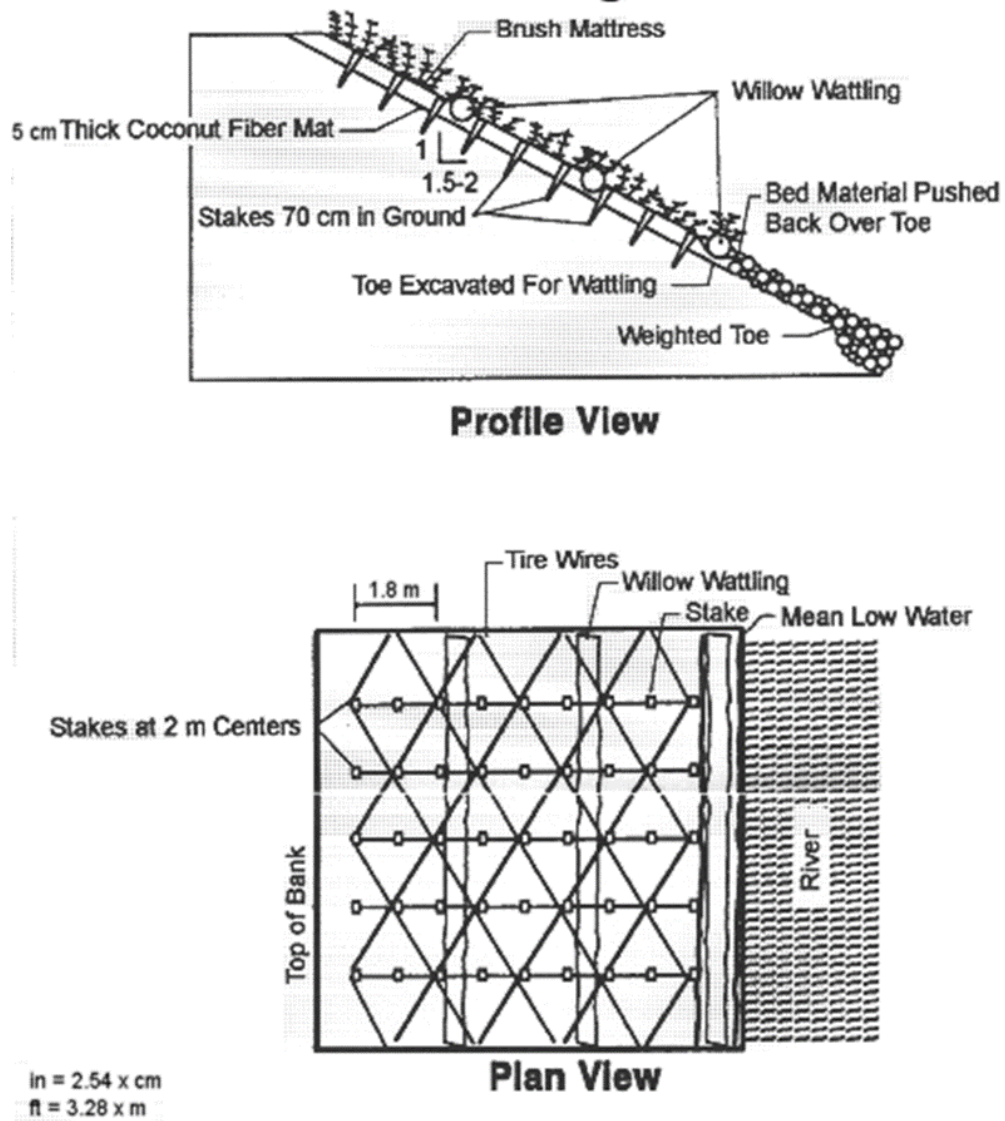


Figure 6-16: Brush and Wattling

Source: USACE 1998



Figure 6-17: Black Walnut Creek LPSTP/Rootwads/Tree Plantings/Prairie Grass



Figure 6-18: Willow Post Planting with LPSTP

6.2 FORMULATION AND COMPARISON OF ALTERNATIVES

The management measures were converted into the most likely alternatives either alone or in combination. The following alternatives and No Action Alternative were considered in response to the Cole Creek channel erosion and stability problems.

6.2.1 ALTERNATIVE PLAN DESCRIPTIONS

At a minimum all plans would include:

- 1) Access points and staging areas on the right bank downstream of Hillside Drive (City-owned property).
- 2) In-channel concrete will either be removed or reworked within the channel to provide general flow conditions to the center of the channel and not directed at either bank line. Material will be broken up and final material shape will conform to USACE ER-1601.
- 3) Combination of bed and bank scour protection measures.

Alternative 1 – No Action

The No Action alternative forms the baseline for evaluating the benefits of the proposed action alternatives. It does not preclude local officials from seeking and/or implementing solutions to mitigate the erosion processes impacting the riverbank. USACE considers the No Action alternative in accordance with the National Environmental Policy Act (NEPA).

Alternative 2 – Steel Sheet Pile Wall

- Likely very expensive.
- Construction area would be large, impacting properties we are trying to protect.

Alternative 3 – Retaining Wall

- Landscaping blocks, GeoWeb, or some other form of vertical wall-type materials
- Likely very expensive.
- Materials do not adjust to toe scour. Foundation is critical.

Alternative 4 – Riprap Blanket with Toe

- Provides total bank protection.
- Likely costly and may impact large parts of properties we are trying to protect.

Alternative 5 – LPSTP or LFSTP with EWN Mid-Upper Bank Re-vegetation

- Low-cost methods that provide continued scour and lower bank protection.
- Option: Toe protection could be extended higher to mid-bank.
- Construction could be completed from in-channel locations.
- The least invasive method for affected property owners.

Alternative 6 – Full Bank Height Rock Wall with Vegetation Cap (EWN)

- Moderate cost but less than sheet pile
- Excavation and shaping of bank to 1.5:1 slope held in place by rock.

- Moderately invasive to affected homeowners, some additional land lost.
- Construction both on high bank and in-channel.
- Least cost “permanent” solution.

Alternative 7 – Loose Rock Riffle Grade Control

- Provides stable channel bed throughout the reach.
- Promotes toe stabilization and protection.
- Provides natural stable aquatic habitat for fish and macro-invertebrates.
- Can be used in combination with other measures, total bank, or toe protection measures.

Alternative 8 – Buyouts

- Remove properties from continued erosion risk.
- Residual risk removed as properties are no longer adjacent to Cole Creek.

Table 6-1: Cole Creek Degradation Mitigation Alternatives

Alternative	Planning Objectives		Planning Constraints			Screening Result
	Meets Purpose and Need	Sustainable	Technically Feasible	Includes Beneficial Environmental Opportunities	Level of Structural Bank Protection	
Alt 1 - No Action	No	No	NA	No	NA	Does not meet the need of the project
Alt 2 – Steel Sheet Pile Wall	Yes	Minimal maintenance	Yes	No, no vegetation components and unnatural in appearance	Total	Not environmentally beneficial, likely not the least cost alternative
Alt 3 – Retaining Wall	Yes	Minimal to moderate maintenance	Yes	No, no vegetation components	Partial to Total	Not environmentally beneficial, Not least cost alternative
Alt 4 – Riprap Blanket w/Toe	Yes	Minimal to moderate maintenance	Yes	Yes, vegetation component above blanket	Partial	Environmentally beneficial, not least cost alternative
Alt 5 – EWN LPSTP/LFSTP w/bioengineering	Yes	Minimal to moderate maintenance	Yes	Yes, potential to incorporate vegetation and contribute to viewshed aesthetic value	Partial: up to half bank height based on final design	Environmentally beneficial, likely a component of least cost alternative
Alt 6 – Full Bank Rock Wall	Yes	Minimal to moderate maintenance	Yes	Yes, majority of wall covered with topsoil and vegetation contributing to viewshed aesthetic value	Total	Environmentally beneficial, not least cost, but long life with minimal maintenance
Alt 7 – GCS	Yes	Minimal to moderate maintenance	Yes	Yes, stone facing; potential to incorporate vegetation and contribute to viewshed aesthetic value	Partial: provided limited toe protection, does prevent channel deepening & widening	Environmentally beneficial, likely a component of least cost plan
Alt 8 – Buyouts	Yes	Moderate to significant maintenance	Yes	Yes, many options if housing removed	NA	Environmentally beneficial, but economically unacceptable

6.3 SITE A – COLE CREEK: BLONDO STREET TO WESTERN AVENUE DESIGN

6.3.1 HYDRAULIC ANALYSIS

The Fluvial Geomorph analysis of Cole Creek covered the entirety of the creek from headwaters to the mouth. In Reach 1, the last reach before the confluence with Big Papillion Creek, Cole Creek runs in a highly narrowed reach through an older residential area of Omaha, with very little access to the historic floodplain. The confining of the channel and multiple road crossings that narrow the channel have resulted in a degradational condition to both the bed and banks of the creek.

The project sponsors identified Cole Creek, from Hillside Drive to Seward Street, as an area of concern, where the degrading bed and eroding banks are impacting private property adjacent to the channel. Previous efforts have removed several properties prone to flooding on the right bank in this reach, but many remain. The backyards of homes on the left bank are increasingly impacted by the high eroding bank as backyards and fences continue to be damaged by erosion.

Hydraulic analysis of the reach was performed using the existing HEC-RAS hydraulic model that was developed with 2016 LiDAR. Because this is an actively degrading reach, new surveys were collected by a contractor for the City of Omaha in early 2020. The HEC-RAS was updated with these surveys and showed an additional two to three feet of degradation in the reach.

The area of interest for the site design was originally the single city block between Hillside Dr. and Seward Avenue. However, after the initial site visit in April 2019, and analysis of the changes in bed elevation between 2016 and 2020 in the hydraulic model, there was clear evidence of degradation extending both above and below this block on Cole Creek. For analysis and design, the reach was extended to Blondo Street to Western Avenue, covering three city blocks.

Hydrology from the 2016 FEMA study was used to determine channel capacities and water surface elevations in the HEC-RAS model. The pre-design analysis showed that while improvements in culverts at Seward Street and Western Avenue have significantly increased capacity in that stretch, the corrugated metal pipe (CMP) culvert at Hillside Drive is restrictive at higher flows, causing a significant backwater effect at high flows which results in local flooding.

This design does not specifically address the culvert at Hillside Drive, as it is under consideration for re-design or removal. This analysis includes the geometry of the existing culvert and road crossing. If replacement of the culvert is done and increases flow capacity at the location, there is concern that increased velocities may increase bed degradation. The addition of GCSs in this design will somewhat mitigate this effect, but the analysis should be revisited and incorporate the new design in the hydraulic analysis, adjusting GCS location, height, and design as necessary.

The final HEC-RAS model for this analysis extends from Sorensen Parkway at the upstream end to the confluence with Little Papillion Creek which is between Cass Street and Dodge Street. The area of interest is between Blondo Street and Western Avenue. The model was updated with new survey data from the City of Omaha from cross section 7764 (just upstream of Blondo Street) to 4190 (Western Avenue). Figure 6-19 shows the original thalweg elevation and initial proposed structure elevations based on the 2016 survey data.

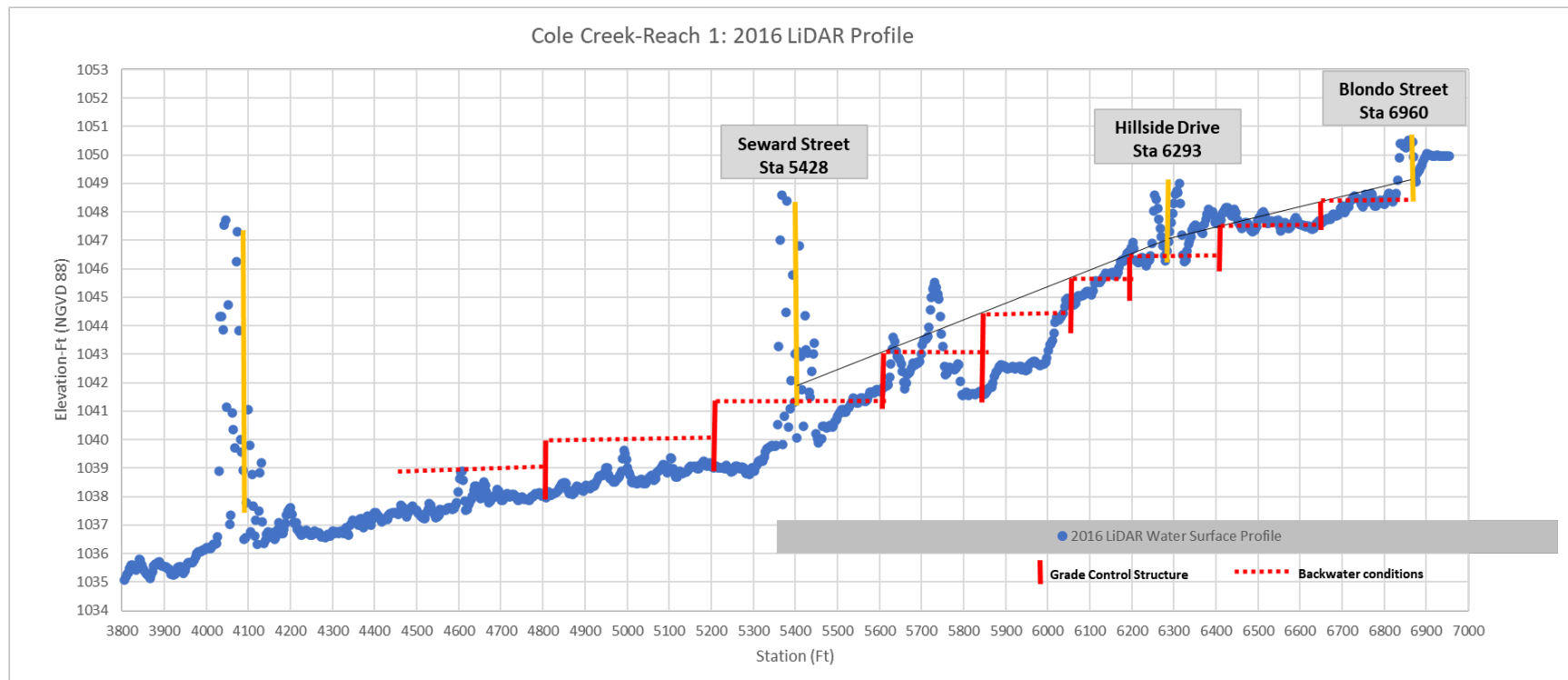


Figure 6-19: Initial Layout of GCS Based on 2016 Survey Data

Following the addition of new survey data from 2020, the proposed structure locations were modified to take advantage of existing high spots in the bed, and crown elevations were adjusted. Figure 6-20 shows the HEC-RAS model water surface profiles in the reach.

The model results of the existing conditions show that while some degradation has occurred that results in the two-year (50-percent AEP) being less than the bankfull condition, the 50-year (two-percent AEP) and higher flow event overtop the culvert at Hillside Drive and result in flooding in the area. Figure 6-20 also shows the inclusion of the GCSs for the design. Their height above the bed ranges from one to three feet depending on local bed conditions.

The results show that there is a minor increase off less than 0.5 feet at the 50- and 100-year (two-percent and one-percent AEP) events. The area with the highest change is around the Hillside Drive culvert crossing. Previous channel work in the lower reaches, including the new culvert and bank setback to increase capacity result in a lower stage impact with the addition of the GCS.

The updated 2020 survey data was used to determine quantities as part of the design; however, this area appears to be actively degrading, and the quantities and costs should be considered conceptual in nature. A new survey and updated design should be completed before construction.

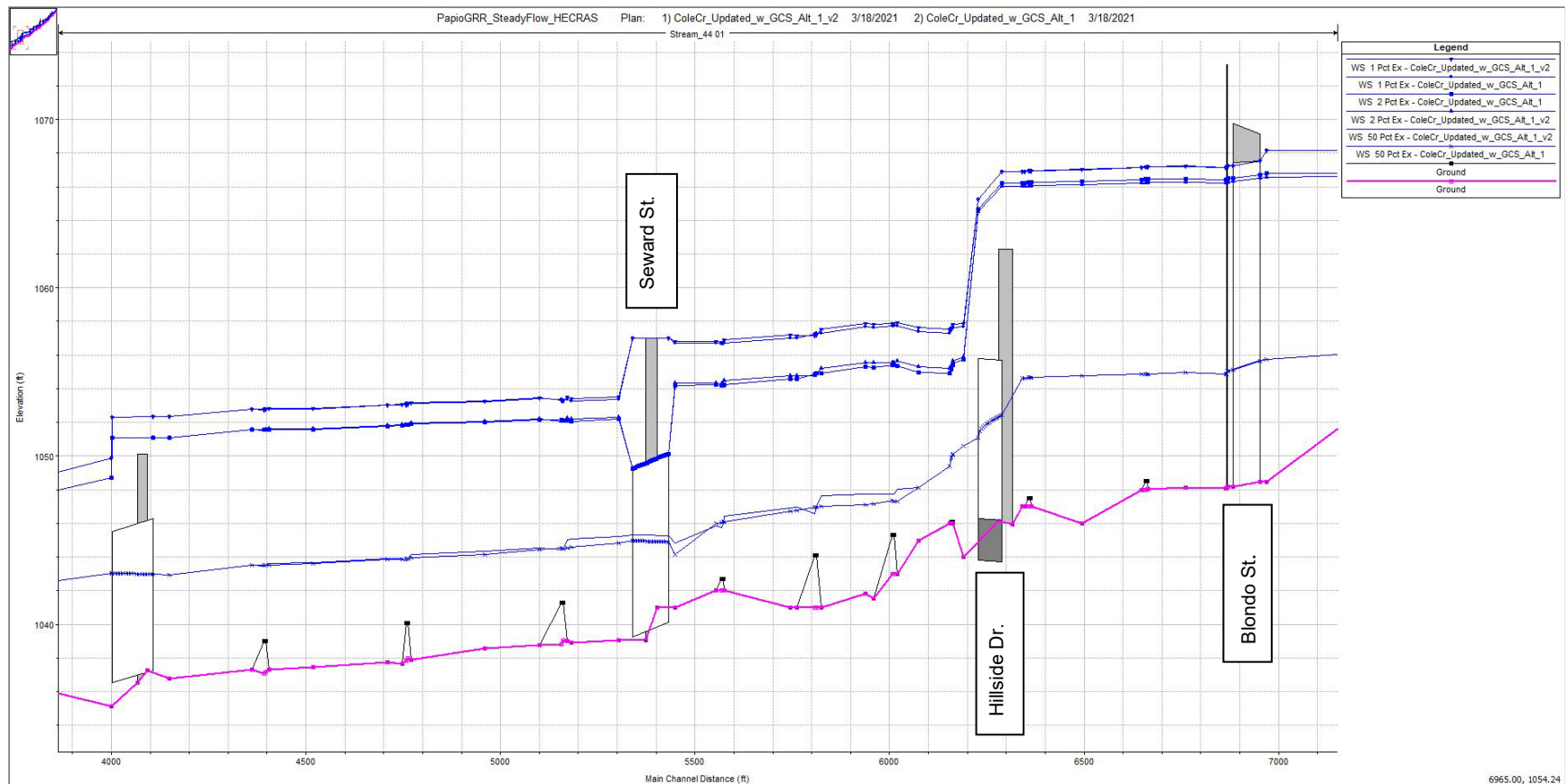


Figure 6-20: HEC-RAS Hydraulic Model Water Surface Profiles in Cole Creek Design Reach (2020 Surveys)

6.3.2 SUGGESTED DESIGN

The three-block reach of Cole Creek has multiple bed and bank stability concerns that should be addressed in the design:

- 1) Prevent further bed degradation.
- 2) Reduce erosion on high left bank between Hillside Drive and Seward Avenue.
- 3) Address concrete rubble impact to bed shape, location, and degradation.

To address ongoing bed degradation, nine GCS structures designed as rock riffles, as shown in Figures 6-13 and 6-14, are to be mechanically placed under low-flow conditions and keyed into the banks. The design recommends Type B riprap to withstand the velocities estimated in the RAS model for moderate and higher flows. This design would be considered Alternative 7 in Table 6-1 above.

In addition to grade control, bank erosion is of major concern in the reach from Hillside Drive to Seward Avenue. Discussions between the project team and sponsors on multiple site visits always included the topic of the large amount of broken concrete in the creek bed, primarily in this reach. The material was refuse from local road construction projects, placed to help mitigate bed degradation. It may have done that initially when exposed in significant quantities; however, in the current condition the concrete rubble is forcing the low-flow channel up against the left bank, likely increasing the rate of bank erosion.

At a minimum, the material should be either removed or repurposed as part of a design to reduce the bank erosion effect. Bank toe protection should be included in this reach at a minimum, and possibly extended to the blocks above and below based on channel response to the design structures in the Hillside Drive to Seward Avenue reach.

As discussed with the sponsors during site visits, the concrete rubble in the channel could serve as source material for some of the toe protection. Much of it would need to be broken up into smaller pieces to interlock like riprap but could somewhat reduce material and transportation costs for construction of bank toe protection.

For bank protection, the minimum level of toe protection should be included, as in Alternative 5. Bank shaping above the toe or extending the height of the toe to match the high bank would provide additional protection. In this design LPSTP is included to estimate quantities and costs.

Alternatives 2, 3, 4, and 6 would provide significantly more protection and LPSTP would only be needed on the left bank below Hillside Drive. Alternative 2 – Sheet Pile could fully protect the high bank real estate, which Alternative 5 – Full Bank Rock Wall would have moderate impacts to create the necessary 1:5:1 slope. Alternatives 3 and 4 would require a 3:1 slope above the blanket to the high bank. This would result in significant loss of real estate on the high bank. These alternatives vary from moderately to very expensive, and if they are considered, Alternative 8 – Buyouts, will likely need to also be considered in lieu of bank stabilization.

The layout of the GCS and LPSTP are shown in Figures 6-21 to 6-23 below, covering the three-block reach of the design. Larger figures are available in Appendix D: Design Plates.







Quantities and Costs

Rough quantities were determined from the volumes of cut and fill determined for the design based on the DEM updated with the 2020 surveys. These updated surveys did not cover the entire reach of the design, so quantities are estimates, and updated surveys may be required, and new quantities calculated before any work is done.

Both rock riffle CGS structures are designed with a 4:1 upstream and a 20:1 downstream slope with a four-foot crest width and a three-foot foundation depth. The LPSTP is designed at four tons per linear foot to provide sufficient toe protection. The quantity estimate provides for full coverage on both banks that ties all the GCSs together and extends above and below the GCS locations. A reduction in size of toe protection may be considered in reaches where banks are more stable, for example between Seward Street and Western Avenue.

