Lower Imhoff Creek Bank Stabilization Project: Erosion Analysis

Norman, OK

prepared for:

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Table of Contents

1.0 PURPOSE & BACKGROUND 4
2.0 GEOTECHNICAL INVESTIGATION 5
3.0 EROSION ANALYSIS 8
3.1 Analysis Approach 8
3.1.1 Historical LiDAR 8
3.1.2 HEC-RAS 9
3.1.3 Bank Stability and Toe Erosion Model 9
3.2 Vertical Analysis 9
3.2.1 Historical Observations 9
3.2.2 HEC-RAS Model 11
3.3 Horizontal Analysis 12
3.3.1 Historical Observations 12
3.3.2 Bank Stability and Toe Erosion Model 14
4.0 EMERGENCY REPAIR 15
4.1.1 Wingwall Failure 15
4.1.2 HEC-RAS Model 17
5.0 EROSION ANALYSIS CONCLUSION 19
6.0 APPENDIX A: GEOTECHNICAL ANALYSIS (2016) 21

List of Figures

Figure 1-1: Left bank of Imhoff Creek just downstream of Imhoff Road, 2016 4
Figure 2-1: Locations of soil samples 6
Figure 3-1: Stream bed profile 10
Figure 3-2: Sediment transport results for the 2-yr storm event 11
Figure 3-3: Area that was evaluated volumetrically 12
Figure 3-4: Locations of cross sections used to evaluate the lateral shift of the bank 13
Figure 4-1: Scour at the south end of the structure at Imhoff Road 15
Figure 4-2: Undermining of the southeast wingwall of the structure at Imhoff Road 16
Figure 4-3: Failure of the southeast wingwall of the structure at Imhoff Road 16
Figure 4-4: Profile view of downstream emergency repair 17
Figure 4-5: Increase in velocity due to the emergency repair 18
Figure 5-1: Future top of bank lines due to erosion 20

List of Tables

Table 2-1: Laboratory Classification Test Results 7
Table 2-2: Pocket Penetrometer Test Results (2016) 7
Table 2-3: DCP Test Results (2021) 8
Table 3-2: Volumetric erosion results 13
Table 3-3: Lateral shift of the east bank 14
Table 3-4: BSTEM Results 14

1.0 Purpose & Background

Imhoff Creek is a small urban watershed with approximately 4 square miles of contributing drainage area located within the City of Norman, Oklahoma. Much of the open channel system is concrete or articulated block lined improved channel. During storm events the excess runoff quickly accumulates causing rapid rising and receding flooding events that can be highly turbulent and very erosive to unprotected channel areas. Over the years the channel has developed numerous areas in which exposed vertical banks have been created by head-cutting along the unlined sections of the channel and scouring induced by vegetative debris thus creating erosive tendencies adjacent to or just downstream of the blockage areas. In some instances, erosion has caused vertical embankments to migrate, encroaching onto private property and jeopardizing critical infrastructure and residential structures. The stability of the existing bridge at Imhoff Road is being threatened by head cutting downstream of the bridge, which is being exacerbated by upstream scour and undermining of the structure. Figure 1-1 below exemplifies the 2016 embankment conditions downstream of Imhoff Road.

Figure 1-1: Left bank of Imhoff Creek just downstream of Imhoff Road, 2016

Meshek & Associates, LLC retained Wood Environment & Infrastructure Solutions, Inc (Wood) to conduct geotechnical, hydrological and hydraulic analyses in support of the engineering and design of structures to restore and stabilize bank erosion of lower Imhoff Creek for the City of Norman, Oklahoma. As part of the analyses, an erosion study was completed to evaluate the historic rate of erosion and predict future erosion and impacts to critical infrastructure.

2.0 Geotechnical Investigation

Two geotechnical engineering studies were conducted (2016 and 2021) to evaluate the stability of proposed improvements along lower Imhoff Creek. The information gathered that is pertinent to the erosion analysis is summarized in Tables 2.1 to 2.3. The complete geotechnical studies and analysis obtained in 2016 and 2021 are included in Appendix A and Appendix B respectively.

The 2016 geotechnical investigation consisted of sieve analysis and pocket penetrometer testing on eight soil samples taken at three locations at various heights along the creek bank (S-1, S-2, and S-3). The 2021 investigation included sieve analysis of one boring (B-1) and four Dynamic Cone Penetrometer (DCP) tests (DCP-1, DCP-2, DCP-3A and DCP-3B). Figure 2-1 shows the locations of the soil samples and penetrometer tests.