Costs associated with placed rock are highly variable, based on location, availability, and access. The costs summarized in the table are for \$80 per ton of placed rock. Table 6-2 and 6-3 summarize the quantities and costs for GCSs and LPSTP.

Table 6-2: Cole Creek Rock Riffle Quantities and Costs

Structure	Elev. (ft)	Area (sf)	Foundation Tonnage	Total Tonnage	Per Ton Placed Rock (\$)	Structure Cost (\$)
GCS - Station 4435	1039	820	150	229	80.00	18,333.33
GCS - Station 4800	1040	723	133	192	80.00	15,326.67
GCS - Station 5200	1041	647	119	178	80.00	14,212.00
GCS - Station 5610	1043	1060	194	266	80.00	21,266.67
GCS - Station 5850	1044.5	2240	411	664	80.00	53,093.33
GCS - Station 6050	1045.7	2880	528	748	80.00	59,840.00
GCS - Station 6200	1046.5	380	70	123	80.00	9,826.67
GCS - Station 6400	1047.5	42	8	54	80.00	4,341.33
GCS - Station 6550	1048.5	288	53	126	80.00	10,061.33
Totals:				10745		206,301.33

Table 6-3: Cole Creek LPSTP Quantities and Costs

Structure	Station (ft)	Length (L&R Banks) (ft)	Tons per Foot (est)	Total Tonnage	Per Ton Placed Rock (\$)	Structure Cost (\$)
Toe Revetment Blondo - Hillside	6910- 6300	610	4	2440	80.00	195,200.00
Toe Revetment Hillside - Seward	6250- 5450	800	4	3200	80.00	256,000.00
Toe Revetment Seward - Western	5350- 4190	1160	4	4640	80.00	371,200.00
Totals:				10280		822,400.00

6.3.3 ADDITIONAL DESIGN CONSIDERATION

The construction of GCSs should be considered the minimum action necessary to reduce bed degradation. The addition of the longitudinal stone toe will provide lower bank scour protection and reduce degradation further; however, neither of these designs directly affects the steep, actively eroding left bank downstream of Hillside Drive.

While the longitudinal stone toe may slow undercutting of the steep bank, it will not prevent mid and upper bank sloughing or mass wasting from delivering large volumes of eroding bank material into the channel. If the steep bank continues to erode, bank materials that deposit in the channel may affect the flow pattern of the creek, possibly pushing it to the opposite bank and changing erosion patterns. In addition, the loss of bank material will continue to impact homeowners through the loss of land in their back yards.

Only Alternative 2 – Sheet Pile Wall could be expected to fully preserve the land on top of the bank. This alternative is expensive, and buyouts should be considered instead of sheet pile. The compromise between toe protection and a full sheet pile wall would be Alternative 6 – Full Bank Height Rock Wall with Vegetation Cap. This would be the lowest cost alternative that would provide a somewhat permanent solution. A design was developed for this alternative to provide an estimate of quantities and costs.

The design area covers only the high left bank of Cole Creek from Hillside Drive to approximately 500 feet downstream. The bank itself would need to be shaped back to a 1.5:1 slope for rock wall and earthen fill stability, and then covered with a three-foot-thick layer of Type-B riprap, with a five-foot toe-in. Figure 6-24 shows the plan view of the design.

The bank shaping would require additional loss of backyard real estate for eight landowners along the length of the rock wall. Adjustments to the location of the wall could be made to move the toe farther into the channel, reducing impacts to the backyards, if equivalent adjustments are made on the right bank.

Any large bank project like the riprap rock wall involves increased risk of affecting stages in the channel. Additional hydraulic analysis would need to be completed to evaluate the ability to construct a design that causes little to no rise in stage.

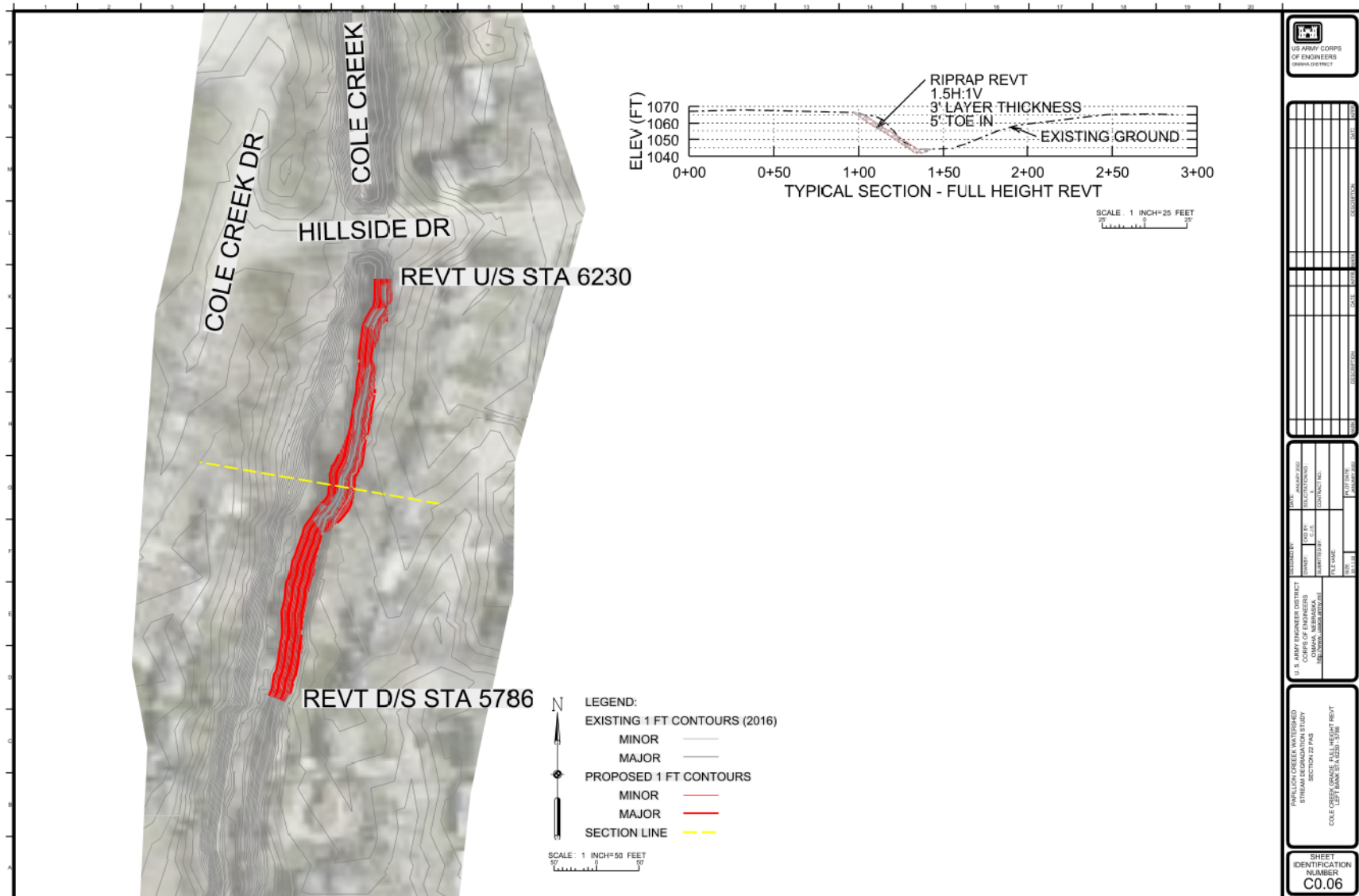


Figure 6-24: Elevation View of the Left Bank Rock Wall Below Hillside Dr. on Cole Creek

The portion of the rock wall above the elevation of the two-year event would be covered with topsoil. It is important that care is taken to push the topsoil into the voids in the rock to provide the necessary soil depths for vegetation plantings to be successful. Sod forming grasses such as smooth brome could be planted in the topsoil to hold the soil in place and screen the riprap from view; however, a native grass mix that includes pollinator-friendly forbs would be environmentally preferable.

An estimated 1750 cubic yards of bank material would need to be excavated to shape the bank to 1.5:1 slope. This design estimates 2400 tons of rock in the wall section, 500 tons to build out the toe, and an additional 100 tons to key in the structure. Table 6-4 summarizes the estimated costs.

Table 6-4: Riprap Rock Wall with Earthen Cap

Structure	Station (ft)	Total Tonnage (CY)	Per Ton Placed Rock (\$)	Structure Cost (\$)
Excavation	5786-6230	1750	20.00	35,000.00
Rock Wall Riprap	5786-6230	2400	80.00	192,000.00
Toe Riprap	5786-6230	500	80.00	40,000.00
Key Riprap	5786-6230	100	80.00	8,000.00
			Total:	275,000.00

7 WEST PAPILLION CREEK SOLUTIONS MATRIX AND DESIGN CONCEPTS

This section includes Site Specific Bank Stabilization for FG priority Reach 5: Hell Creek to 132nd Street Bridge, including EWN Measures.

7.1 PRELIMINARY STRUCTURAL AND NON-STRUCTURAL MEASURES

Bank protection and bed stabilizing measures were considered to stabilize the FG Reach 5 (Figure 7-1). Typical structural measures were considered in addition to EWN measures. Measures were developed into alternatives, based on preliminary information and best professional engineering judgement, and described below.

Note: The No Action alternative is always considered in USACE analyses.

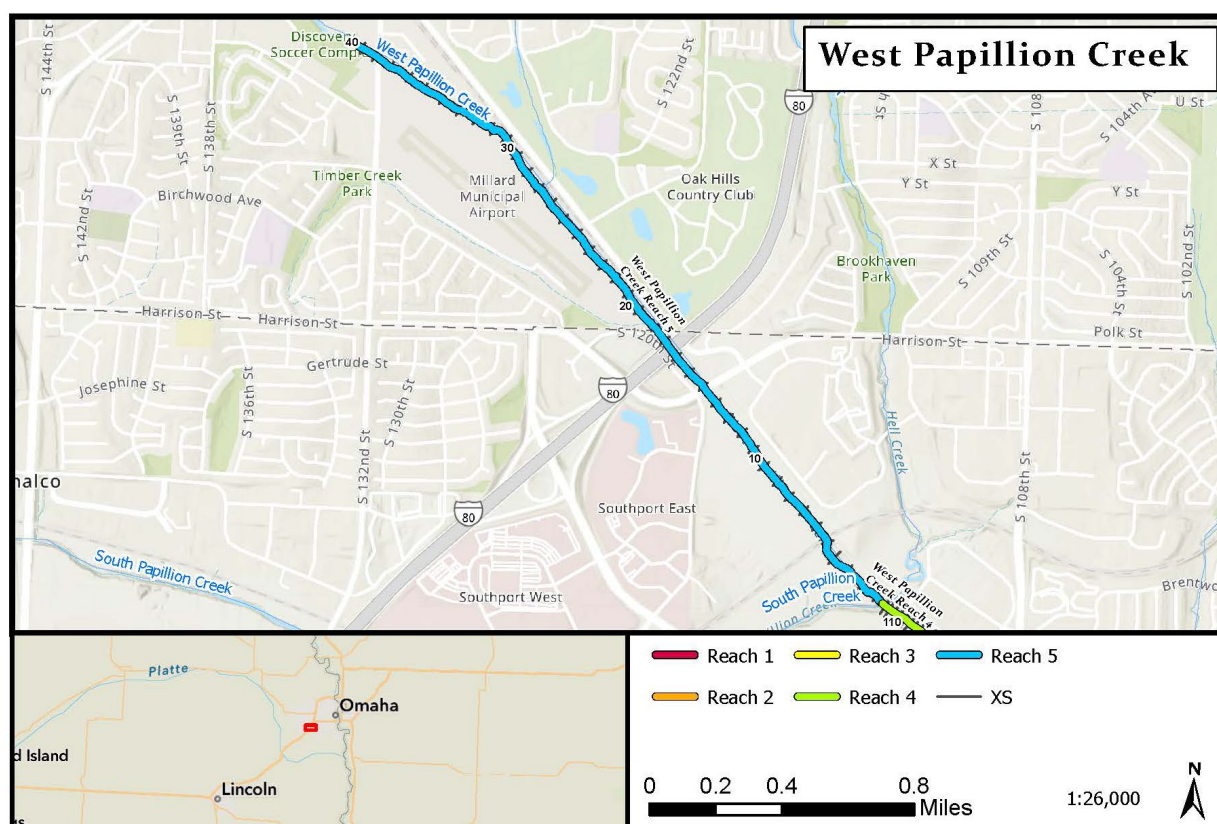


Figure 7-1: FG Reach 5 – West Papillion Creek

Based on the West Papillion Creek FG analysis and field site investigations in March 2021, bed degradation trends and bank stabilization areas were identified and prioritized in Reach 5. The primary bed stabilization locations are at the 132nd Street Bridge location (Figure 7-2) and downstream at the Sardoz Park/Golf Course and West Papillion Creek confluence.

At the 132nd Street Bridge location there is bed scour and local bank erosion with 15-to-20-foot bank heights. The existing HEC-RAS (2016 geometry) model profiles were compared to FG-LiDAR profiles (2004 and 2016) and show channel bed degradation occurring throughout the reach upstream of the Railroad Bridge (Figure 7-3). To effectively treat channel degradation,

some form of bed stabilization is required for any bank protection measures to be successful. Measures are further developed in the next section for Reach 5.



Figure 7-2: FG Reach 5 – Right Bank Erosion Downstream of 132nd Street Bridge, West Papillion Creek

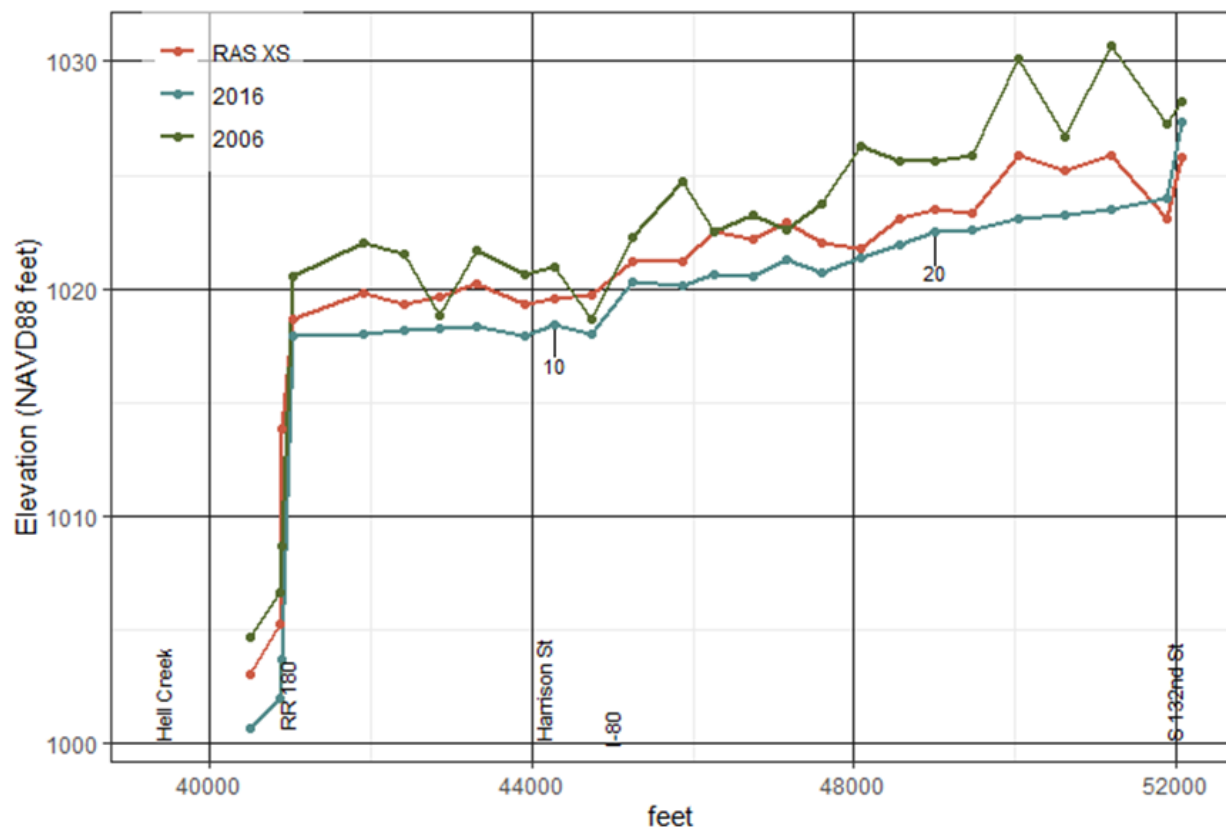


Figure 7-3: FG Reach 5 West Papillion Creek Profiles Illustrating a Channel Degradation Trend

7.1.1 STRUCTURAL MEASURES

Sheet Pile Wall:

See description in Section 6.1.1 and Figure 6-1.

Riprap Blanket-Bank Lining with Riprap Stone Protection:

See description in Section 6.1.1 and Figure 6-5.

Engineering with Nature Measures

EWN-Longitudinal Peaked Stone Toe Protection (LPSTP):

See description in Section 6.1.1 and Figures 6-6 through 6-9.

EWN-Longitudinal Fill Stone Toe Protection (LFSTP):

See description in Section 6.1.1 and Figures 6-10 through 6-11.

EWN-Loose Rock Riffle Grade Control Structures:

See description in Section 6.1.1 and Figures 6-12 through 6-14.

7.1.2 NON-STRUCTURAL MEASURES

Buyouts were not considered since most of West Papillion Creek has existing setback and a developed recreational trail system along the stream corridor.

EWN Enhancement Measures

- For West Papillion Creek, EWN enhancements may include the same options described for Cole Creek. Refer to Section 6.1.2 for more information regarding EWN Enhancement Measures.
- Examples of EWN Enhancements that can be supplemented with structural components are described in Section 6.1.2 and shown in Figures 6-15 through 6-18.

7.2 FORMULATION AND COMPARISON OF ALTERNATIVES

The management measures were converted into the most likely alternatives either alone or in combination. The following alternatives and No Action Alternative were considered in response to the West Papillion Creek channel erosion and stability problems. The planning objectives for the project are to stabilize the channel bed and banks in Reach 5, with priority on the 132nd Street Bridge corridor.

7.2.1 ALTERNATIVE PLAN DESCRIPTIONS

Alternative 1 – No Action

The No Action alternative forms the baseline for evaluating the benefits of the proposed action alternatives. The No Action alternative does not preclude local officials from seeking and/or implementing solutions to mitigate the erosion processes impacting the riverbank. USACE considers the No Action alternative in accordance with the NEPA. Table 7-1 provides an assessment of potential alternatives.

Alternative 2 – Steel Sheet Pile Wall

- Typically very expensive; however, if erosion is close to critical infrastructure, this alternative should be considered.

- Construction area would be large and there may be issues with access around the bridge and utilities within the 132nd Street Bridge location.

Alternative 3 – Riprap Blanket with Toe

- Provides total bank protection.
- Likely costly and may impact large parts of properties we are trying to protect.

Alternative 4 – LPSTP or LFSTP with EWN Mid-upper Bank Re-vegetation

- Lower cost methods that provide continued scour and lower bank protection.
- Option: toe protection could be extended higher to mid-bank.
- Construction could be completed from in-channel locations.
- The least invasive method for affected property owners.

Alternative 5 – Loose Rock Riffle Grade Control

- Provides stable channel bed locations throughout the reach.
- Promotes toe stabilization and protection.
- Provides natural stable aquatic habitat for fish and macro-invertebrates.
- Can be used in combination with other measures, total bank, toe protection and vegetation enhancement measures.

Alternative 6 – Loose Rock Riffle Grade Control, with Riprap Blanket with Toe and LPSTP or LFSTP with EWN mid-upper bank re-vegetation

- Provides benefits as listed under Alternatives 3, 4 and 5.

Table 7-1: West Papillion Creek Degradation Mitigation Alternatives

Alternative	Planning Objectives		Planning Constraints			Screening Result
	Meets Purpose and Need	Sustainable	Technically Feasible	Includes Beneficial Environmental Opportunities	Level of Structural Bank Protection	
Alt 1 - No Action	No	No	NA	No	NA	Does not meet the need of the project
Alt 2 – Steel Sheet Pile Wall	Partial	Minimal maintenance	Yes	No, No vegetation components and unnatural in appearance	Total	Not environmentally beneficial, likely not the least cost alternative
Alt 3 – Riprap Blanket w/Toe	Partial	Minimal to moderate maintenance	Yes	Yes, vegetation component above blanket	Partial	Environmentally beneficial, Not least cost alternative
Alt 4 – EWN LPSTP/LFSTP w/bioengineering	Partial	Minimal to moderate maintenance	Yes	Yes, potential to incorporate vegetation and contribute to viewshed aesthetic value	Partial: up to half bank height based on final design	Environmentally beneficial, likely least cost alternative
Alt 5 – GCS	Partial	Minimal to moderate maintenance	Yes	Yes, stone facing; potential to incorporate vegetation and contribute to viewshed aesthetic value	Partial: provided limited toe protection, does prevent channel deepening & widening	Environmentally beneficial, likely a component of least cost plan
Alt 6 – GCS, Riprap Blanket w/Toe, EWN LPSTP/LFSTP w/bioengineering	Yes	Moderate to significant maintenance	Yes	Yes, stone facing; potential to incorporate vegetation and contribute to viewshed aesthetic value	Total	Environmentally beneficial, comprehensive plan incorporating low cost and EWN

7.2.2 SELECTED PLAN DESCRIPTIONS

At a minimum, all plans would include:

- 1) Access points and staging areas for both project site areas are located on the right bank downstream of 132nd Street Bridge and across from the Sardoz Park/Golf Course and West Papillion Creek confluence. Both sites are located on the Millard Airport.
- 2) If in-channel concrete is encountered during construction, it will be removed or could be broken up and reused onsite. If reused onsite, final material dimensions will conform to USACE ER-1601.
- 3) A combination of bed and bank scour protection measures were chosen to provide a comprehensive stabilization and restoration plan. The plan includes measures that effectively provide essential bed and bank stabilization while also potentially enhancing biological and ecological stream functions. The GCS plan is illustrated on the HEC-RAS plots in Figure 7-4.

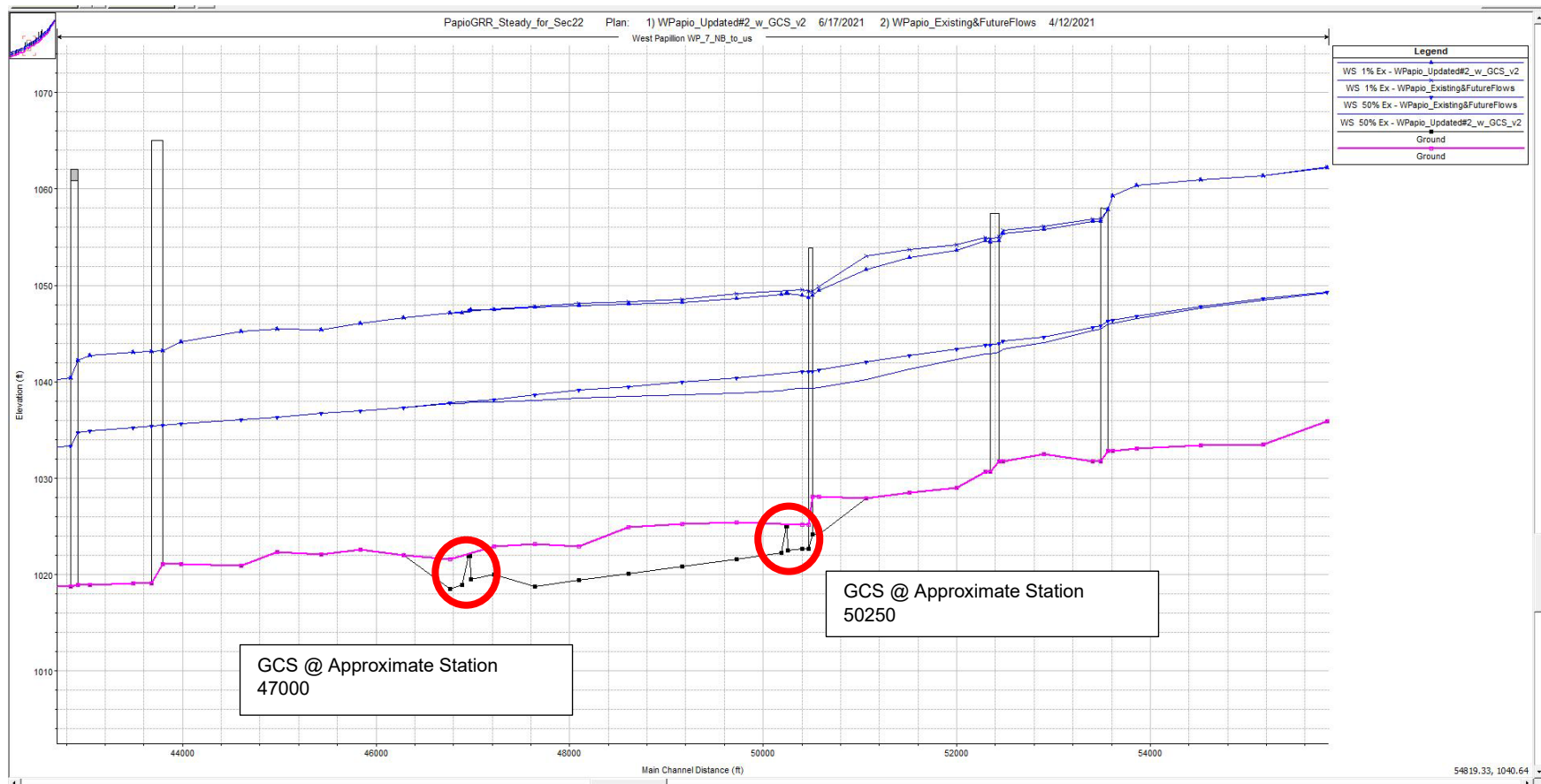


Figure 7-4: West Papillion Creek HEC-RAS Profile with New Survey Data and Plotted Locations of Proposed New GCS at ~ Stations 50250 and 47000 (Option 1)

7.3 SITE B – WEST PAPILLION CREEK AT 132ND STREET DESIGN

There are two options under consideration at the West Papillion Creek at 132nd Street Bridge site. The options include two locations of a GCS and treatment of locally eroding banks. Both options are varying layouts associated with Alternative 6.

Option 1:

Place a loose rock riffle grade control structure 250 feet downstream of 132nd Street Bridge (Figure 7-5, red trapezoid). The crest elevation of the GCS is set at 1025.0 feet, which is one foot lower than the newly constructed upstream left bank storm sewer outfall pipe. Construction of the loose rock riffle GCS includes a 4:1 front slope, 20:1 backslope, keys tied into high bank terraces (Figures 6-14 and 6-15). The backslope apron tied into existing banks from upstream key to downstream apron outlet.

A riprap blanket with toe protection will be tied into existing revetment materials upstream of the bridge and continued downstream to the right bank drainage ditch (Figure 7-5, blue rectangles). The drainage ditch will be shaped, and riprap used to provide a stable outlet from the high terrace to the lower elevation Papillion Creek. Another option for this location is to treat the drainage ditch erosion by constructing a Water and Sediment Control Basin (WASCOB). WASCOBs catch and store small drainage areas and outlet the flow through a pipe to a lower stable stream outlet. Figure 7-6 illustrates an example of a WASCOB.

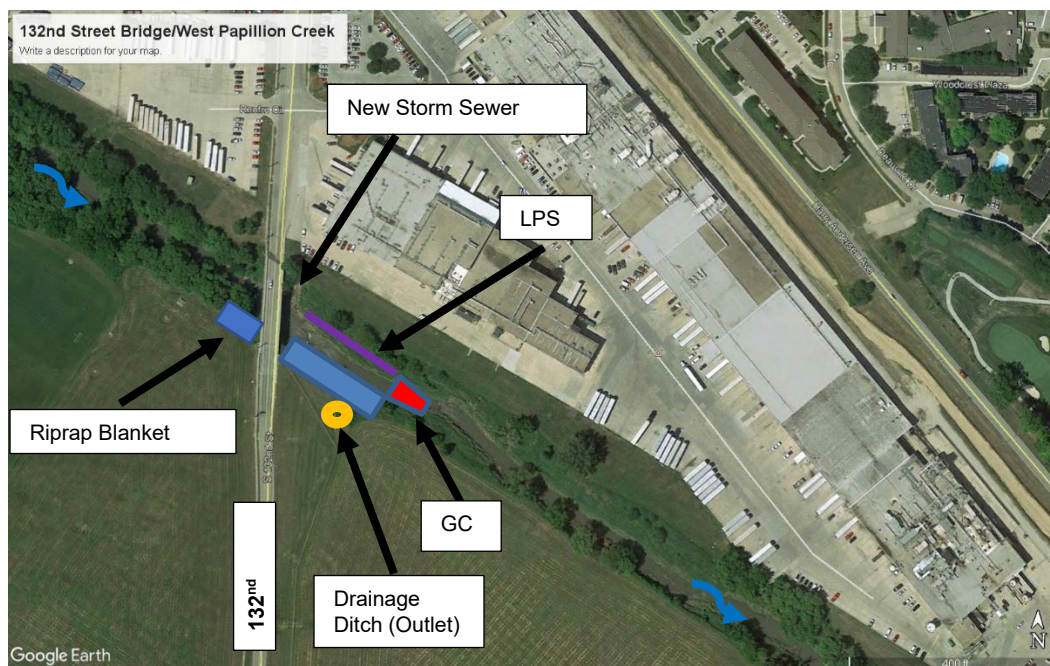


Figure 7-5: Option 1-132nd Street/West Papillion Creek Stabilization Project



Figure 7-6: Example Water and Sediment Control Basin (WASCOB)

LPSTP (Figure 7-5, purple line) is used to establish bank protection on the left bank, downstream of the bridge, tying the new left bank storm sewer outfall into the downstream GCS. The length of the LPSTP is approximately 220 feet.

Option 2:

There is a left bank erosion site just downstream of the proposed GCS; the location of the GCS could be adjusted downstream another 250 feet to stabilize the additional area. The left bank erosion may be partially caused from runoff of the adjacent parking area. This should be investigated further as additional upper terrace erosion control practices may need to be considered.

A loose rock riffle GCS could be placed 500 feet downstream of 132nd Street Bridge (Figure 7-7, red trapezoid). The crest elevation of the GCS is set at 1025.0 feet, which is one foot lower than the newly constructed upstream left bank storm sewer outfall pipe. Construction of the loose rock riffle GCS includes a 4:1 front slope, 20:1 backslope, keys tied into high bank terraces (Figures 6-14 and 6-15). The backslope apron tied into existing banks from upstream key to downstream apron outlet.

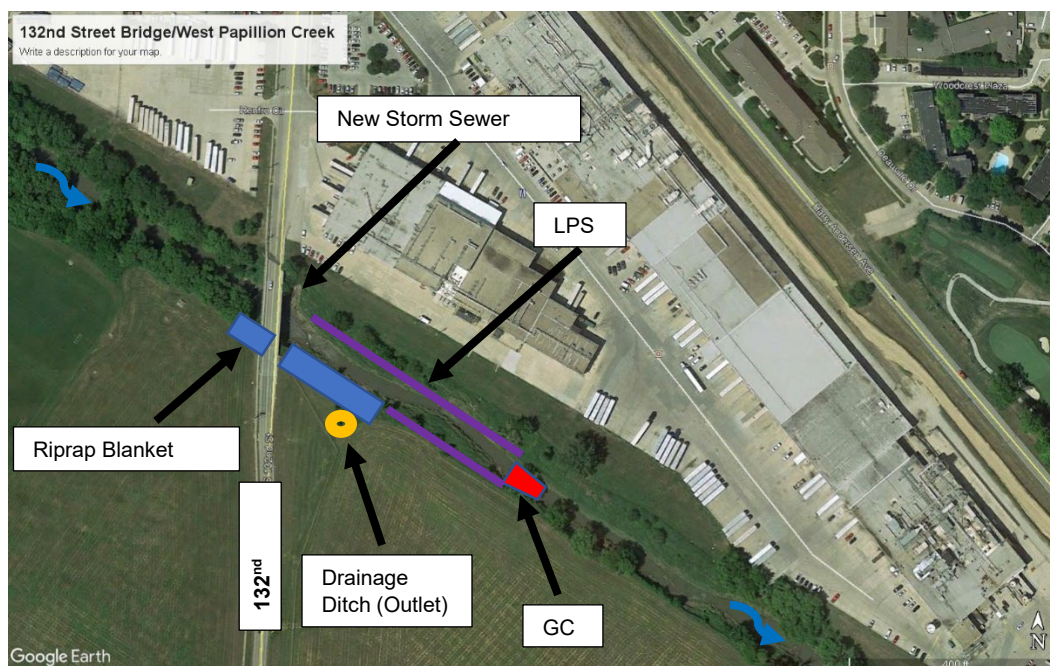


Figure 7-7: Option 2 – 132nd Street/West Papillion Creek Stabilization Project

A riprap blanket with toe protection will be tied into existing revetment materials upstream of the bridge and continued downstream to the right bank drainage ditch (Figure 7-7, blue rectangles). The drainage ditch will be shaped, and riprap will be used to provide a stable outlet from the high terrace to the lower elevation Papillion Creek. Another option for this location is to treat the drainage ditch erosion by constructing a WASCOB (Figure 7-6).

LPSTP (Figure 7-7, purple line) is used to establish bank protection on the left bank, downstream of the bridge, tying the new left bank storm sewer outfall into the downstream GCS. With the GCS moved downstream, another 250 feet of LPSTP will be added to the left and right banks. The length of the LPSTP is approximately 720 feet.

Site 2: Sardoz Park – Golf Course

With either Option 1 or 2 above, a loose rock riffle grade control structure is planned downstream to provide additional bed and bank stability for the reach and assist in stabilizing the 132nd Street Bridge site. It is located at approximate station 47000 (Figure 7-4) and is constructed the same as the upstream structure (Figures 6-14 and 6-15). The crest elevation at 1022 feet will provide back water to the downstream apron of the 132nd Street GCS.

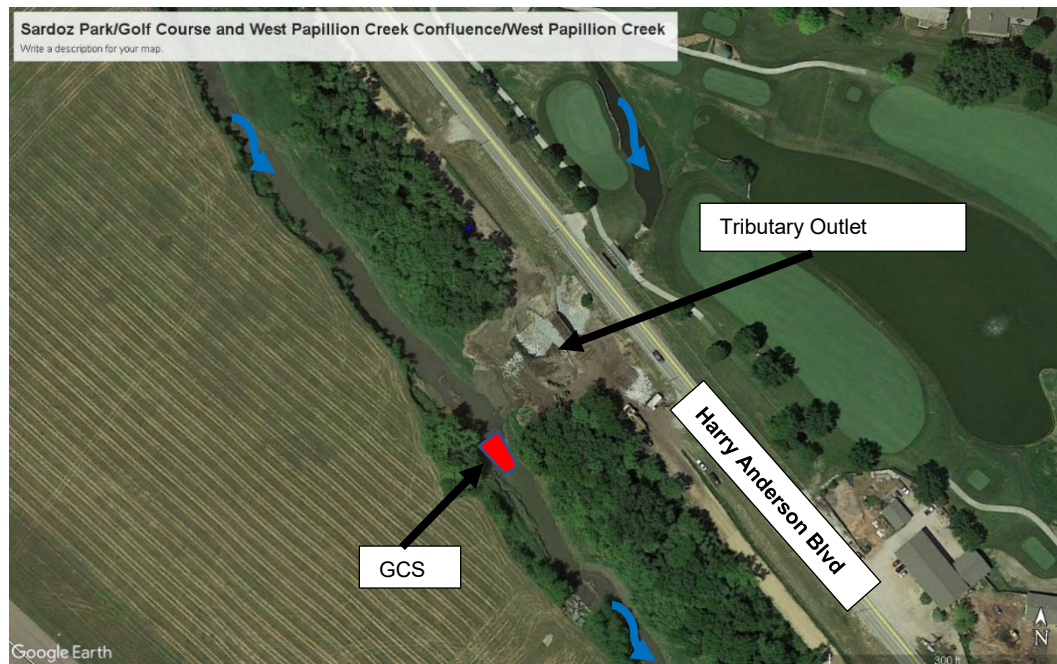


Figure 7-8: Options 1 & 2-Sardoz Park-Golf Course/West Papillion Creek Stabilization Project

The restoration and stabilization alternatives provided in this report will require additional quantity details and developed costs to provide comparisons for each recommended option. A recommended option that includes all the structural measures in Option 1 at Site 1, as well as the reinforcement of the GCS at the Site 2 tributary outfall structure is proposed with basic design drawings, quantities, and costs in the following section.

Additional restoration recommendations are completed for West Papillion Creek Reaches 1 through 4 in the West Papillion Creek Fluvial Geomorph Report. The report outlines additional GCSs, bank stabilization alternatives, and areas where further studies are recommended.

7.3.1 HYDRAULIC ANALYSIS

West Papillion Creek in the reach adjacent to 132nd street has continued to show signs of degradation throughout the duration of this study. With the City of Omaha constructing a new storm sewer outfall on the left bank below the bridge to increase capacity and direct flows away from the right bank, a grade and bank control design should be developed to integrate the new outfall and increase overall protection from bed and bank erosion in the reach.

Hydraulic analysis of the reach using the existing RAS model was compared to existing site conditions in early 2021 and signs of additional degradation since 2016 were observed. The West Papillion Creek model extends from just West of 216th Street and Fort Street at the upstream end to the confluence with Big Papillion Creek just East of 36th Street. The area of interest is downstream of the 132nd Street bridge. The cross sections just upstream and downstream of the bridge were updated with the City of Omaha survey data.

To additionally reduce uncertainty in the water surface profile estimates made in the model, USACE Omaha District conducted a brief survey in April 2021 to determine new estimates of the channel thalweg through the reach and at the GCS at the tributary outlet downstream. Figure 7-

9 plots the original 2016 survey thalweg as well as the 2021 update showing up to four additional feet of degradation in the reach near the bridge.

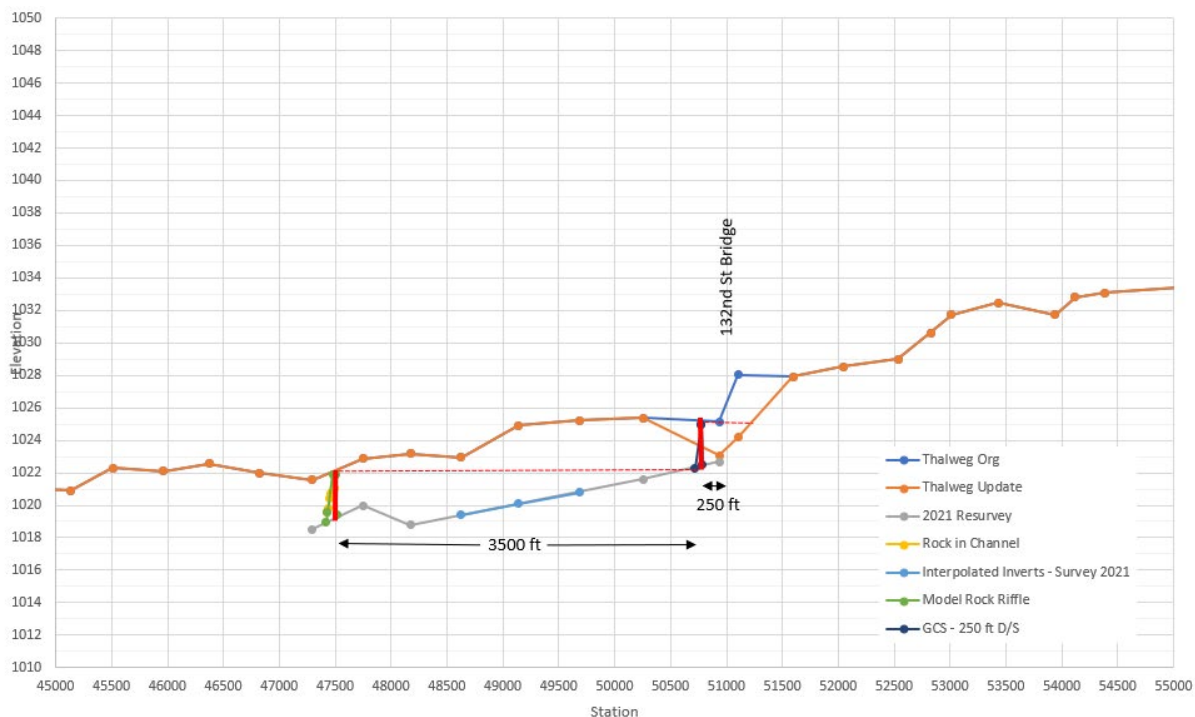


Figure 7-9: HEC-RAS Hydraulic Model Thalweg Profile of West Papillion Creek Near 132nd Street

The updated 2021 thalweg geometry was used to determine quantities as part of the design; however, this area appears to be actively degrading, and the quantities and costs should be considered conceptual in nature, and a new survey and updated design should be completed before construction.

The HEC-RAS model was run with the updated geometry to assess the current flow frequency stages and those that would be expected with the construction of the two GCSs in the design. Figure 7-10 shows that there is a minor increase of less than 0.5 feet at the one-percent AEP event. Due to the highly degraded nature of the reach, the one-percent event does not exceed channel capacity. Continued degradation would result in even lower frequency events staying in the channel.

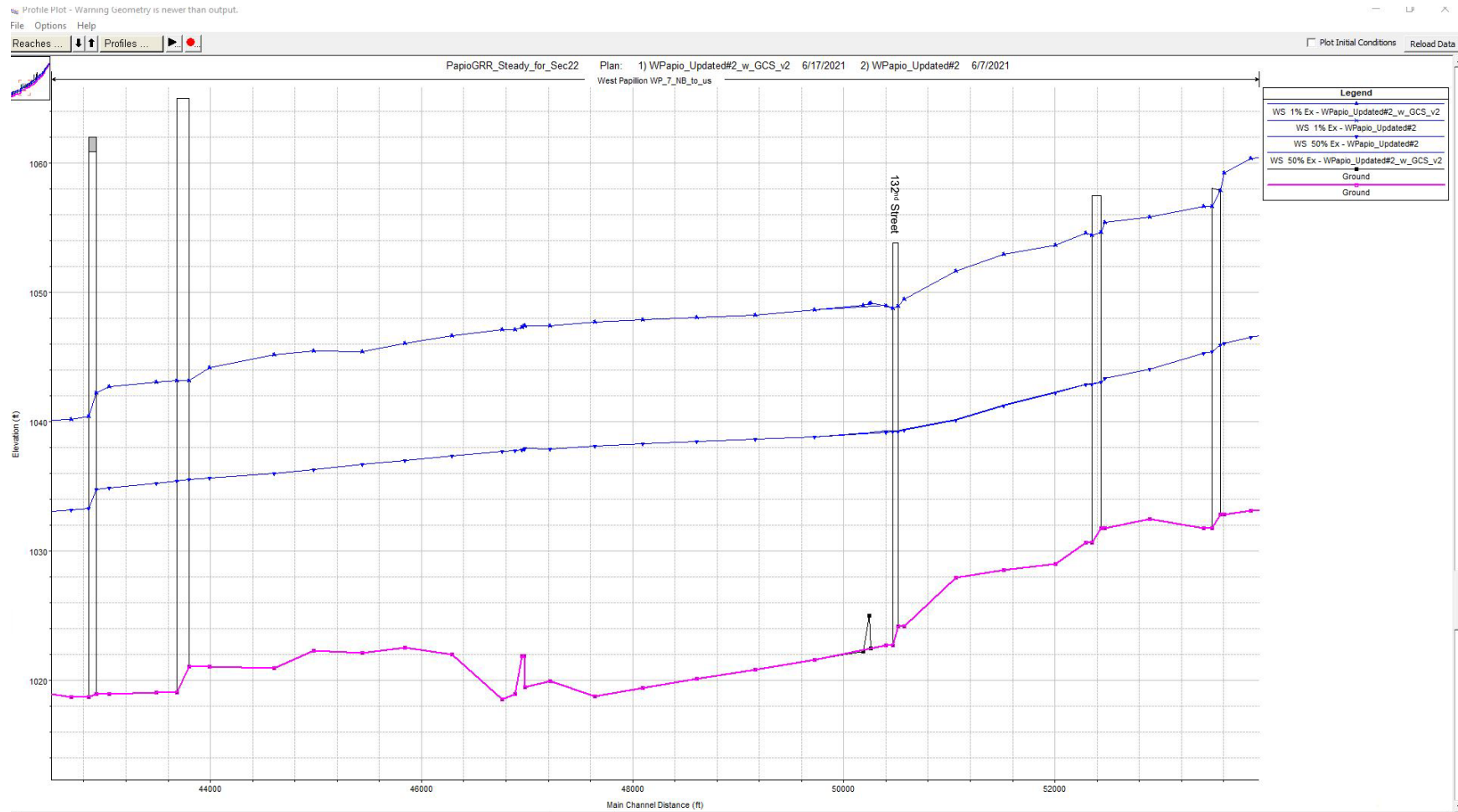


Figure 7-10: Change in Water Surface Elevations at 1% and 50% AEP Flows from GCS

7.3.2 SUGGESTED DESIGN

While the design area has a small footprint, it has multiple bed and bank stability concerns that should be addressed in the design:

- 1) Protection for exposed bridge pier footings.
- 2) Mitigate right bank erosion below bridge from storm sewer outfall.
- 3) Stop drainage headcut on right bank below bridge.
- 4) Control bed elevation with GCSs.
- 5) Do not create a backwater effect onto storm sewer outfall at low to moderate flows.
- 6) Extend bank protection below left bank storm sewer outfall to prevent undermining.
- 7) Maintain stable river slope by raising outlet structure downstream.