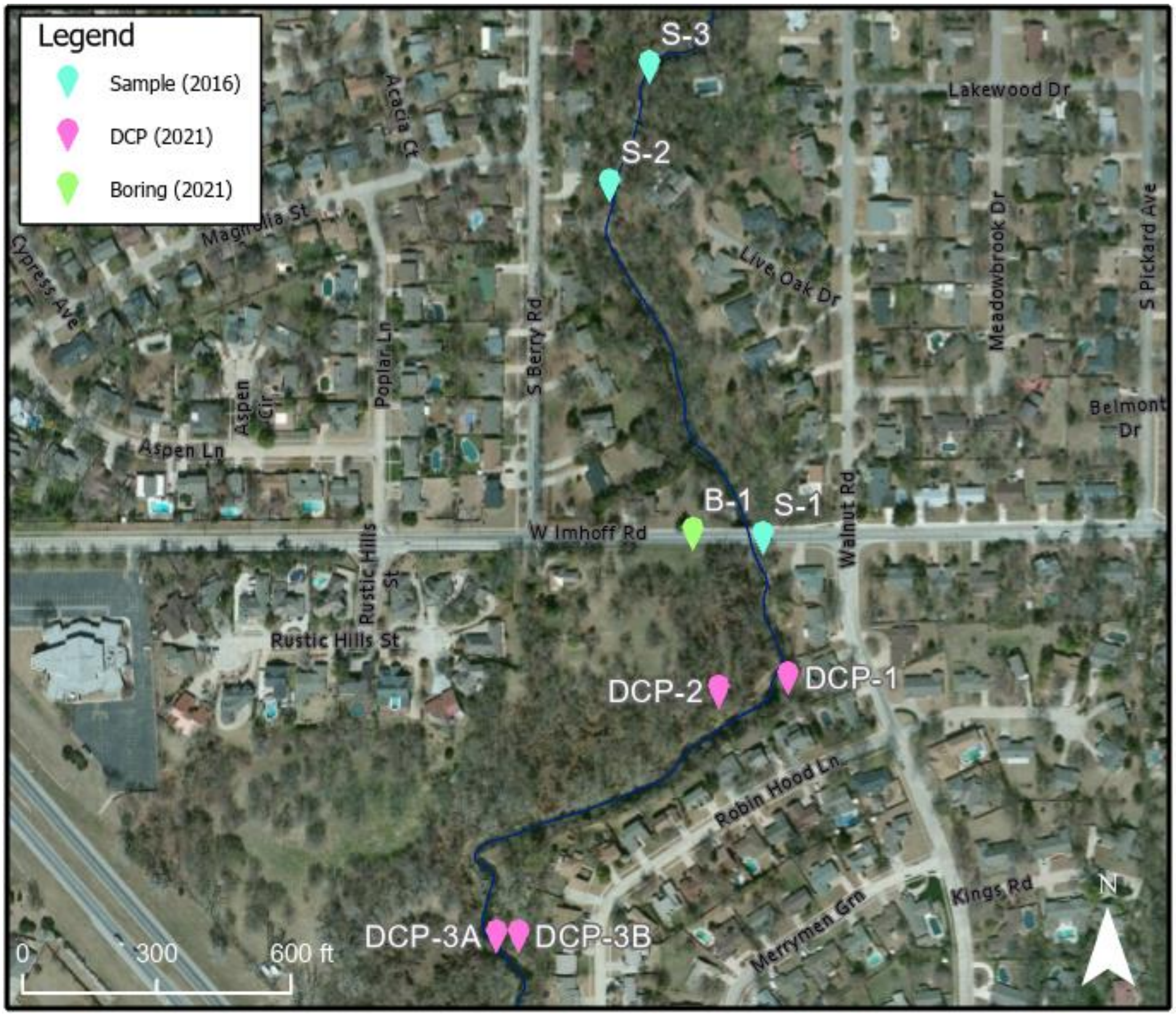

Figure 2-1: Locations of soil samples

Table 2-1 summarizes the sieve analysis results for the 2016 and 2021 soil samples. The 2016 samples taken along the creek bank (S-1, S-2 and S-3) consist predominantly of clay with varying amounts of silt and sand. The boring at B-1 was taken from the west overbank and all three samples were classified as silty sands.