The GCSs are rock riffles, as shown in Figure 6-14 and 6-15, to be mechanically placed under low-flow conditions. The design recommends Type-B riprap to withstand the four to eight feet per second velocities estimated in the RAS model for moderate and higher flows.

The bank protection extends above the two-year event, and the crest elevation of the GCS is set at 1025 feet, approximately 1.0 feet below the apron on the storm sewer outfall structure. This elevation is a compromise between maintaining an acceptable bed slope and reducing the frequency of backwater effects on the apron during lower flows. Conceptually, the design is shown in Figure 7-11. When drawn upon the 2016 terrain from the LiDAR, the elevation view is shown in figure 7-12.

To help reduce downstream bed degradation, additional GCSs should be constructed as appropriate. It is recommended to locate at least one additional GCS approximately 3500 feet downstream, located at the golf course drainage outlet. This will reinforce an existing riffle to provide additional channel stability. The elevation is estimated to be 1022.25 feet to maintain a 0.0008 ft/ft slope in the reach. This slope represents similar stable channel conditions elsewhere on West Papillion Creek based on the FG analysis. Figure 7-13 shows the location of the fortified GCS structure. Full size plates of figures are contained in Appendix D.



Figure 7-11: Conceptual Design of West Papillion Creek at 132nd Street





Figure 7-13: Elevation View of Fortification of Tributary Outfall Structure

7.3.3 QUANTITIES AND COSTS

Rough quantities were determined from the volumes of cut and fill determined for the design based on the 2016 LiDAR DEM. A survey check in 2021 that updated the creek thalweg for the hydraulic modeling showed a consistent three to four feet of additional channel degradation since 2016. To adjust for this discrepancy, the crown elevation on the GCS below the bridge (STA 50774 in figure and table) was set to 1028 feet to reflect a more realistic quantity of rock to compensate for this degradation.

Both rock riffle GCSs are designed with a 4:1 upstream and a 20:1 downstream slope with a four-foot crest width and a three-foot foundation depth. The other structures, including revetments and right bank wash protection have a three-foot foundation depth. To address the exposed piers of the 132nd Street bridge, the rock thickness surrounding the piers is increased to five feet in depth.

Costs associated with placed rock is highly variable, based on location, availability, and access. The costs summarized in the table are for \$80 per placed ton of rock. Table 7-2 summarizes the quantities and costs for the structures in the design.

Table 7-2: West Papillion Creek at 132nd Street Bridge Rock Quantities and Costs

Structure	Station (ft)	Elev (ft)	Area (sf)	Foundation Tonnage	Total Tonnage	Per Ton Placed Rock (\$)	Structure Cost (\$)
GCS #1	50774	1025	1286	236	393.8	80.00	31,504
GCS #2	47274	1022.25	2320	425	717.0	80.00	57,361
RB Revetment	50950-50685	1040	7633	1399	1399.4	80.00	111,950
LB Revetment	50875-50685	1040	6610	1212	1211.8	80.00	96,946
RB Wash Riprap	50825	1040	1373	252	251.7	80.00	20,137
Rock Under Bridge	51100-50950	1040	4410	1348	1348	80.00	107,800
				Totals:	1110.8		434,295

8 SOUTH PAPILLION CREEK SOLUTIONS MATRIX AND DESIGN CONCEPTS

This report is based on the Papillion Creek watershed assessment documented in the Geomorphic Study of South Papillion Creek, Omaha, NE using FluvialGeomorph (FG) (Haring, 2022). No site-specific stabilization was identified in the report but a system and reach stabilization perspective was developed. The measures and alternatives are described in this report with emphasis on EWN Natural and Nature Based Features (NNBF).

The study reaches were developed from natural watershed divisions where tributary streams enter the mainstem South Papillion Creek. From a watershed perspective, stabilizing measures should include a combination of EWN measures with bed and bank stabilization recommended to stabilize the South Papillion reaches depicted in the watershed map (Figure 8-1) and corresponding LiDAR profiles. The next section provides more detailed information about individual reaches.

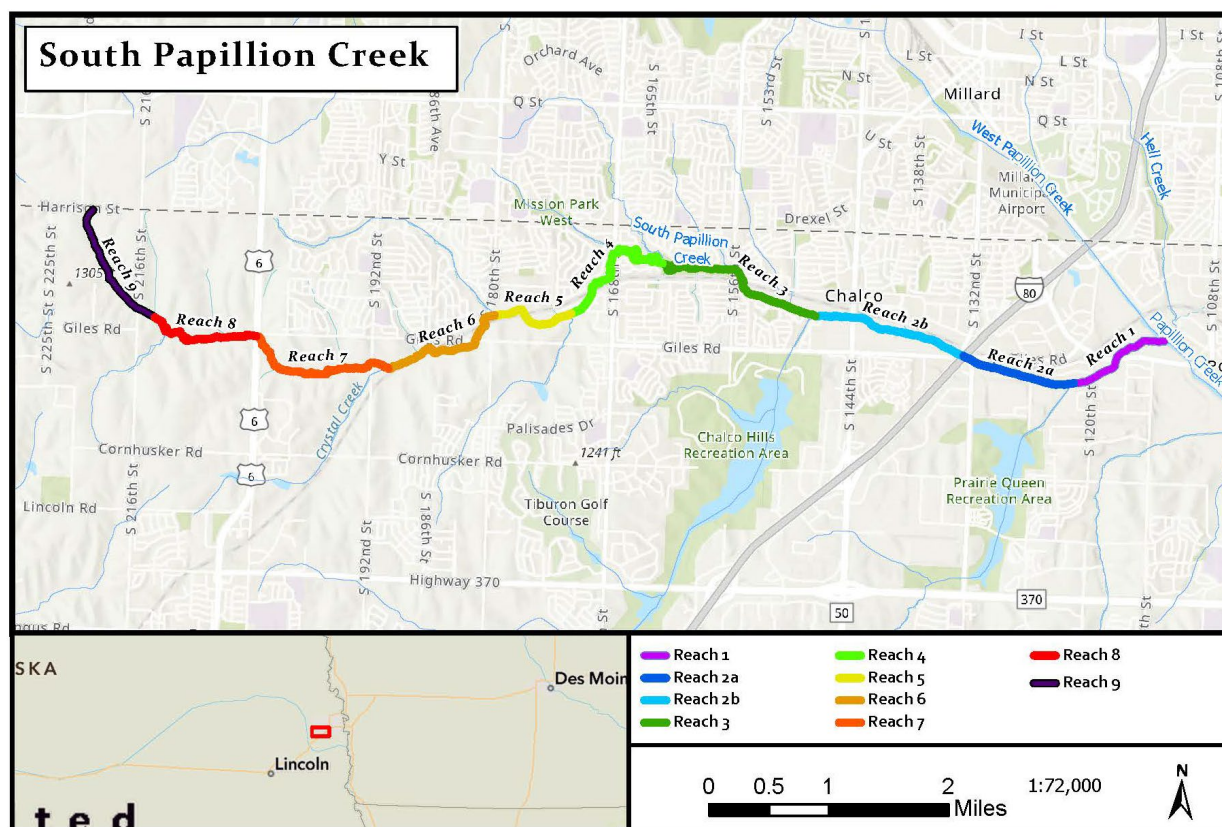


Figure 8-1: FG South Papillion Creek Watershed, Reaches 1 – 9

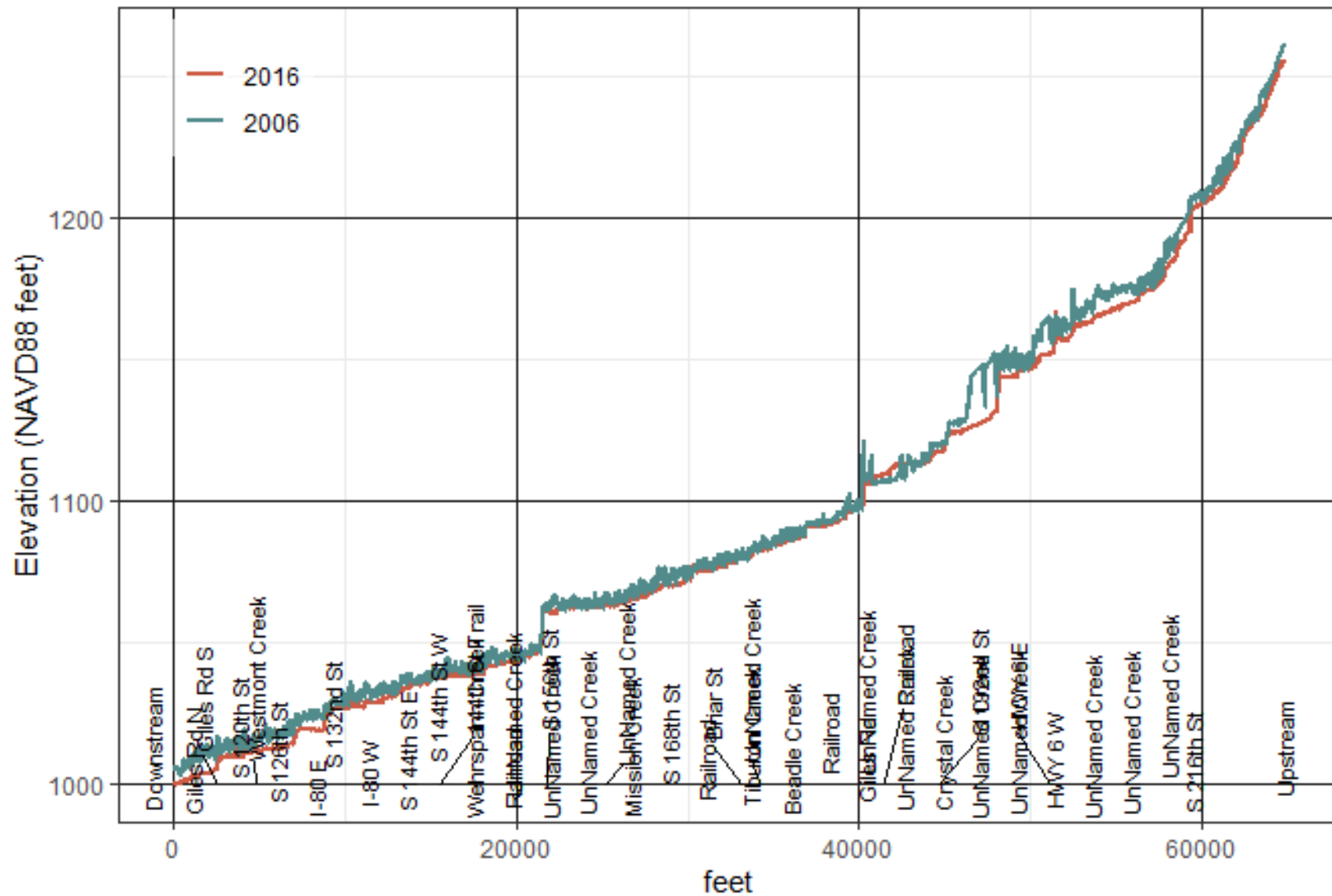


Figure 8-2: FG South Papillion Creek LiDAR Profiles (2004 and 2016), Reaches 1 – 9

8.1 SUMMARY OF FINDINGS

This section expands upon the summary of recommendations from the South Papillion Creek FG report and discussion of possible stabilization measures. The FG report provides geomorphic information based on analysis of high-resolution terrain data, field visits and information provided by the P-MRNRD. The South Papillion Creek has progressed through a series of channel degradational and aggradational phases caused from channelization and land-use changes throughout the watershed. From a geomorphic perspective, stream channels are continuing to adjust from previous channel and watershed alterations and continued changes as urban development impacts the watershed shifting agriculture land-use to residential and commercial land-uses.

Some general trends based on the FG analysis and field reconnaissance are as follows.

8.1.1 CHANNEL DEGRADATION

Based on LiDAR profile slope comparisons, channel degradational trends appear in Reaches 1, 2, 7, 8 and 9 (Figure 8-3). The upstream limit of Reach 9 illustrates channel degradation at the Harrison Road culvert (Figure 8-4) and the downstream end at South 216th Street culvert (Figure 8-5). The structures are providing grade control to the channel upstream of the structure; if they are undercut and fail, then large amounts of sediment and initiation of channel degradation will propagate to the upstream reach. Degradation trends in reaches 7, 8 and 9 have some bed control (Figure 8-3, green circles) with a somewhat erosion-resistant glacial till in the channel bed (Figure 8-4). The glacial till (clay layer) is providing some bed stabilization benefits to the reaches.

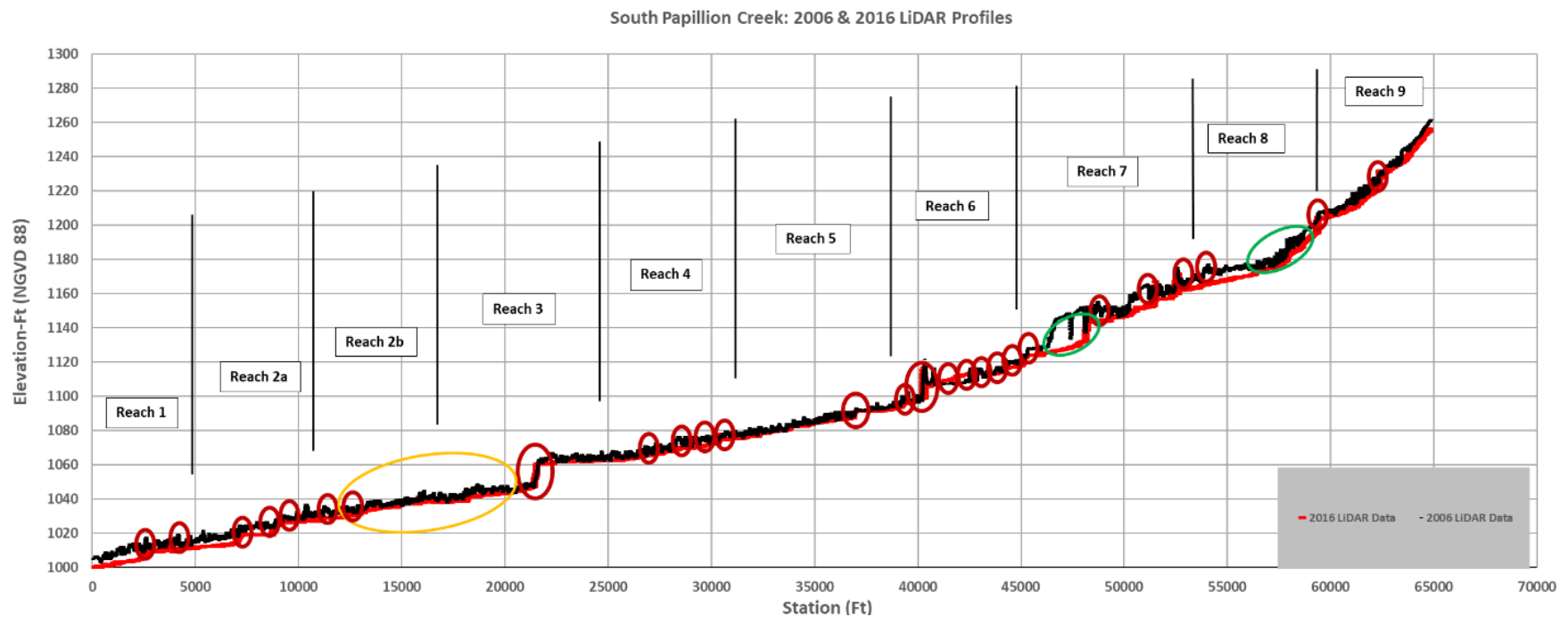


Figure 8-3: FG South Papillion Creek LiDAR Profiles (2004 and 2016), Reaches 1 – 9, Illustrating Existing GCSs (red circles), Erosion-Resistant Materials (green circles), and Potential Equilibrium Slope (orange circle)



Figure 8-4: South Papillion Creek FG, Reach 9 – Perched Culvert at Harrison Street, Upstream End of Reach 9



Figure 8-5: South Papillion Creek FG, Reach 9 – Downstream Terminus of Reach 9, Illustrating a Perched Culvert at South 216th Street

From the FG analysis and site visits, multiple locations within the nine reaches (Figure 8-3, red circles) were identified that are providing grade control and bank stabilization benefits to the channel; however, these structures were not designed to prevent channel degradation so many of them are adjusting and are in possible failure condition (Figure 8-6). Many of the bridges within the reaches have existing rock or riprap materials that are acting as GCSs as rock launches from scour protection, such as at South 126th Street Bridge (Figure 8-6). Undercut filter fabric at many locations is acting as a slide moving riprap material downslope as the scour protection is being undercut. The structures are providing substantial bed stabilization benefits as illustrated in Figure 8-7.



Figure 8-6: FG Reach 2b –South Papillion Creek: Existing Riprap Forming GCS Under South 126th Street Bridge



Figure 8-7: FG Reach 2b –South Papillion Creek: Illustrating the Benefits of GCS Upstream of South 126th Street Bridge

Additional GCSs identified include two large sheet pile grade control structures at railroad bridge crossings (Figure 8-8). These structures compensate for eight to 10 feet of elevation grade and have provided bed and bank stabilization benefits upstream, but are a barrier to fish passage in the upstream reaches. If these structures are modified, careful consideration in developing new channel grade-line profiles needs to be evaluated.



Figure 8-8: FG Reach 3, South Papillion Creek – Illustrating Railroad Bridge GCS

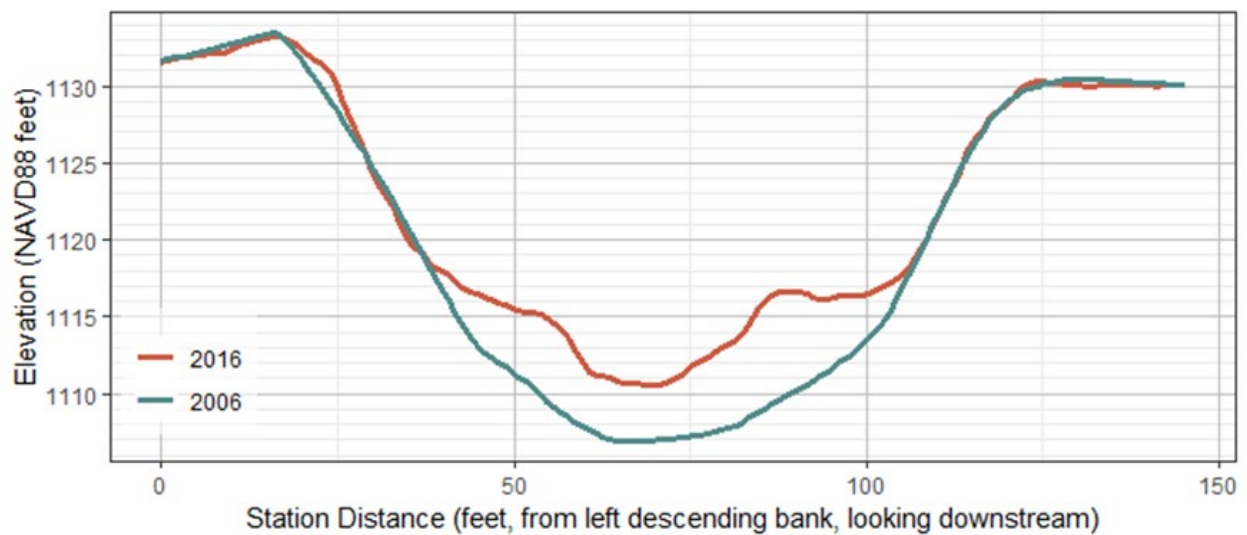
Other road culverts provide bed and bank stabilizing benefits within the watershed. For example, the Giles Road culverts (Figure 8-9) provide bed and bank stabilizing benefits upstream in one of the only reaches (Reach 6) that illustrates aggradation, where sediment has redeposited in the previous degraded channel and built new floodplains (Figures 8-10 and 8-11). Downstream of the culverts, the channel has degraded and has eroding vertical left banks (Figures 8-11 and 8-12). If the Giles Road culverts are replaced, careful consideration needs to be considered when designing a replacement as changing the culverts size and invert elevations will cause de-stabilization to the reach upstream.



Figure 8-9: FG Reach 6, South Papillion Creek – Giles Road Culverts



**Figure 8-10: FG Reach 6, South Papillion Creek – Upstream of Giles Road Culverts
Showing Aggraded, Stable Channel Reach**



**Figure 8-11: FG Reach 6, South Papillion Creek – LiDAR Cross-sections Illustrating
Channel Aggradation and Floodplain Building in a Previously Incised Channel**



Figure 8-12: FG Reach 6, South Papillion Creek – Downstream of Giles Road Culverts Showing Local Channel Degradation at Culvert Outlets and Unstable Banks Downstream

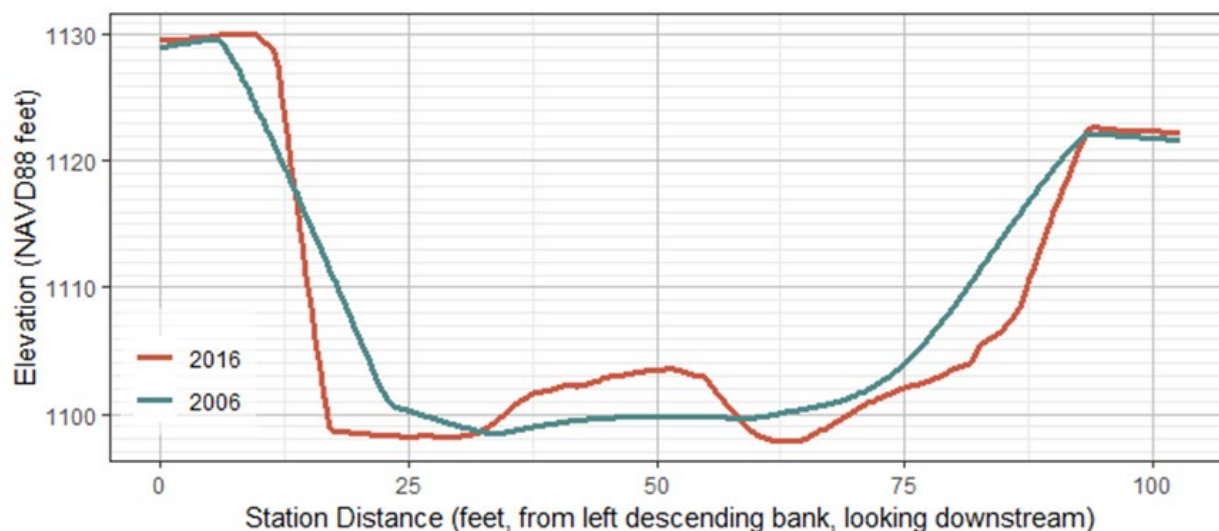


Figure 8-13: FG Reach 6, South Papillion Creek Creek – LiDAR Cross-sections Illustrating Relatively Stable Channel with Left Bank Erosion

Based on the LiDAR analysis for Reach 6, there is a degradation trend upstream of the aggrading section upstream of the Giles Road culverts. During the site visit, this was verified by visiting the upper section of Reach 6. The railroad bridge crossing in this location does not have any GCSs under it and there appears to be channel lowering, local pier scour or possibly a combination of both. Whatever the exact cause, this location should be investigated further as the wood footing for the center pier span is threatening to be undercut.



Figure 8-14: FG Reach 6, South Papillion Creek – Railroad Bridge in Upstream Section of Reach Showing Scour and Potential Undercutting of the Wood Footings

8.1.2 BANK EROSION

Local bank erosion throughout the nine reaches was located using FG and the associated metrics and was field verified in some locations. The more sinuous channel reaches show the most extensive bank erosion problems. Reach 4 has a lot of channel meanders that are assumed to be natural and are likely the only un-straightened channel areas left within the watershed. In many locations seen during field visits, some erosion-resistant lower bank materials were encountered (Figure 8-15). The banks are eroding but would likely erode faster without some of the lower bank toe erosion-resistant materials.



Figure 8-15: FG Reach 4, South Papillion Creek – Channel Section Immediately West of South 167th Court Showing Vertical Right Banks in a Meandering Incised Channel

Critical Bank Erosion Sites

The FG report identifies areas within the watershed that are more likely to be experiencing severe erosion and unstable channel conditions. There are likely utility and other crossings that should be cross-referenced with this report to determine if there are utilities or other sensitive areas that should be targeted for stabilization within the watershed. Focused restoration and stabilization areas are listed in the next section of this report.

8.2 SUMMARY OF RECOMMENDATIONS

This summary is based on FG Level I and Level II analysis and field reconnaissance completed in March 2021.

Priority #1: Use existing GCS locations to continue to stabilize the channel.

In evaluating the condition of every GCS within the watershed, the plan should include an assessment of each structure and determination if the location is appropriate based on channel stability and hydraulic perspectives. Most every bridge has a form of GCS underneath or immediately downstream. The GCSs are protecting the piers and abutments and providing bank and bed stability to the reach upstream. Further protection of these areas is critical in continuing to promote channel stability.

Additional analysis of the spacing of the existing GCSs and assessment of stable channel slopes could assist in siting of additional GCSs (Figure 8-16). Spacing of GCSs may also reduce local bank erosion by providing stable channel slopes in all reaches. In addition, equalizing the energy slope and spreading the elevation change more naturally through reaches will provide additional stabilization benefits. In all reaches, the stream channel sections immediately upstream of GCSs were stable or in the process of stabilizing building floodplain berms.

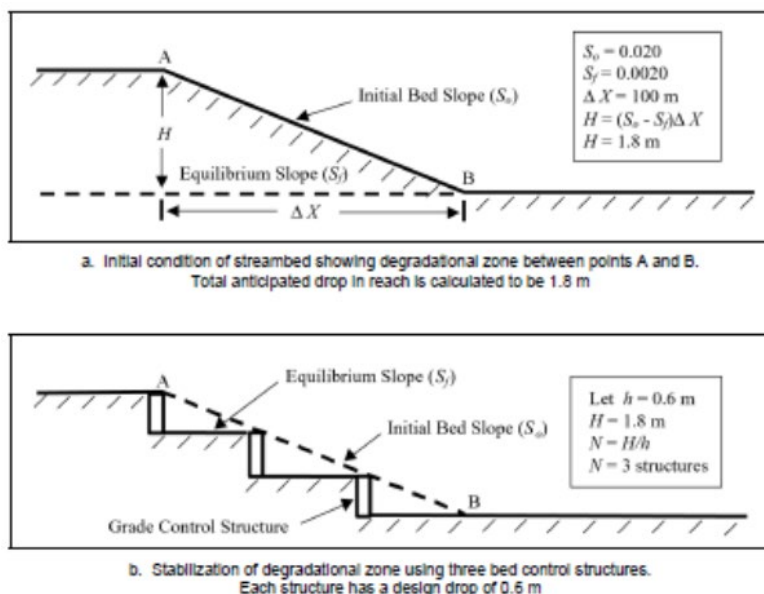


Figure 8-16: Hydraulic Siting of Bed Control Structures

Source: Biedenharn and Hubbard, 2001

Priority #2: Grade control should be considered in the areas where there has been the most bed degradation: Reaches 7, 8 and 9.

These reaches also have the steepest slopes and the presence of the erosion-resistant glacial-till clay beds. The areas will continue to contribute sediment to the downstream reaches if future bed degradation is not treated.

Priority #3: Develop a comprehensive plan to monitor general watershed development and infrastructure enhancements.

Any changes to land-use, floodplains, existing bridges, and culverts could have large impacts to the stability of the South Papillion Creek watershed. Regulating and monitoring of stormwater in addition to sediment management and erosion control are paramount in promoting a stable watershed.

Priority #4: Target low W/D ratio areas for additional bed and bank erosion control.

Based on the W/D ratios, many reaches are considered incised ($W/D < 10$), with others on the lower end of stable (W/D 10-20) less than 12, and very few sections that were considered over widened ($W/D > 20$).

Priority #5: Target low channel sinuosity and ER sections for bank erosion protection.

Low sinuosity and ER typically signifies previously channelized sections resulting in lack of floodplain connection and higher channel velocities and near-bank shear stress.

Priority #6: Target upland areas for water and sediment retention structures.

As the watershed land-use changes from agricultural to urban areas, locations that can be used for water and sediment control retention should be identified to assist with increased sediment and discharge rates. Structures such as WASCOBs can be used to assist with retention of flow and sediment by temporarily adding flood storage and some sediment collection. As with all detention/retention basins, maintenance is required to maintain storage capacity.

8.3 PRELIMINARY STRUCTURAL AND NON-STRUCTURAL MEASURES

Typical structural measures were considered in addition to EWN measures. EWN measures are described in further detail in Section 6.1.2.

Measures and alternatives are described below. Measures were developed into alternatives, based on preliminary information and best profession engineering judgement. Note: The No Action alternative is always considered in USACE analysis.

Based on the South Papillion Creek FG analysis and field investigations in March 2021, bed degradation trends and bank stabilization areas were identified and prioritized.

8.3.1 STRUCTURAL MEASURES

Sheet Pile Wall:

See description in Section 6.1.1 and Figure 6-1.

Riprap Blanket-Bank Lining with Riprap Stone Protection:

See description in Section 6.1.1 and Figure 6-5.

EWN-Longitudinal Peaked Stone Toe Protection (LPSTP):

See description in Section 6.1.1 and Figures 6-6 through 6-9. Another example is shown in Figure 8-17 below.



Figure 8-17: EWN LPSTP Project Completed on South Papillion Creek-Reach 3

EWN-Longitudinal Fill Stone Toe Protection (LFSTP):

See description in Section 6.1.1 and Figures 6-10 and 6-11.

EWN-Loose Rock Riffle Grade Control Structures:

See description in Section 6.1.1 and Figures 6-12 through 6-14. Another example is shown in Figure 8-18 below.



Figure 8-18: Lincoln, NE – Beal Creek Rock Riffle Grade Control Structure

EWN-Cross-Vein Grade Control Structures:

This method provides bed stabilization to the reach through a series of structures similar to the loose rock riffle structures that equalize the channel grade over the entire reach. The difference between these structures and loose rock riffles is the size of stone material in the design. The cross-veins use larger landscape wall rock to build the structure. This is typical of many western U.S. streams, so the structures are used extensively in landscapes that promote more threshold channel designs. The structures should be used in locations that have access to active floodplains so excessive near-bank shear stress does not move materials from the channel margins and undercut the large stone structure. GCSs, in general, promote stabilization of the eroding bankline toe to an upstream reach (Figures 8-19 and 8-20).



Figure 8-19: Fayetteville, AR, Urban Creek with Cross-Vein Grade Control Structures

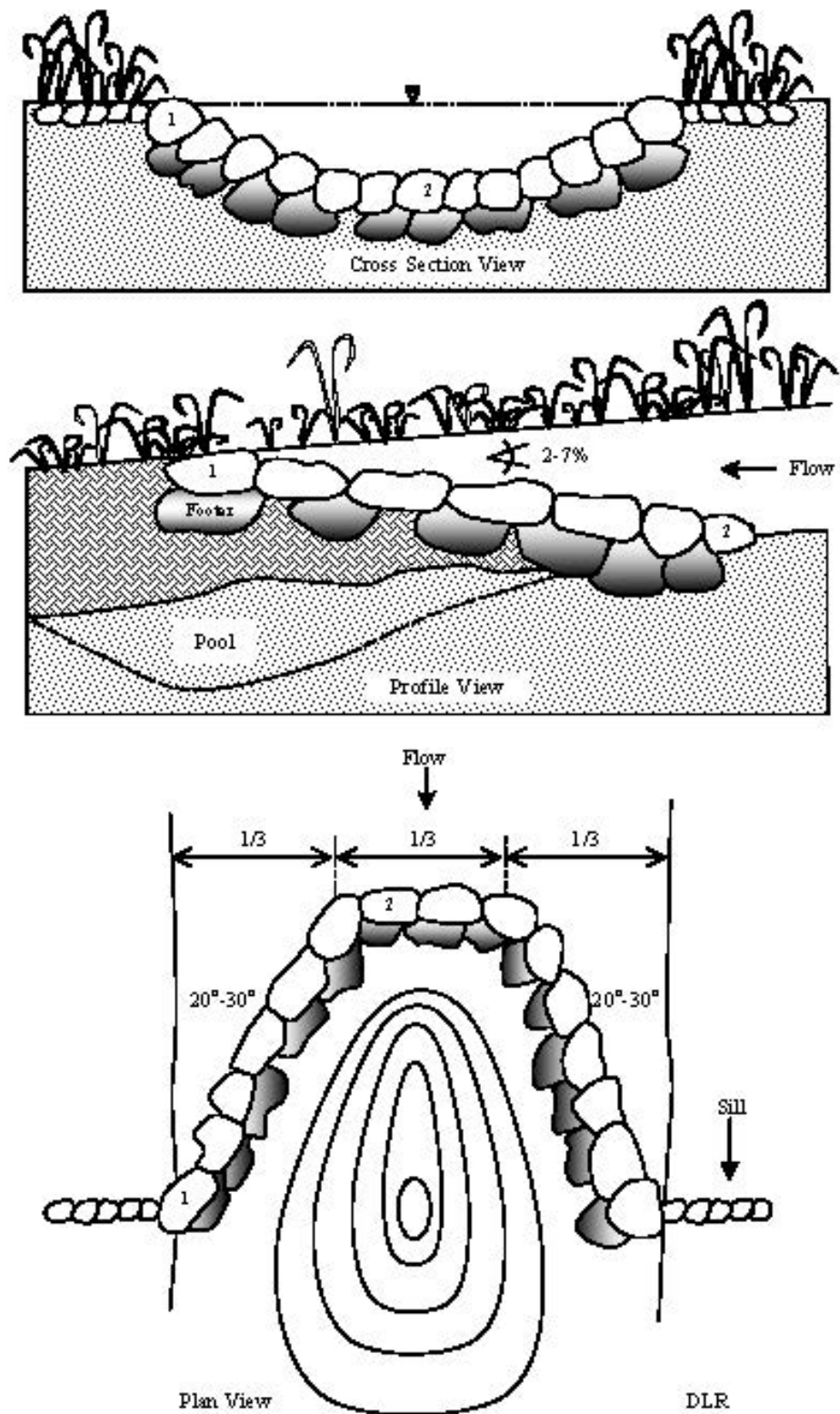


Figure 8-20: Typical Cross-Vein GCS Design Details

8.3.2 NON-STRUCTURAL MEASURES

Buyouts were not considered since most of South Papillion Creek has an existing setback and a developed recreational trail system along the stream corridor.

EWN Enhancement Measures

- For South Papillion Creek, EWN enhancements may include the same options described for Cole Creek and West Papillion Creek. Refer to Section 6.1.2 for more information regarding EWN Enhancement Measures.
- Examples of EWN Enhancements that can be supplemented with structural components are provided in Figures 6-16 through 6-19.

8.4 FORMULATION AND COMPARISON OF ALTERNATIVES

The management measures were converted into the most likely alternatives either alone or in combination. The following alternatives and No Action Alternative were considered in response to the South Papillion Creek channel erosion and stability problems. The planning objectives for the project are to stabilize the channel bed and banks within the watershed. Targeted areas will be further defined based on the previous recommendations. The stabilization measures can be used in multiple locations throughout the watershed and this analysis is to provide a base for what measures are applicable.

8.4.1 ALTERNATIVE PLAN DESCRIPTIONS

Alternative 1 – No Action

The No Action alternative forms the baseline for evaluating the benefits of the proposed action alternatives. The No Action alternative does not preclude local officials from seeking and/or implementing solutions to mitigate the erosion processes impacting the riverbank. USACE considers the No Action alternative in accordance with NEPA. Table 8-1 provides an assessment of potential alternatives.

Bank Stabilization:

Alternative 2- Steel Sheet Pile Wall

- Typically very expensive; however, if erosion is close to critical infrastructure, this alternative should be considered.
- Should be considered for protecting critical public infrastructure and other high-profile areas.

Alternative 3 –Riprap Blanket with Toe

- Provides total bank protection.
- Likely costly and may impact large parts of properties we are trying to protect.

Alternative 4 – LPSTP or LFSTP with EWN Mid-upper Bank Re-vegetation

- Low-cost methods that provide continued scour and lower bank protection.
- Option: Toe protection could be extended higher to mid-bank.
- Construction could be completed from in-channel locations.
- The least invasive method for affected property owners.

Bed Stabilization:**Alternative 1 & 2– Loose Rock Riffle Grade Control or Cross-vein**

- Provides stable channel bed locations throughout the reach.
- Promotes toe stabilization and protection.
- Provides natural stable aquatic habitat for fish and micro-invertebrates.
- Can be used in combination with other measures, total bank, toe protection and vegetation enhancement measures.

Alternative 3 – Loose Rock Riffle Grade Control or Cross-vein, with Riprap Blanket with Toe and LPSTP or LFSTP with EWN mid-upper bank re-vegetation

- Provides benefits as listed under Bank Stabilization Alternatives 3 and 4 and Bed Stabilization Alternatives 1 and 2.

Table 8-1: South Papillion Creek Measures Combined into Alternatives

Alternative	Planning Objectives		Planning Constraints			Screening Result
	Meets Purpose and Need	Sustainable	Technically Feasible	Includes Beneficial Environmental Opportunities	Level of Structural Bank Protection	
Alt 1 - No Action	No	No	NA	No	NA	Does not meet the need of the project
Bank Stabilization:						
Alt 2 – Steel Sheet Pile Wall	Partial	Minimal maintenance	Yes	No, No vegetation component and unnatural in appearance	Total	Not environmentally beneficial, likely not the least cost alternative
Alt 3 – Riprap Blanket w/Toe	Partial	Minimal to moderate maintenance	Yes	Yes, vegetation component above blanket	Partial	Environmentally beneficial, Not least cost alternative
Alt 4 – EWN LPSTP/LFSTP w/bioengineering	Partial	Minimal to moderate maintenance	Yes	Yes, potential to incorporate vegetation and contribute to viewshed aesthetic value	Partial: up to half bank height based on final design	Environmentally beneficial, likely least cost alternative
Bed Stabilization:						
Alt 1 – Loose Rock Riffle Grade Control Structure or Cross-vein	Partial	Minimal to moderate maintenance	Yes	Yes, stone facing; potential to incorporate vegetation and contribute to viewshed aesthetic value	Partial: provided limited toe protection, does prevent channel deepening & widening	Environmentally beneficial, likely a component of least cost plan
Alt 2 – Cross-vane Grade Control Structure	Partial	Minimal to moderate maintenance	Yes, use should be limited to non-incised channel areas where good floodplain connections exist	Yes, stone facing; potential to incorporate vegetation and contribute to viewshed aesthetic value	Partial: provided limited toe protection, does prevent channel deepening & widening	Environmentally beneficial, likely a component of least cost plan
Alt 3 – GCS, EWN LPSTP/LFSTP w/bioengineering	Yes	Moderate to significant maintenance	Yes	Yes, stone facing; potential to incorporate vegetation and contribute to viewshed aesthetic value	Total	Environmentally beneficial, comprehensive plan incorporating low cost and EWN

8.5 SITE C – SOUTH PAPILLION CREEK PROPOSED STRUCTURE LOCATIONS

The restoration and stabilization alternatives provided in this report will require additional quantity details and developed costs to provide comparisons for each recommended option.

Additional restoration recommendations are completed for South Papillion Creek Reaches 1 through 9 in the South Papillion Creek FluvialGeomorph Report section. The report outlines additional GCSs and bank stabilization alternatives and areas where further studies are recommended.

This is a preliminary layout of GCSs and bank protection based on FG analysis and limited field visits. Additional field visits, surveys, and hydraulic designs will be required prior to modification of existing structures or construction of new revetments. Additional permitting requirements also need to be met prior to implementing channel restoration and stabilization measures.

Reach maps are provided to illustrate the potential locations for bed and bank stabilization practices (Figures 8-21-8-29).

- Existing GCSs (may or may not have been designed as GCS) are identified with *Red* circles.
- Potential new GCSs are identified with *Green* circles.
- Existing bank stabilization revetment is identified with *Blue* circles.
- Potential new bank stabilization locations are identified with *Yellow* circles.

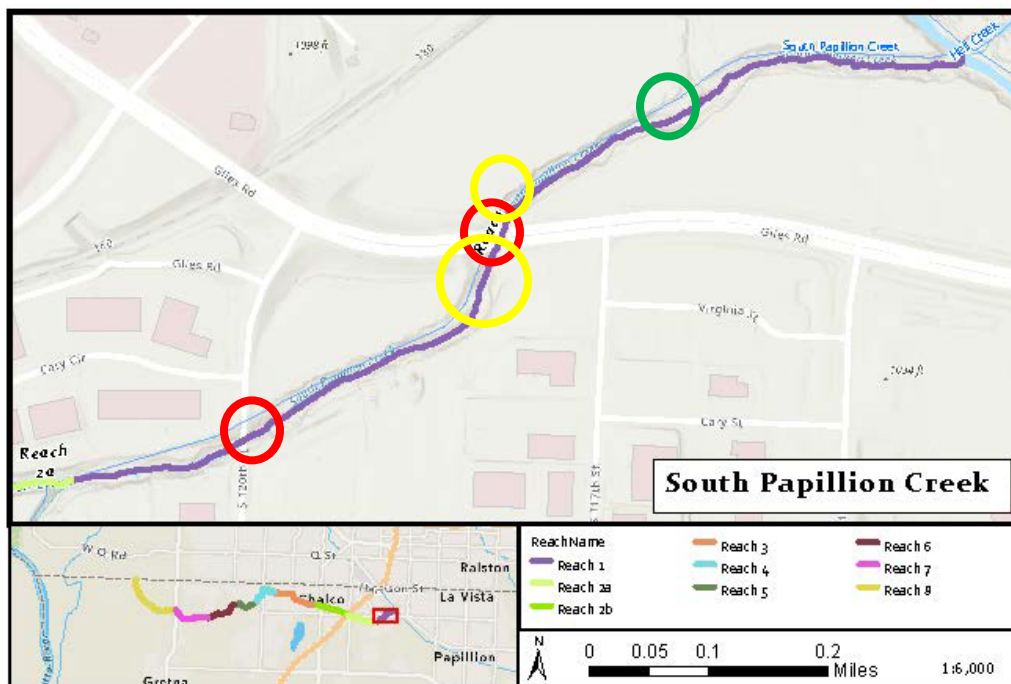
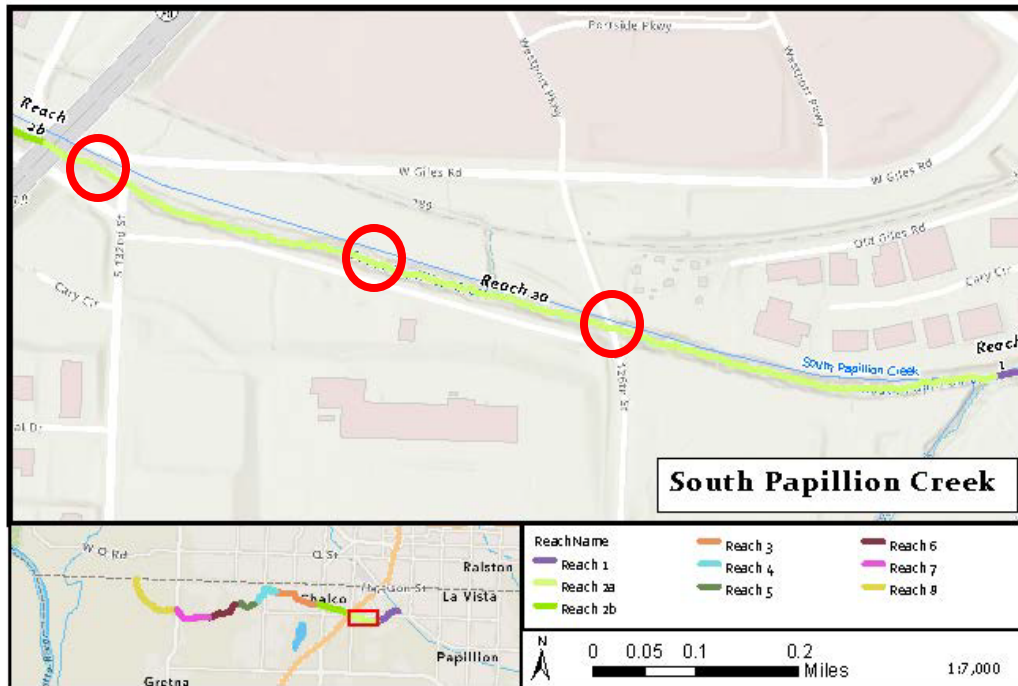
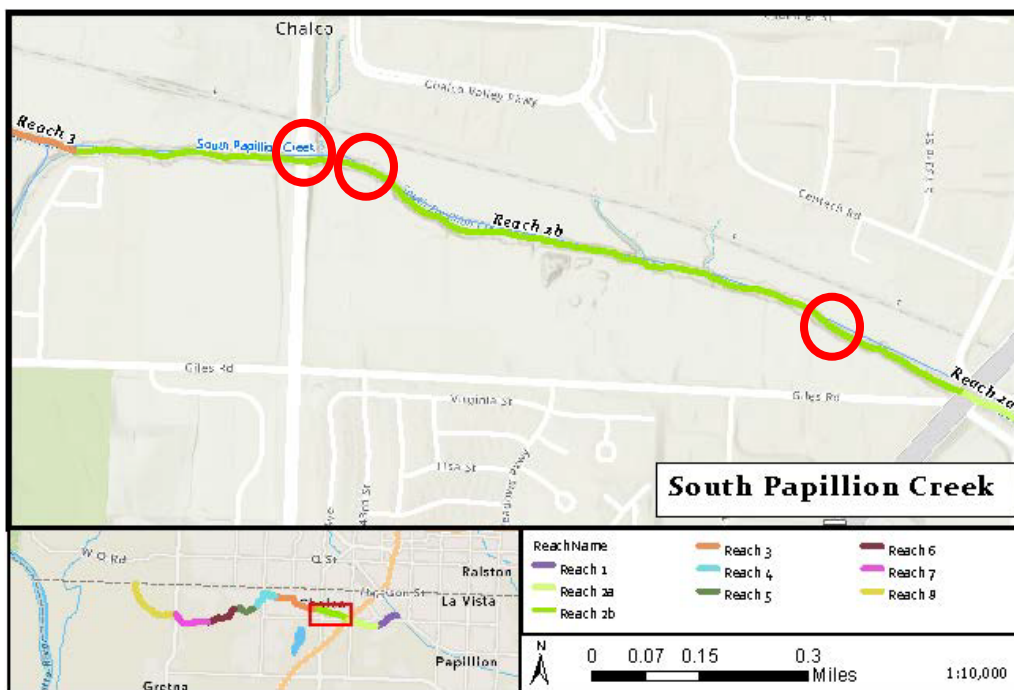