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Table 2-1: Laboratory Classification Test Results

Sample ID	Depth (ft)	Moisture (%)	Gravel (%)	Sand (%)	Fines (%)	Description
S-1A	9	11.9	14	39	47	Clayey Sand, brown
S-1B	19	19	0	14	86	Lean Clay, brown
S-1C	21	19.7	0	46	54	Lean Clay, sandy, reddish brown
S-2A	15	15.2	0	32	68	Silty Clay, sandy, dark brown
S-2B	21	10.6	0	56	44	Silty Sand, reddish brown
S-2C	25	17.3	0	42	58	Lean Clay, sandy, brown
S-3A	10	7.6	0	18	82	Silty Clay, with sand, brown
S-3B	18	17.4	0	32	68	Lean Clay, sandy, reddish brown
B-1A	4.5-10	11.3	0.03	62.81	27.16	SM - Silty Sand
B-1B	18.5-25	9.1	0	88.66	11.34	SP-SM - poorly graded sand with silt
B-1C	28.5-35	23.7	1.43	82.92	15.66	SM - Silty Sand

Table 2-2: Laboratory Classification Test Results

Table 2-3 summarize results for the 2016 and 2021 penetrometer tests, respectively. The results indicate stiff to very stiff soils along the banks of the creek.

Table 2-2: Pocket Penetrometer Test Results (2016)

Test Location	Depth (ft)	Pocket Penetrometer Reading (tsf)
S-1	9	1.5-2
	19	3.5-4.5
	21	4.5+
S-2	15	1.5-2.2
	21	1.5-2.2
	25	2.5-3.5
S-3	10	4.5
	18	3-4.5

Table 2-3: DCP Test Results (2021)

Test Location	Depth (in)	Bearing Capacity (psi)
DCP-1	9.4	11.5
	13.8	20.5
	14	342.6
	14.2	204.6
	14.4	342.6
	14.6	204.6
DCP-2	9.4	11.5
	15.2	16.7
DCP-3A	8.3	12.7
	13.8	17.2
	18.9	18.1
	23.6	19.3
DCP-3B	10.2	10.8
	18.1	13.2
	25.6	13.7

3.0 Erosion Analysis

3.1 Analysis Approach

The goal of the erosion analysis is to evaluate the historical vertical and horizontal rate of streambank erosion and predict the future erosion and impacts to critical infrastructure and residential property. Historical LiDAR was used to estimate observed historical erosion. A HEC-RAS Unsteady Sediment Transport Model and a Bank Stability and Toe Erosion Model were developed to quantitatively evaluate the vertical and horizontal changes in the Imhoff stream to and validate the historical observations.

3.1.1 Historical LiDAR

The LiDAR elevation data developed for the conceptual phase of the project consisted of 2015 survey data incorporated into the 2007 1-foot contour topography provided by the City of Norman. The 2015 LiDAR was established as the baseline against which the 2021 LiDAR was compared to analyze the topographical changes over six years.

3.1.2 HEC-RAS

The unsteady-state, one-dimensional (1D), Hydrologic Engineering Center's River Analysis System (HEC-RAS), version 4.1.0 effective FEMA hydraulic model for the Zone AE study of Imhoff Creek was modified with updated hydrology and survey data as part of the conceptual phase of this project in 2017. The model was updated to version 6.0, LiDAR was incorporated into the model that included the most recent survey data, and the geometry was updated to create the new existing conditions model.

3.1.3 Bank Stability and Toe Erosion Model

The Bank Stability and Toe Erosion Model (BSTEM) is a combination of models developed by the U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS) that runs in Microsoft Office Excel™. The Bank Stability model calculates the factor of safety of an input bank geometry and provides a plane of failure, while the Toe Erosion Model estimates the amount of erosion at the toe of the bank based on input flow parameters.

3.2 Vertical Analysis

3.2.1 Historical Observations

Figure 3-1 shows the stream bed profile for Imhoff Creek from the Imhoff Road bridge to approximately 400 ft downstream of the structure using channel survey and LiDAR data for 2007, 2015 and 2021.