Figure 8-21: Reach 1 – South Papillion Creek

**Figure 8-22: Reach 2a – South Papillion Creek****Figure 8-23: Reach 2b – South Papillion Creek**

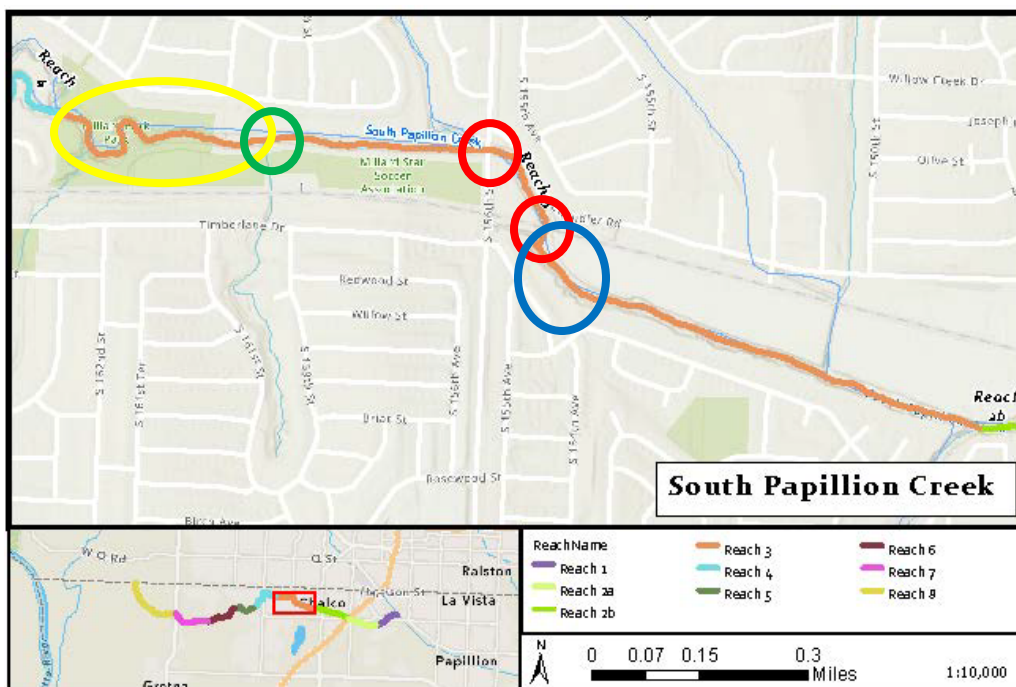


Figure 8-24: Reach 3 – South Papillion Creek

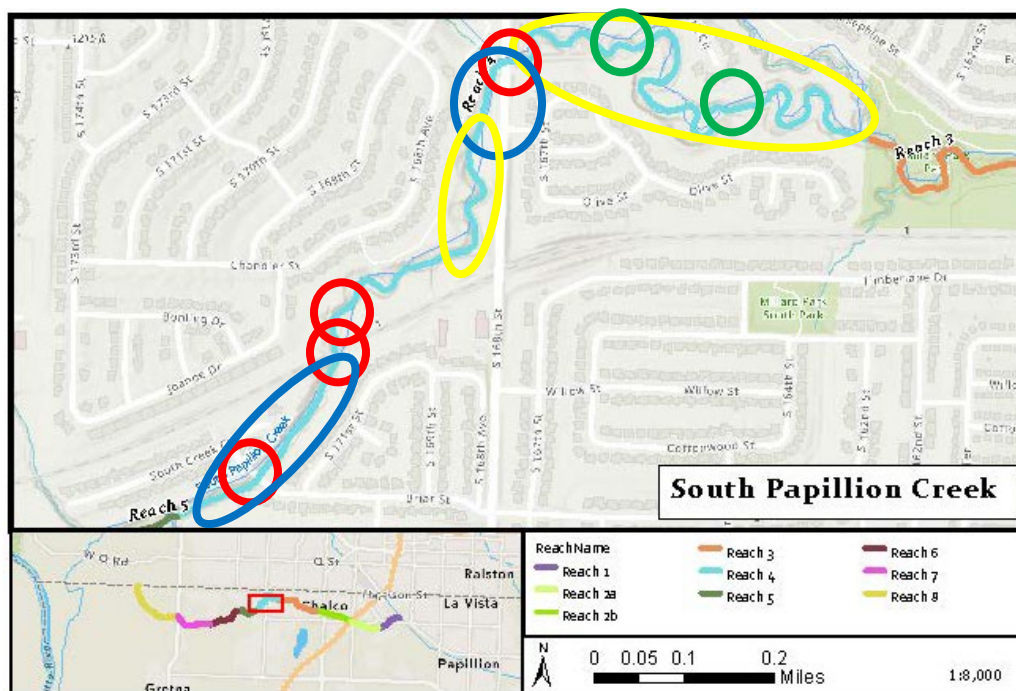


Figure 8-25: Reach 4 – South Papillion Creek

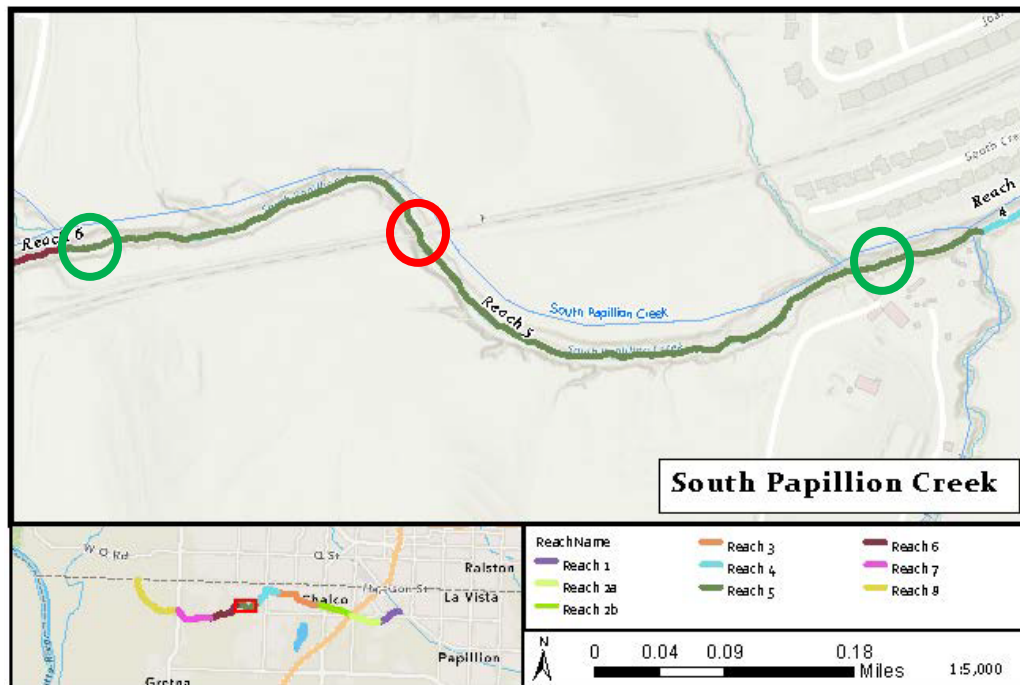


Figure 8-26: Reach 5 – South Papillion Creek

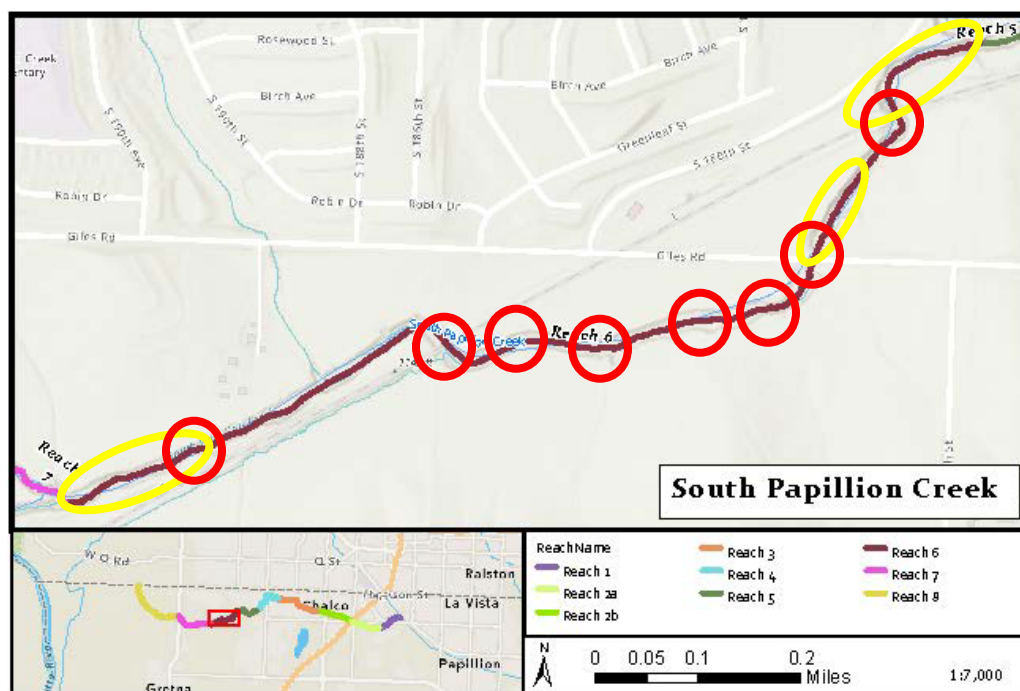


Figure 8-27: Reach 6 – South Papillion Creek

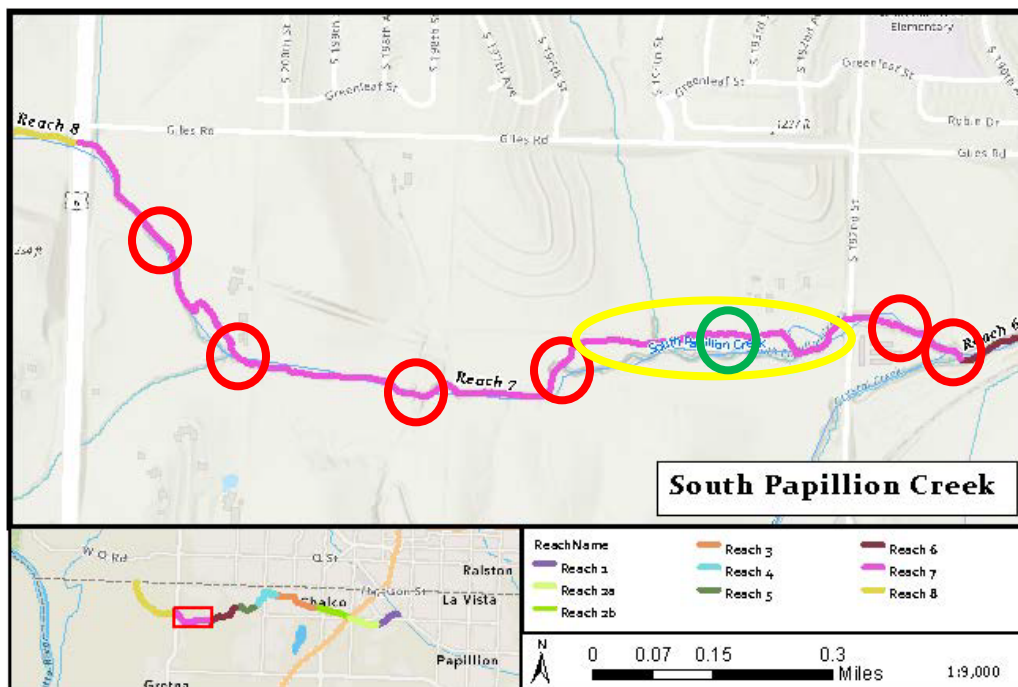


Figure 8-28: Reach 7 – South Papillion Creek

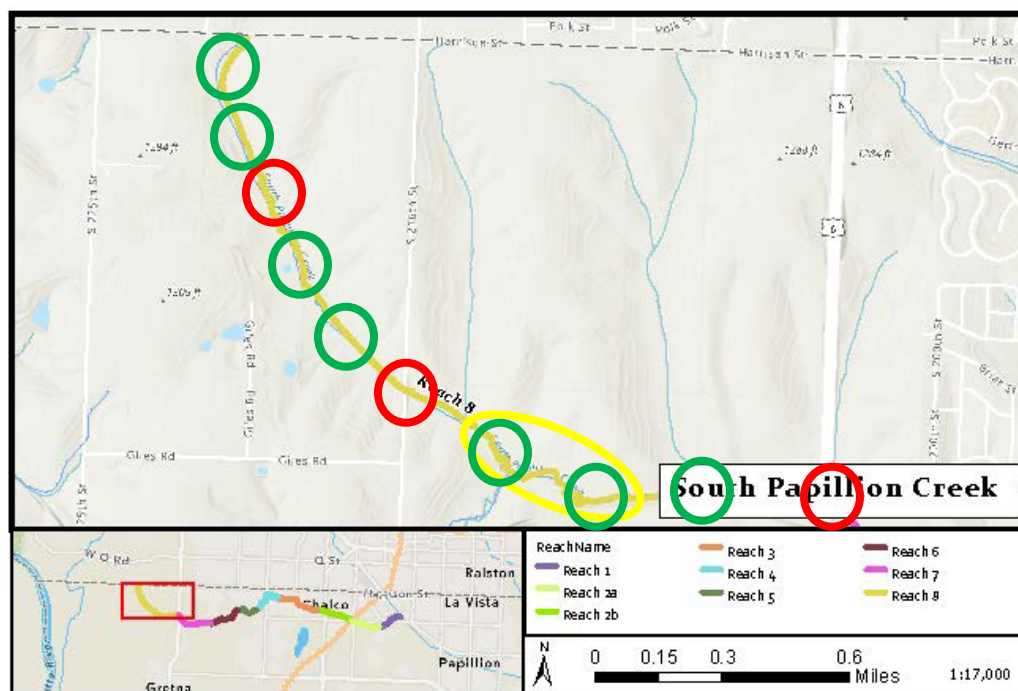


Figure 8-29: Reach 8 – South Papillion Creek

9 ENVIRONMENTAL CONSIDERATIONS

The health or quality of the fish community in the Papillion Creek Watershed is generally considered to be poor, and generally gets worse as you move higher up the watershed. The lack of habitat in the streams resulting from extensive channelization and bed degradation has contributed to the decline of the fish community.

The addition of rock riffle GCSs would add some habitat diversity to the affected streams. The proposed 20:1 slope on the downstream side of the GCSs will allow for upstream fish migration. In addition, these structures would reintroduce riffle pool sequences to the stream that allow for flow-energy dissipation over a series of structures. This would result in areas with more stable substrate for macro-invertebrates, fish species (stonerollers, and others), and other aquatic species to colonize. The increased roughness across the riffle on the downstream side of the structure would introduce more oxygen into the water for the benefit of aquatic species.

The riparian and wetland habitat within the Papillion creek basin has also been severely degraded. Commercial, residential, and agricultural development on the floodplain has eliminated native vegetation near the streams, and levee construction, bed degradation, and bank erosion have adversely impacted the riparian and wetland habitat along the bed and banks of the streams. In many locations, there are sheer cutbanks where no vegetation can grow. Bank stabilization measures that include native vegetation components, and potential development of wetland benches are recommended wherever possible. The incorporation of vegetation components would provide needed habitat for birds, small mammals, insects, and other wildlife. Leaves, sticks, and other organic matter from this vegetation that falls into the stream would provide nutrients, food, and substrate for aquatic organisms in the stream.

10 REGULATORY CONSIDERATIONS

Caveat: The Regulatory Considerations within this report are not final USACE decisions or determinations. These considerations are to be incorporated into final designs and/or permit applications. Complete Section 404 permit applications must be provided to and evaluated by the Nebraska Regulatory Office to determine final permitting requirements.

10.1 OVERALL SECTION 404 CLEAN WATER ACT (CWA) REGULATORY CONSIDERATIONS

Many of the activities described in this study could involve a discharge of fill material into WOTUS, which would require Section 404 authorization from USACE. There are multiple Section 404 Clean Water Act permitting options and limitations to consider when designing and constructing stream stabilization/rehabilitation projects to address stream degradation within the Papillion Creek Watershed, Omaha Metro Area.

Specifically, under the USACE Nationwide Permit (NWP) program, there are only a few NWPs available that authorize different types of stream/bank stabilization, stream restoration/rehabilitation, and grade-control activities. Those NWPs include *NWP-13 Bank Stabilization*, *NWP-43 Stormwater Management Facilities*, and *NWP-27 Aquatic Habitat Restoration, Enhancement, and Establishment Activities*. Key terms, conditions, thresholds and limiting factors of each of those NWPs are discussed below. Furthermore, some important considerations from *NWP General Conditions and definitions* (applicable to all NWPs) are also discussed below, in the context of stream stabilization projects. Other NWPs, such as *NWP 3 Maintenance* or *NWP 14 Linear Transportation Activities*, also allow minimal stream bank stabilization activities associated with maintenance or transportation activity but are not discussed further in this study. All NWPs, terms, conditions and definitions are available online at: <http://www.usace.army.mil/Missions/Civil-Works/Regulatory-Program-and-Permits/Nationwide-Permits/>.

It is important to note that in order to utilize an NWP, or multiple NWPs within an area, the activities must result in no more than minimal individual and cumulative adverse environmental effects. When making minimal adverse environmental effects determinations, USACE will consider:

- The direct and indirect effects caused by the NWP activity.
- Cumulative adverse environmental effects caused by activities authorized by an NWP.
- Site specific factors, such as the environmental setting in the vicinity of the NWP activity.
- The type of resource that will be affected by the NWP activity.
- The functions provided by the aquatic resources that will be affected by the NWP activity.
- The degree or magnitude to which the aquatic resources perform those functions.
- The extent that aquatic resource functions will be lost because of the NWP activity (e.g., partial or complete loss).
- The duration of the adverse effects (temporary or permanent).

- The importance of the aquatic resource functions to the region (e.g., watershed or ecoregion).
- Mon required by USACE.
- USACE may add case-specific special conditions to the NWP authorization to address site-specific environmental concerns.
- If an appropriate functional or condition assessment method is available and practicable to use, that assessment method may be used by USACE to assist in the minimal adverse environmental effects determination. The Omaha District, Nebraska Regulatory Office utilizes the [Nebraska Stream Condition Assessment Procedure \(NeSCAP\)](#) for assessing stream conditions (discussed further below).
- If a project/activity does have more than minimal individual and cumulative adverse environmental effects, then an individual permit (IP) would be required.

It is also important to identify what information is required to be submitted within a Section 404 permit application, also known as a preconstruction notification (PCN) under the NWP Program. The information required for a PCN is found in NWP General Condition 32(b) *Contents of Pre-Construction Notification*, and in ENG FORM 6082. Per GC 32(b)(5), the PCN must include a delineation of wetlands and streams, on the project site. Wetland delineations must be prepared in accordance with the current method required by USACE, which in this case would be the USACE 1987 *Wetlands Delineation Manual* and current *Regional Supplement to the USACE Wetland Delineation Manual: Midwest Region*.

In addition to and separate from the NWPs, the Omaha District, Nebraska Regulatory Office, has issued Regional General Permit (RGP) 88-04 to P-MRNRD for *Maintenance of existing Flood Control Facilities in Big Papillion Creek and its tributaries*. The RGP 88-04 is limited, as it can only be used by P-MRNRD (no other applicants/permittees), only in the Big Papillion Creek Watershed, for maintenance activities associated with the existing flood control and protection facility (levee), flood damage restoration (repair work), and maintenance of existing levee infrastructure. The RGP 88-04 does allow for slope-protection armoring of stream banks and grade-control structures, and does not have thresholds associated with the linear foot or acreage impacts to WOUS. Due to the RGP 88-04's limitations and the sponsor/P-MRNRD's familiarity with it, it is not discussed further in this report.

Link to RGP 88-04:

<https://usace.contentdm.oclc.org/utis/getfile/collection/p16021coll7/id/19081>.

The RGP and NWP are two types of *general permits*, which are authorizations that are issued on a nationwide, statewide, or regional basis for a category or categories of activities that are similar in nature and do not cause more than minimal individual and cumulative adverse environmental effects. General permits also include programmatic general permits. Regional and programmatic general permits may be issued by a district or division engineer. Regional general permits can improve regulatory consistency and enhance program efficiency. Programmatic general permits (PGPs) are a type of general permit that can be used to avoid duplication with other agencies, such as state programs regulating discharges of dredged or fill material into wetlands, to simplify the permit process for the regulated public, while protecting the aquatic environment. Programmatic general permits can help districts direct their limited resources to permit applications that may have greater environmental impacts. (USACE

Regulatory SOP, 2009.) The Omaha District Regulatory Branch Chief is the delegated authority responsible for issuing any new RGPs or PGPs within the district, with support from the local Regulatory Offices. The issuance of a new RGP requires public notice/comment, agency coordination, and compliance with all applicable laws and regulations. Contact the Nebraska Regulatory Office for more information.

10.2 REGULATORY CONSIDERATIONS APPLICABLE TO ALL THREE EXAMPLE REACHES / WHOLE WATERSHED (WEST PAPIO, SOUTH PAPIO, AND COLE CREEK):

- The current extent of impacts to WOTUS, including wetlands, due to these proposed structures involving filling activities are not calculated or known, but rough estimates are calculated in the sections below based off the approximate quantities and figures provided.
- A site-specific delineation of aquatic resources, including wetlands (special aquatic sites) and stream(s) ordinary high-water mark (OHWM), will need to be completed by the project proponent/applicant prior to applying for a Section 404 permit.
- Impacts due to filling and excavation of the streambed, fill below OHWM, and filling and excavation of wetlands, will need to be calculated based on the final designs and aquatic resource delineations.
- Impacts to the streambed and area below OHWM should be minimized when considering the location, configuration, and dimensions of the final designs. Some design considerations to minimize adverse impacts are:
 - Design GCSs with low interior elevations and gradual slopes to maintain low flows for aquatic life movement up and downstream. (See NWP GC #2)
 - Design GCSs to lowest practicable elevation to minimize impeding of water and maintain flows. (See NWP GC #9)
 - Revetments should be designed to the minimum length necessary and minimize fill below OHWM as practicable.
- Impacts to wetlands should be avoided to the extent practicable; for wetlands that cannot be avoided, minimize the footprint of impact within wetlands.
- Utilize only native species appropriate for the region for revegetation and planting efforts.
- Suitable grade and type of material shall be used. (See NWP GC 6. *Suitable Material* and Omaha District's list of *Prohibited and -Restricted Materials* <https://www.nwo.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/487696/prohibited-restricted-materials/>)
- Be aware of current NWP thresholds for impacts to streams and wetlands, that either require compensatory mitigation or waivers, or preclude the use of certain NWPs.
 - NWPs to consider include NWP 3, 13, 14, 27, 43.
 - Compensatory mitigation would be required, if impacts to wetlands exceed 0.1 acres, or streambed loss exceeds 0.03 acres. This requirement may be waived; however, additional information may be required to consider a waiver. (See NWP GC #23)

- See NWP thresholds, general conditions and definitions, including GC 28. *Use of Multiple Nationwide Permits*, and the definition of a single and complete project.
- If pursuing a NWP and the NWP thresholds that allow for waivers are exceeded, further information/efforts may be required (such as a NeSCAP assessment, riparian/water quality buffers, and/or compensatory mitigation plan) to be submitted by the applicant, in order for USACE to grant a waiver and/or issue a permit.
- If NWP thresholds are exceeded with the final designs, and waiver is not allowed or granted by USACE, then an individual permit would be required.
- Prior to submitting a 404 application, a pre-application meeting should be requested by the applicant to the Nebraska Regulatory office to discuss permitting requirements along with options for avoidance, minimization, and compensatory mitigation.

10.3 WAIVERS WITHIN THE NWP PROGRAM AND HIGHLIGHTS:

- USACE must make a written determination concluding that the activity will result in no more than minimal adverse environmental effects.
- Applicant may be required to provide environmentally based reasons to support the waiver request.
- Applicant may be required to provide NeSCAP or other functional assessment.
- Agency coordination is required. USACE coordinates the complete PCN with EPA, USFWS, NGPC, and NDEE (this coordination process may take up to 25 days).
- There is no guarantee that a waiver will be granted. If no waiver, then an individual permit (IP) would be required.
- Compensatory mitigation, or other special conditions, to ensure the activity will result in no more than minimal adverse environmental effects, may still be required with waivers.

10.4 ROUGHLY ESTIMATED STREAM IMPACT AMOUNTS AND REGULATORY CONSIDERATIONS FOR EACH EXAMPLE REACH

Caveat: The Regulatory Considerations within this report are not final USACE decisions or determinations. These considerations are to be incorporated in any final designs and/or permit applications. Complete Section 404 permit applications must be provided to and evaluated by the Nebraska Regulatory Office to determine final permitting requirements.

West Papio Creek Reach (Overall Scope from Station 51100 - 47274 = 3,826 feet)

Scope from Rock Under Bridge (Station 51100) to LB/RB Revetments (Station 50685) = 415 feet; this includes GCS #1, but not GCS #2 (Station 47274), which is located approximately 3,411 feet downstream.

Table 10-1: West Papio Creek Reach Estimated Stream Impact Amounts

Structure	Station (ft)	Elev (ft)	Stream Elev (ft)	Area (sf)	~Acres or linear feet (lf)
GCS #1	50774	1025	1021	1286	0.0295 acre
GCS #2	47274	1022.25	1018	2320	0.053 acre
RB Revetment	50950-50685	1040	1021	7633	265 lf
LB Revetment	50875-50685	1040	1021	6610	190 lf
RB Wash Riprap	50825	1040	1022	1373	0.031 acre
Rock Under Bridge	51100-50950	1040	1022	4410	0.101 acre (50 lf)
				Totals:	~0.21 acre and ~505 lf

- Based on these rough quantities, design figures, and estimates of stream impact this example might qualify for NWP 13 and would need to be verified by the Nebraska Regulatory office. Due to the location of the sixth structure (GCS #2) downstream, this structure would likely be treated as a single and complete project needing separate application and permit.
- A waiver of NWP 13 conditions may be needed, depending on the presence and extent of impact to wetlands (special aquatic sites), amount of cubic yards per running foot, and linear feet of bank stabilization. If a waiver is not granted, an IP may be required.
- Compensatory mitigation would be required, if impacts to wetlands exceed 0.1 acres, or streambed loss exceeds 0.03-acres.

Cole Creek Reach (Overall Scope from Station 6550 – Station 4435 = 2,115 feet)**Table 10-2: Cole Creek Reach Estimated Stream Impact Amounts**

Structure	Elev (ft)	Streambed Elev(ft)	Length (ft)	Area (sf)	Acres
GCS - Station 4435	1039	1037	57	820	0.019
GCS - Station 4800	1040	1039	51	723	0.017
GCS - Station 5200	1041	1040	49	647	0.015
GCS - Station 5610	1043	1042	38	1060	0.024
GCS - Station 5850	1044.5	1044	90	2240	0.051
GCS - Station 6050	1045.7	1045	82	2880	0.066
GCS - Station 6200	1046.5	1047	25	380	0.009
GCS - Station 6400	1047.5	1047	25	42	0.001
GCS - Station 6550	1048.5	1048	25	288	0.007
				Total:	0.209 acres

- Based on these rough quantities, design figures, and estimates of stream impact this example might qualify for NWP 13 and would need to be verified by the Nebraska

Regulatory office. All nine structures would likely be considered under one single and complete project.

- A waiver of NWP 13 conditions may be needed, depending on the presence and extent of impact to wetlands (special aquatic sites), amount of cubic yards per running foot, and linear feet of bank stabilization. If a waiver is not granted, an IP may be required.
- Compensatory mitigation would be required, if impacts to wetlands exceed 0.1 acres, or streambed loss exceeds 0.03-acres.

Cole Creek Longitudinal Placed Stone Toe Protection

Table 10-3: Cole Creek LPSTP Features

Structure	Station (ft)	Length (LB&RB) (ft)
Toe Revetment Blondo - Hillside	6910-6300	610 Lt + 610 Rt
Toe Revetment Hillside - Seward	6250-5450	800 Lt + 800 Rt
Toe Revetment Seward - Western	5350-4190	1160 Lt + 1160 Rt
	Total:	~5,140 lf

- Based on these rough estimates and design figures, these revetments greatly exceed the 500 linear foot threshold (measured along each bank separately) under the NWP 13, and a waiver may not be practicable/granted.
- An Individual Permit would likely be required.
- When developing final designs, the linear feet of impact and amount of fill below OHWM and within wetlands should be minimized to the minimum amounts necessary.

South Papillion Creek Reaches 1 through 9

- No specific estimates/quantities provided, but figures 8.21 through 8.29 illustrate the potential locations for bed and bank stabilization practices, as follows:
 - A total of 32 existing GCSs (may or may not have been designed as GCS) are identified with *Red* circles.
 - A total of 14 potential new GCSs are identified with *Green* circles.
 - A total of three existing bank stabilization revetments are identified with *Blue* circles.
 - A total of 10 potential new bank stabilization locations are identified with *Yellow* circles.
- If any maintenance/modifications are proposed to the 32 existing GCSs or the three existing revetments that involve fill in WOTUS, the existing dimensions and material in WOTUS compared to the modified dimensions and material should be provided to the Nebraska Regulatory Office in order to determine 404 permit requirements, if the applicant is unsure whether a 404 permit is required.
 - Maintenance permits or exemptions may be applicable, depending on final designs.
 - If the modification goes beyond minor modifications within WOTUS, a new permit would be required.
- For the 14 new GCS locations:
 - Multiple NWP's may be pursued, depending on the number of impacts, distance between the sites, and timing of construction proposed.
 - A waiver of NWP 13 conditions may be needed, depending on the presence and extent of impact to wetlands (special aquatic sites), amount of cubic yards per running foot, and linear feet of bank stabilization. If a waiver is not granted, an IP may be required.
 - Compensatory mitigation would be required if impacts to wetlands exceed 0.1 acres, or streambed loss exceeds 0.03-acres.
 - Even if multiple single and complete NWP's may be pursued, cumulative impacts and mitigation needs may need to be assessed.
- For the 10 new bank stabilization locations:
 - Multiple NWP's may be pursued, depending on the number of impacts, distance between the sites, and timing of construction proposed.
 - A waiver of NWP 13 conditions may be needed, depending on the presence and extent of impact to wetlands (special aquatic sites), amount of cubic yards per running foot, and linear feet of bank stabilization. If a waiver is not granted, an IP may be required.

- Compensatory mitigation would be required, if impacts to wetlands exceed 0.1 acres, or streambed loss exceeds 0.03-acres.
- Even if multiple single and complete NWP's may be pursued, cumulative impacts and mitigation needs may need to be assessed.
- The linear feet, amount of fill below OHWM and within wetlands should be minimized to the minimum amounts necessary.
- NeSCAP may be required for permit applications associated with the new GCS or bank stabilization locations.
- See NWP thresholds, general conditions and definitions, including GC 28. *Use of Multiple Nationwide Permits*, and the definition of a single and complete project.
- An Individual Permit or new Regional General Permit that evaluates multiple stream stabilization alternatives within South Papillion Creek reaches may be appropriate, to adequately address the individual and cumulative impacts.

10.5 CONSIDERATIONS AND LIMITATIONS OF THREE NWPs THAT AUTHORIZE CERTAIN STREAM STABILIZATION/REHABILITATION ACTIVITIES

NWP 13. Bank Stabilization:

This NWP can be used for bank stabilization activities necessary for erosion control or prevention, such as vegetative stabilization, bio-engineering, sills, riprap, revetment, gabion baskets, stream barbs, and bulkheads, or combinations of bank stabilization techniques. The activity must meet all the following criteria*:

- a) No material is placed in excess of the minimum needed for erosion protection;
- b) The activity is **no more than 500 feet** in length along the bank**, (note for example: 500 feet on the right bank and 500 feet on the left bank in the same stream reach/location equates to 1,000 linear feet, and therefore would require a waiver.)
- c) The activity will **not exceed an average of one cubic yard per running foot**, as measured along the length of the treated bank, below the plane of the ordinary high water mark or the high tide line**,
- d) The activity does **not involve discharges of dredged or fill material into special aquatic sites (wetlands)**,**
- e) No material is of a type, or is placed in any location, or in any manner, that will impair surface water flow into or out of any waters of the United States;
- f) No material is placed in a manner that will be eroded by normal or expected high flows (properly anchored native trees and treetops may be used in low energy areas);
- g) Native plants appropriate for current site conditions, including salinity, must be used for bio-engineering or vegetative bank stabilization.
- h) The activity is not a stream channelization activity; and
- i) The activity must be properly maintained, which may require repairing it after severe storms or erosion events.

*Also see *NWP General Condition 23* for streambed loss (0.03-acres) and wetland loss (0.01-acres) thresholds, requiring compensatory mitigation or waivers.

**Unless USACE *waives* this criterion by making a written determination concluding that the discharge of dredged or fill material will result in no more than minimal adverse environmental effects. This requires USACE coordination with resource agencies (EPA, USFWS, NGPC, and NDEE), and may require additional information from the applicant, including a stream conditional assessment and/or compensatory mitigation. See sections regarding waiver and the [Nebraska Stream Condition Assessment Procedure \(NeSCAP\)](#) discussed further below.

NWP 43. Stormwater Management Facilities:

This NWP can be used for the *construction* and *maintenance* of stormwater management facilities, including stormwater detention basins and retention basins and other stormwater management facilities; the construction of water control structures, outfall structures and emergency spillways; the construction of low impact development integrated management features such as bioretention facilities (e.g., rain gardens), vegetated filter strips, grassed swales, and infiltration trenches; and the construction of pollutant reduction green infrastructure features designed to reduce inputs of sediments, nutrients, and other pollutants into waters, such as features needed to meet reduction targets established under Total Maximum Daily Loads set under the Clean Water Act.

- The discharge must not cause the loss of greater than one-half acre of non-tidal waters of the United States.
- This NWP does not authorize discharges of dredged or fill material for the construction of new stormwater management facilities in perennial streams.
- Maintenance activities do not require pre-construction notification if they are limited to restoring the original design capacities of the stormwater management facility or pollutant reduction green infrastructure feature.
- Due to the restriction on perennial streams, this NWP is likely not as useful within the study area of the Papio Watershed, unless the project is located in an ephemeral or intermittent stream, or the project is maintaining an existing stormwater management facility.
- Also see *NWP General Condition 23* for streambed loss (0.03-acres) and wetland loss (0.01-acres) thresholds, requiring compensatory mitigation or waivers.

NWP 27. Aquatic Habitat Restoration, Enhancement, and Establishment Activities:

Activities associated with the restoration, enhancement, and establishment of wetlands and riparian areas, and the *restoration and enhancement of streams* must *result in net increases in aquatic resource functions and services*, planned, designed, and implemented so that it results in aquatic habitat that resembles an *ecological reference*. An ecological reference may be based on the characteristics of one or more intact aquatic habitats or riparian areas of the same type that exist in the region. An ecological reference may be based on a conceptual model developed from regional ecological knowledge of the target aquatic habitat type or riparian area.

To the extent that a Corps permit is required, activities authorized by this NWP include, but are not limited to:

- the removal of accumulated sediments
 - the installation, removal, and maintenance of small water control structures, dikes, and berms
 - discharges of dredged or fill material to restore appropriate stream channel configurations after small water control structures, dikes, and berms are removed
 - the installation of current deflectors
 - the enhancement, rehabilitation, or re-establishment of riffle and pool stream structure
 - the placement of in-stream habitat structures
 - modifications of the streambed and/or banks to enhance, rehabilitate, or re-establish stream meanders
 - the removal of stream barriers, such as undersized culverts, fords, and grade control structures
 - the backfilling of artificial channels
 - the removal of existing drainage structures, such as drain tiles, and the filling, blocking, or reshaping of drainage ditches to restore wetland hydrology
 - the installation of structures or fills necessary to restore or enhance wetland or stream hydrology
- Only native plant species should be planted at the site.
 - This NWP authorizes the relocation of wetlands and streams on the project site provided there are net increases in aquatic resource functions and services.
 - Except for the relocation of non-tidal waters on the project site, this NWP does not authorize the conversion of a stream or natural wetlands to another aquatic habitat type (e.g., the conversion of a stream to wetland or vice versa) or uplands.
 - Changes in wetland plant communities that occur when wetland hydrology is more fully restored during wetland rehabilitation activities are not considered a conversion to another aquatic habitat type.
 - This NWP does not authorize *stream channelization*.
 - Compensatory mitigation is not required for activities authorized by this NWP since these activities must result in net increases in aquatic resource functions and services.
 - Utilize [Nebraska Stream Condition Assessment Procedure \(NeSCAP\)](#) (discussed further below).

10.6 CONSIDERATIONS AND CONCEPTS WITHIN NWP GENERAL CONDITIONS AND DEFINITIONS APPLICABLE TO STREAM STABILIZATION/REHABILITATION ACTIVITIES

NWP Definitions for Determining Whether an Activity in WOTUS Meets NWP Limits/Thresholds:

- **Loss of waters of the United States:** WOTUS permanently adversely affected by filling, flooding, excavation, or drainage because of the regulated activity. The loss of streambed includes the acres of streambed that are permanently adversely affected by filling or excavation because of the regulated activity. Permanent adverse effects include permanent discharges of dredged or fill material that change an aquatic area to dry land, increase the bottom elevation of a waterbody, or change the use of a waterbody. The acreage of loss of waters of the United States is a threshold measurement of the impact to jurisdictional waters or wetlands for determining whether a project may qualify for an NWP; it is not a net threshold that is calculated after considering compensatory mitigation that may be used to offset losses of aquatic functions and services. Does not include temporary impacts.
 - **Streambed:** The substrate of the stream channel between the ordinary high water marks. The substrate may be bedrock or inorganic particles that range in size from clay to boulders. Wetlands contiguous to the streambed, but outside of the ordinary high water marks, are not considered part of the streambed.
- **Single and complete non-linear project:** For non-linear projects, the term “single and complete project” is defined at 33 CFR 330.2(i) as the total project proposed or accomplished by one owner/developer or partnership or other association of owners/developers. A single and complete non-linear project must have independent utility (see definition of “*independent utility*”). Single and complete non-linear projects may not be “piecemealed” to avoid the limits in an NWP authorization.
 - **Independent utility:** A test to determine what constitutes a single and complete non-linear project in the Corps Regulatory Program. A project is considered to have independent utility if it would be constructed absent the construction of other projects in the project area. Portions of a multi-phase project that depend upon other phases of the project do not have independent utility. Phases of a project that would be constructed even if the other phases were not built can be considered as separate single and complete projects with independent utility.
 - **Waterbody:** For purposes of the NWPs, a waterbody is a “water of the United States.” If a wetland is adjacent to a waterbody determined to be a water of the United States, that waterbody and any adjacent wetlands are considered together as a single aquatic unit (see 33 CFR 328.4(c)(2)).
- **Stormwater management:** Stormwater management is the mechanism for controlling stormwater runoff for the purposes of reducing downstream erosion, water quality degradation, and flooding and mitigating the adverse effects of changes in land use on the aquatic environment.
- **Stormwater management facilities:** Stormwater management facilities are those facilities, including but not limited to, stormwater retention and detention ponds and best management practices, which retain water for a period of time to control runoff and/or improve the quality (i.e., by reducing the concentration of nutrients, sediments, hazardous substances, and other pollutants) of stormwater runoff.

- *Stream channelization*: The manipulation of a stream's course, condition, capacity, or location that causes more than minimal interruption of normal stream processes. A channelized jurisdictional stream remains a water of the United States.

NWP Definitions Applicable to Aquatic Resource Restoration and Mitigation:

- *Riffle and pool complex*: Riffle and pool complexes are special aquatic sites under the 404(b)(1) Guidelines. Riffle and pool complexes sometimes characterize steep gradient sections of streams. Such stream sections are recognizable by their hydraulic characteristics. The rapid movement of water over a coarse substrate in riffles results in a rough flow, a turbulent surface, and high dissolved oxygen levels in the water. Pools are deeper areas associated with riffles. A slower stream velocity, a streaming flow, a smooth surface, and a finer substrate characterize pools.
- *Riparian areas*: Riparian areas are lands next to streams, lakes, and estuarine-marine shorelines. Riparian areas are transitional between terrestrial and aquatic ecosystems, through which surface and subsurface hydrology connects riverine, lacustrine, estuarine, and marine waters with their adjacent wetlands, non-wetland waters, or uplands. Riparian areas provide a variety of ecological functions and services and help improve or maintain local water quality. (See general condition 23.)
- *Enhancement*: The manipulation of the physical, chemical, or biological characteristics of an aquatic resource to heighten, intensify, or improve a specific aquatic resource function(s). Enhancement results in the gain of selected aquatic resource function(s), but may also lead to a decline in other aquatic resource function(s). Enhancement does not result in a gain in aquatic resource area.
- *Establishment (creation)*: The manipulation of the physical, chemical, or biological characteristics present to develop an aquatic resource that did not previously exist at an upland site. Establishment results in a gain in aquatic resource area.
- *Restoration*: 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. For the purpose of tracking net gains in aquatic resource area, restoration is two categories: Reestablishment and rehabilitation.
 - *Re-establishment*: The manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former aquatic resource. Reestablishment results in rebuilding a former aquatic resource and results in a gain in aquatic resource area and functions.
 - *Rehabilitation*: The manipulation of the physical, chemical, or biological characteristics of a site with the goal of repairing natural/historic functions to a degraded aquatic resource. Rehabilitation results in a gain in aquatic resource function, but does not result in a gain in aquatic resource area.

Key NWP General Conditions to Consider when Designing Stream Stabilization Projects:

- *GC 2. Aquatic Life Movements*. No activity may substantially disrupt the necessary life cycle movements of those species of aquatic life indigenous to the waterbody, including those species that normally migrate through the area, unless the activity's primary purpose is to impound water. All permanent and temporary crossings of waterbodies shall be suitably culverted, bridged, or otherwise designed and constructed to maintain

low flows to sustain the movement of those aquatic species. If a bottomless culvert cannot be used, then the crossing should be designed and constructed to minimize adverse effects to aquatic life movements.

- *GC 6. Suitable Material.* No activity may use unsuitable material (e.g., trash, debris, car bodies, asphalt, etc.). Material used for construction or discharged must be free from toxic pollutants in toxic amounts (see section 307 of the Clean Water Act). Refer to Omaha District's list of *Prohibited and -Restricted Materials* (<https://www.nwo.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/487696/prohibited-restricted-materials/>).
- *GC 8. Adverse Effects From Impoundments.* If the activity creates an impoundment of water, adverse effects to the aquatic system due to accelerating the passage of water, and/or restricting its flow must be minimized to the maximum extent practicable.
- *GC 9. Management of Water Flows.* To the maximum extent practicable, the pre-construction course, condition, capacity, and location of open waters must be maintained for each activity, including stream channelization, storm water management activities, and temporary and permanent road crossings, except as provided below. The activity must be constructed to withstand expected high flows. The activity must not restrict or impede the passage of normal or high flows, unless the primary purpose of the activity is to impound water or manage high flows. The activity may alter the pre-construction course, condition, capacity, and location of open waters if it benefits the aquatic environment (e.g., stream restoration or relocation activities).
- *GC 10. Fills Within 100-Year Floodplains.* The activity must comply with applicable FEMA-approved state or local floodplain management requirements.
- *GC 12. Soil Erosion and Sediment Controls.* Appropriate soil erosion and sediment controls must be used and maintained in effective operating condition during construction, and all exposed soil and other fills, as well as any work below the ordinary high water mark or high tide line, must be permanently stabilized at the earliest practicable date. Permittees are encouraged to perform work within waters of the United States during periods of low-flow or no-flow, or during low tides.
- *GC 25. Water Quality.* (a) Where the certifying authority (state, authorized tribe, or EPA, as appropriate) has not previously certified compliance of an NWP with CWA section 401, a CWA section 401 water quality certification for the proposed discharge must be obtained or waived (see 33 CFR 330.4(c)). If the permittee cannot comply with all of the conditions of a water quality certification previously issued by certifying authority for the issuance of the NWP, then the permittee must obtain a water quality certification or waiver for the proposed discharge in order for the activity to be authorized by an NWP. (b) If the NWP activity requires preconstruction notification and the certifying authority has not previously certified compliance of an NWP with CWA section 401, the proposed discharge is not authorized by an NWP until water quality certification is obtained or waived. If the certifying authority issues a water quality certification for the proposed discharge, the permittee must submit a copy of the certification to the district engineer. The discharge is not authorized by an NWP until the district engineer has notified the permittee that the water quality certification requirement has been satisfied by the issuance of a water quality certification or a waiver. (c) The district engineer or certifying

authority may require additional water quality management measures to ensure that the authorized activity does not result in more than minimal degradation of water quality.

Nebraska 401 WQC for the NWP:

<https://usace.contentdm.oclc.org/utis/getfile/collection/p16021coll11/id/5174>

- **GC 28. Use of Multiple Nationwide Permits.** The use of more than one NWP for a *single and complete project* is authorized, subject to the following restrictions: (a) If only one of the NWPs used to authorize the single and complete project has a specified acreage limit, the acreage loss of waters of the United States cannot exceed the acreage limit of the NWP with the highest specified acreage limit. For example, if a road crossing over tidal waters is constructed under NWP 14, with associated bank stabilization authorized by NWP 13, the maximum acreage loss of waters of the United States for the total project cannot exceed 1/3-acre. (b) If one or more of the NWPs used to authorize the single and complete project has specified acreage limits, the acreage loss of waters of the United States authorized by those NWPs cannot exceed their respective specified acreage limits. For example, if a commercial development is constructed under NWP 39, and the single and complete project includes the filling of an upland ditch authorized by NWP 46, the maximum acreage loss of waters of the United States for the commercial development under NWP 39 cannot exceed 1/2-acre, and the total acreage loss of waters of United States due to the NWP 39 and 46 activities cannot exceed 1 acre.
 - Another example: if a development is to be constructed and permitted under a NWP 29 or NWP 39, with associated bank stabilization under NWP 13, the maximum acreage loss of waters of the United States for the total project cannot exceed 0.5 acre.
 - If multiple grade control structures and revetments/LPSTP are to be used, or in combination with a development project, be mindful of these thresholds.
 - See NWP definition of *single and complete project*.
- **GC 31. Activities Affecting Structures or Works Built by the United States.** If an NWP activity also requires review by, or permission from, the Corps pursuant to 33 U.S.C. 408 because it will alter or temporarily or permanently occupy or use a U.S. Army Corps of Engineers (USACE) federally authorized Civil Works project (a “USACE project”), the prospective permittee must submit a pre-construction notification. See paragraph (b)(10) of general condition 32. An activity that requires section 408 permission and/or review is not authorized by an NWP until the appropriate Corps office issues the section 408 permission or completes its review to alter, occupy, or use the USACE project, and the district engineer issues a written NWP verification.
- **GC 27. Regional and Case-By-Case Conditions.** The activity must comply with any regional conditions and with any case specific conditions added by the Corps or by the state in its CWA section 401 Water Quality Certification.
 - Link to Nebraska Regional Conditions (RC):
<https://usace.contentdm.oclc.org/utis/getfile/collection/p16021coll11/id/5042>
 - a) **NE RC # 8. Revegetation of Disturbed Areas** - revegetate with native species appropriate for the region.

b) *NE RC # 4 Stream Channelization and Relocation Projects* - PCN required for stream channelization or relocation activities.

- Link to Nebraska 401 WQCs:
<https://usace.contentdm.oclc.org/utis/getfile/collection/p16021coll11/id/5174>

Mitigation (Avoid, Minimize, Compensate)

GC 23. *Mitigation*. The USACE must consider the following factors when determining appropriate and practicable mitigation necessary to ensure that the *individual and cumulative adverse environmental effects are no more than minimal*:

- The activity must be designed and constructed to avoid and minimize adverse effects, both temporary and permanent, to waters of the United States to the maximum extent practicable at the project site (i.e., on site).
- Mitigation in all its forms (avoiding, minimizing, rectifying, reducing, or compensating for resource losses) will be required to the extent necessary to ensure that the individual and cumulative adverse environmental effects are no more than minimal.
- *Compensatory mitigation at a minimum one-for-one ratio will be required for all wetland losses that exceed 1/10-acre.*
 - unless the USACE determines in writing that either some other form of mitigation would be more environmentally appropriate OR the adverse environmental effects of the proposed activity are no more than minimal, and provides an activity-specific waiver of this requirement.
- Compensatory mitigation at a minimum one-for-one ratio will be required for all losses of streambed that exceed 3/100-acre
 - unless the USACE determines in writing that either some other form of mitigation would be more environmentally appropriate OR the adverse environmental effects of the proposed activity are no more than minimal and provides an activity-specific waiver of this requirement.
 - may be satisfied through the restoration or enhancement of riparian areas next to streams in accordance with paragraph (e) of this general condition.
 - Compensatory mitigation for losses of streams should be provided, if practicable, through *stream rehabilitation, enhancement, or preservation*, since streams are difficult-to-replace resources (see 33 CFR 332.3(e)(3)).
- Compensatory mitigation plans for NWP activities in or near streams or other open waters will normally include a requirement for the *restoration or enhancement, maintenance, and legal protection (e.g., conservation easements) of riparian areas* next to the stream [aka “Buffers”].
 - In some cases, the restoration or maintenance/protection of riparian areas may be the only compensatory mitigation required.
 - If restoring riparian areas involves planting vegetation, only native species should be planted.

- The width of the required riparian area will address documented water quality or aquatic habitat loss concerns.
- Normally, the riparian area will be *25 to 50 feet wide* on each side of the stream, but USACE may require slightly wider riparian areas to address documented water quality or habitat loss concerns.
- If it is not possible to restore or maintain/protect a riparian area on both sides of a stream, then restoring or maintaining/protecting a riparian area along a single bank or shoreline may be sufficient.
- Where both wetlands and open waters exist on the project site, the USACE will determine the appropriate compensatory mitigation (e.g., riparian areas and/or wetlands compensation) based on what is best for the aquatic environment on a watershed basis.
- In cases where riparian areas are determined to be the most appropriate form of minimization or compensatory mitigation, the USACE may waive or reduce the requirement to provide wetland compensatory mitigation for wetland losses.
- Compensatory mitigation projects provided to offset losses of aquatic resources must comply with the applicable provisions of 33 CFR part 332 ("2008 Mitigation Rule").
 - The permittee is responsible for proposing an appropriate compensatory mitigation option if compensatory mitigation is necessary to ensure that the activity results in no more than minimal adverse environmental effects. The preferred mechanism is mitigation bank credits or in-lieu fee program credits (see 33 CFR 332.3(b)(2) and (3)). However, if an appropriate number and type of mitigation bank or in-lieu credits are not available, USACE may approve the use of permittee-responsible mitigation.
 - The amount of compensatory mitigation required must be sufficient to ensure that the authorized activity results in no more than minimal individual and cumulative adverse environmental effects (see 33 CFR 330.1(e)(3)). (See also 33 CFR 332.3(f).)
 - Since the likelihood of success is greater and the impacts to potentially valuable uplands are reduced, *aquatic resource restoration should be the first compensatory mitigation* option considered for permittee-responsible mitigation.
 - If permittee-responsible mitigation is the proposed option, the prospective permittee is responsible for submitting a mitigation plan.
 - A conceptual or detailed mitigation plan may be used by USACE to make the decision on the NWP verification request, but a final mitigation plan that addresses the applicable requirements of 33 CFR 332.4(c)(2) through (14) must be approved by USACE before the permittee begins work in WOUS.
 - If permittee-responsible mitigation is the proposed option, and the proposed compensatory mitigation site is located on land in which

another federal agency holds an easement, the district engineer will coordinate with that federal agency to determine if proposed compensatory mitigation project is compatible with the terms of the easement.

- If mitigation bank or in-lieu fee program credits are the proposed option, the mitigation plan needs to address only the baseline conditions at the impact site and the number of credits to be provided (see 33 CFR 332.4(c)(1)(ii)).
- Compensatory mitigation requirements (e.g., resource type and amount to be provided as compensatory mitigation, site protection, ecological performance standards, monitoring requirements) may be addressed through conditions added to the NWP authorization, instead of components of a compensatory mitigation plan (see 33 CFR 332.4(c)(1)(ii)).
- Compensatory mitigation will not be used to increase the acreage losses allowed by the acreage limits of the NWPs. For example, if an NWP has an acreage limit of 1/2-acre, it cannot be used to authorize any NWP activity resulting in the loss of greater than 1/2-acre of waters of the United States, even if compensatory mitigation is provided that replaces or restores some of the lost waters. However, compensatory mitigation can and should be used, as necessary, to ensure that an NWP activity already meeting the established acreage limits also satisfies the no more than minimal impact requirement for the NWPs.
- Permittees may propose the use of mitigation banks, in-lieu fee programs, or permittee-responsible mitigation. When developing a compensatory mitigation proposal, the permittee must consider appropriate and practicable options consistent with the framework at 33 CFR 332.3(b). For permittee-responsible mitigation, the special conditions of the NWP verification must clearly indicate the party or parties responsible for the implementation and performance of the compensatory mitigation project, and, if required, its long-term management.
- Where certain functions and services of waters of the United States are permanently adversely affected by a regulated activity, such as discharges of dredged or fill material into waters of the United States that will convert a forested or scrub-shrub wetland to a herbaceous wetland in a permanently maintained utility line right-of-way, mitigation may be required to reduce the adverse environmental effects of the activity to the no more than minimal level.

10.7 NEBRASKA STREAM CONDITION ASSESSMENT PROCEDURE (NESCAP)

This procedure has been developed for interagency use in the evaluation of streams and floodplains/riparian areas. The intent of this assessment methodology is to provide reconnaissance level characterization to:

- Document baseline information for a site prior to development activities.
- Develop potential alternatives that may lessen impacts.
- Support analyses in the evaluation of public interest review factors.
- Used for assessing potential impacts and/or functional lift due to proposed development or restoration activities.
- Guide decisions regarding the appropriate amount of compensatory mitigation required for stream impacts.
- Guide decisions on waivers of stream impact thresholds and conditions.
- Serve as an initial “screen” for determining the need for more detailed assessment or data needs in the evaluation of regulatory or resource management actions.

Essentially, NeSCAP is a tool that is used to assess existing stream conditions and compare to post-project (stabilization, restoration/rehabilitation, mitigation, or other in-stream projects) conditions, to show increase or decreases in stream and floodplain/riparian area conditions. The variables that the NeSCAP assesses are:

- V1 Hydraulic Conveyance and Sediment Dynamics
- V2 In-stream Habitat/Available Cover
- V3 Floodplain Interaction–Connectivity
- V4 Riparian Vegetation Composition
- V5 Riparian Buffer Continuity and Width
- V6 Riparian Land Use

When determined necessary, the Nebraska Regulatory Office will require a NeSCAP assessment (including the field variable worksheets, figures/maps of reaches, photos, narrative, and calculation books) to be provided by the applicant in order to review the project application/PCN for permitting.

11 CONCLUSIONS

Through this study a number of chronic concerns have been identified associated with ongoing streambed and bank degradation throughout the Papillion Creek watershed. While the study did not examine every stream mile throughout the watershed, the concerns are widespread and may be prevalent in other areas. The concerns can be categorized as follows:

11.1 CURRENT AREAS OF CONCERN

A number of indicators point to areas within the watershed that are currently experiencing problems. Those include bank failures or sloughing, exposed infrastructure, failed fences, erosion approaching sidewalks and roadways, undercut bridge piers, and many other visible indicators. In addition to these acute symptoms, there is chronic ongoing degradation throughout the watershed. While often hard to identify physical channel erosion processes until catastrophic bank failure or impacts to infrastructure occur, new tools were used for investigating geomorphic channel trends within the study watersheds that provide indication of future areas of concern.

11.2 FUTURE AREAS OF CONCERN

The tools provided in the FluvialGeomorph Toolbox allow for multiple levels of analysis using remote sensed terrain data (LiDAR), offering a spatial and temporal scale of watershed and channel assessment. The Level 1 analysis provides rapid analysis of channel profile and cross-sectional changes-both spatial and temporally, providing a 'first cut' review of geomorphic changes in the individual watershed reaches.

Expanding to the FG Level 2 analysis (completed on Cole Creek, West Papillion Creek, and South Papillion Creek for this study) allows for a more detailed look at geomorphic processes with focus on channel analysis based on geomorphic metrics. The FG Level 2 metrics are used to identify locations experiencing stable and unstable channel conditions that may not be visibly obvious as well as predicting future trends and areas of concern.

This report has identified a number of areas through FG Level 2 analysis. Cole Creek, West Papillion and South Papillion Creeks have differing trends in metric values that provide insight into significant future impacts due to channel degradation. For Cole Creek, Reach 4 metric values illustrate channel incision with bank instability. West Papillion Creek has many locations identified by the City and the watershed has extensive reaches (2, 5, 7, 8) with metric values showing unstable channel conditions and trends. As South Papillion Creek continues to be urbanized, the runoff rates will increase and assert more erosion potential on the existing channel system. The upper Reaches (7-9) are the steepest areas of the watershed and will likely be impacted the most as the channel enlarges and deepens. A system of GCSs through all of the South Papillion Creek reaches is advisable as the watershed continues to urbanize.

When new LiDAR is collected in the future, FluvialGeomorph analysis can be updated to capture the most recent geomorphic changes and compared against previous data. The FluvialGeomorph GIS extension, user's manual, and associated reports can be found at <https://github.com/FluvialGeomorph/FG-User-Manual> and <https://www.techmanual.fluvialgeomorph.org/>.

11.3 INNOVATIVE WAYS TO REDUCE CHANNEL DEGRADATION

Throughout this study, the project delivery team has considered ways to apply known and innovative grade control and stabilization techniques in the watershed. While each specific site is unique, the channels in the watershed can generally be categorized into three groups:

1. Highly incised, relatively mature, narrow channels with limited to non-existent access to the floodplain. Cole Creek is a prime example of this type of channel with frequent road crossings and neighborhood infrastructure severely limiting the capacity and shape of the channel. These constraints have impacted the channel for many decades.
2. Dynamic channels experiencing changes in sinuosity and location where the early stages of bed and bank degradation are visible as watershed hydrology and sediment supply changes. West Papillion Creek has a number of areas where channel migration is threatening infrastructure while the channel is attempting to find an equilibrium slope and balance sediment delivery. This watershed has generally been developed in the last few decades.
3. Rapidly changing, immature channels that are mainly influenced by agricultural hydrology. The western extents of South Papillion Creek are a mix of areas undergoing rapid development and those where surface runoff from agricultural land is the driver. This watershed will be developed rapidly over the next decade, changing from agricultural to urban hydrology.

The proposed designs to reduce or eliminate bed degradation vary based on the 'maturity' of the watershed. From fairly extreme measures required in Cole Creek to the reinforcement with passive grade control to rock being placed in washes by farmers in far west South Papillion Creek to reduce headcuts (channel degradation) into farm fields.

Across all watersheds, regardless of maturity, three clear conclusions can be supported:

Conclusion #1 –

Existing structures are having a significant impact on the morphology of the channels in the Papillion Creek watershed.

From limited culvert capacity at Hillside Drive on Cole Creek affecting upstream stages and flooding, to rock placed to protect the storm sewer outfall at 132nd Street on West Papillion Creek, to the farmer-placed rock piles to reduce headcutting into farm fields, all these structures are influencing degradation in the watershed.

Throughout the watershed, there are hundreds of locations where some existing structure, designed for grade control or not, is influencing channel stability. When considering structural solutions to reduce bed degradation, existing structures should be integrated into any solution, either by reinforcing, raising, extending, etc. Inclusion and improvement of these structures will help reduce uncertainty in channel response to new structures, as the channel has already somewhat adjusted to the existing structure. In addition, cost savings may be realized.

Conclusion #2 –

Continued Urbanization of the Watershed will alter the hydrology and sediment supply.

Both visual inspection on site visits, and FluvialGeomorph analysis illustrated areas that are currently experiencing massive channel changes due to altered hydrology and sediment supply. With these changes comes a significant increase in stream power and the ability to erode and

transport sediment, often resulting in severe bank erosion and rapid headcutting up the watershed.

Once these aggressive processes begin, they are very difficult to stop. Every effort should be made to develop a grade control plan appropriate to the coming urbanization and to construct the necessary structures before development commences.

Conclusion #3 –

Urbanization shows no signs of slowing, so the speed at which grade control can be designed, permitted, and constructed is on the critical path to successfully preventing degradation in the watershed.

There are numerous examples of insufficient grade control throughout the watershed, resulting in bank instability and failure and bed degradation. In some cases, urbanization is not yet complete when bank failures are threatening new construction.

Efficiencies in the design and regulatory (Clean Water Act) permitting process can be realized through utilizing a suite of standard designs, some proposed in this report, that can be adjusted with site-specific measures and BMPs to address stream degradation issues, maintain the integrity of the natural stream system, and minimize impacts to aquatic resources.

11.4 FINDING REGULATORY EFFICIENCIES

The NWP program provides efficiencies for Section 404 permitting, but has conditions, limitations, and thresholds to ensure activities do not have more than minimal individual and cumulative adverse environmental effect. Some of the proposed designs in this report may fit under the current Nationwide Permit program, or the Regional General Permit that is only available for use by the NRD; however, that RGP is fairly limited in scope, as it is limited to one permittee and geographic area; and some designs in this report would not qualify for a NWP. If a project exceeds thresholds of a NWP and is not able to obtain a waiver, an individual permit would be required to construct grade control in the Papillion Creek watershed. If a waiver of NWP conditions is pursued, or compensatory mitigation is required for unavoidable impacts to streams or wetlands, more time and resources are needed during the permitting process. In the event an individual permit is needed, or even during a complex project pursuing a NWP (with waiver or mitigation), pre-coordination can be very valuable. To make the permitting process manageable a few strategies should be employed:

- a. Utilize pre-application meetings with the Nebraska State Regulatory Office of USACE.* Pre-application meetings will allow for feedback from regulatory staff on concerns that might arise in the formal permit review process, allowing for modification and identifying information needs before submittal.
- b. Ensure that permit applications are complete.* If pertinent information is omitted from the permit application, it will be returned with a request that the information be added, extending the preparation and review timeline. The NRD and cities/counties in the watershed should encourage developers to provide complete applications and can possibly serve as a quality control check before submittal.

It should be noted that the conceptual designs proposed in this report were not specifically designed to fit under any existing permit. They were designed as the best solution for the specific site with consideration of the broader applicability throughout the watershed.

11.5 FUTURE OPPORTUNITIES

Management and prevention of bed degradation throughout the watershed is not a static process. As the hydrology and sediment delivery change, modification of existing designs and the addition of new solutions will be warranted. Revisiting the analysis completed in this report in the future should be a high priority when new LiDAR is available.

USACE understands the interest of several entities (NRD, Cities, and developers) in the watershed in a more streamlined permitting approach for activities that address stream degradation, such as development of a new Regional General Permit. The goal of this report was not to develop a new Regional General Permit for the Papillion Creek Watershed. Through review of the existing RGP, the site visits and analysis, and development of conceptual designs, it is apparent that individual permits would be required for those designs and locations that exceed existing NWP and RGP thresholds. The effort to develop, analyze, coordinate and review a new RGP package can be extensive, but with continual urbanization in the Papillion Creek watershed expected for the next few decades, the flexibility that may be provided by a broader RGP may be beneficial. Much of the analysis completed in this report and the conceptual designs could be used as foundation toward a new RGP that may be utilized by multiple entities across a broad footprint in the watershed. The creation of a new RGP would be dependent on the availability of resources and analysis by the Nebraska State Regulatory Office and Regulatory Branch of USACE.

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