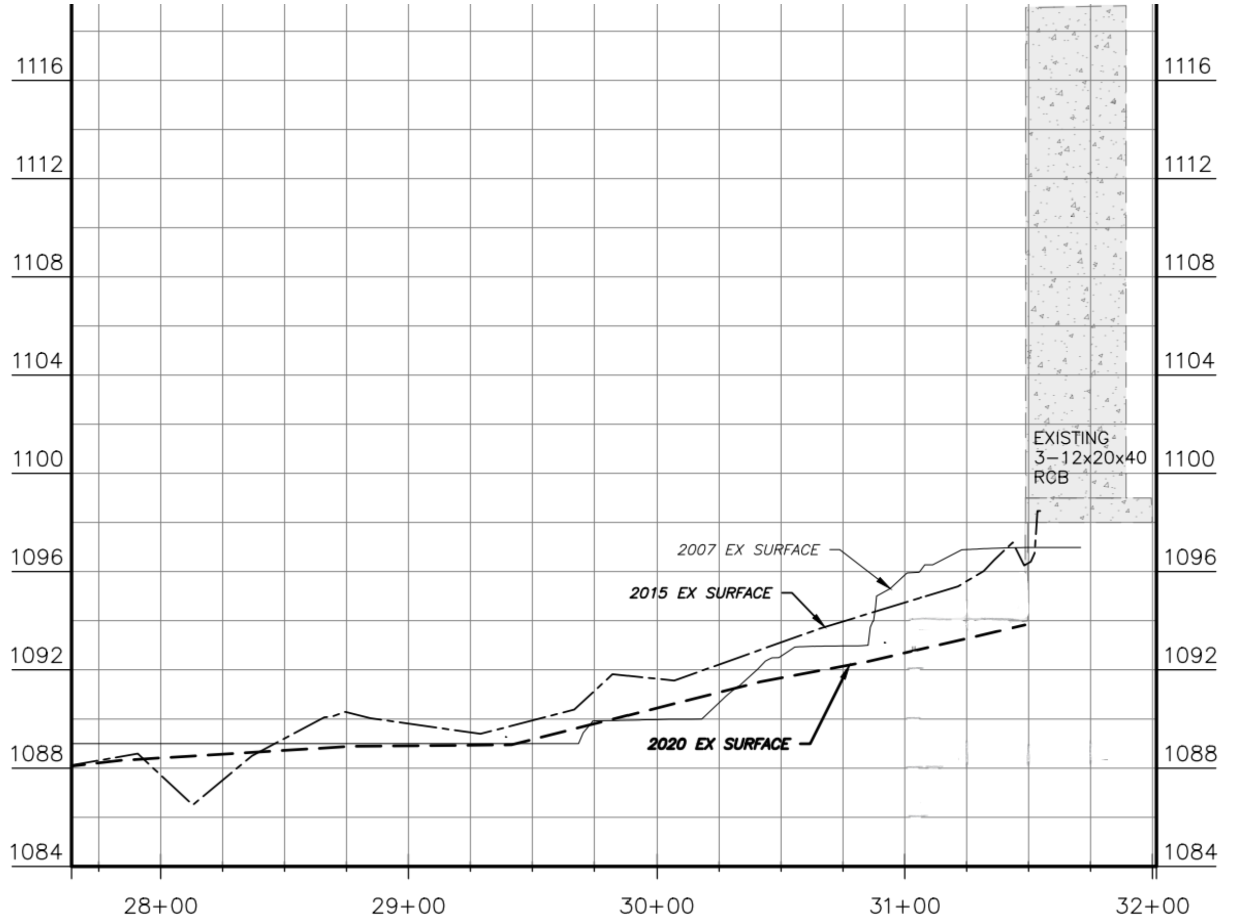

Figure 3-1: Stream bed profile

As seen in Figure 3-1, there is significant scour occurring just downstream of the bridge structure at Imhoff Road, as well as vertical head cutting. The scour immediately downstream of the bridge is shown to have eroded vertically at an average rate of 2.25 inches per year between 2007 and 2015, and an average rate of 6 inches per year from 2015 to 2020. As the drop at the downstream face of the structure continues to increase, the rate of erosion will continue to increase as well.

The head cut is moving upstream at an average rate of approximately 5 feet per year. At this rate, the head cut will begin to undermine the Imhoff Road bridge by 9 feet in approximately 30 years if no counteractive measures are taken.

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3.2.2 HEC-RAS Model

A HEC-RAS unsteady sediment transport model was developed to simulate the bed change along Imhoff Creek. The existing conditions unsteady model was trimmed down to the reach downstream of the articulated block channel for model stability, and inflows from the existing conditions model were applied. Sediment data was developed based on the geotechnical information available and interpolated between sample locations.

Due to the lack of accurate historical flow data for Imhoff Creek, as well as minimal sediment data and the variety of materials present in the reach, accurate calibration of the model is unattainable. Though the model results cannot be quantitatively validated, general trends in erosion driven by the channel geometry and flow characteristics can be inferred. Figure 3-2 shows the results of the 50 percent annual chance (2-year) storm event.

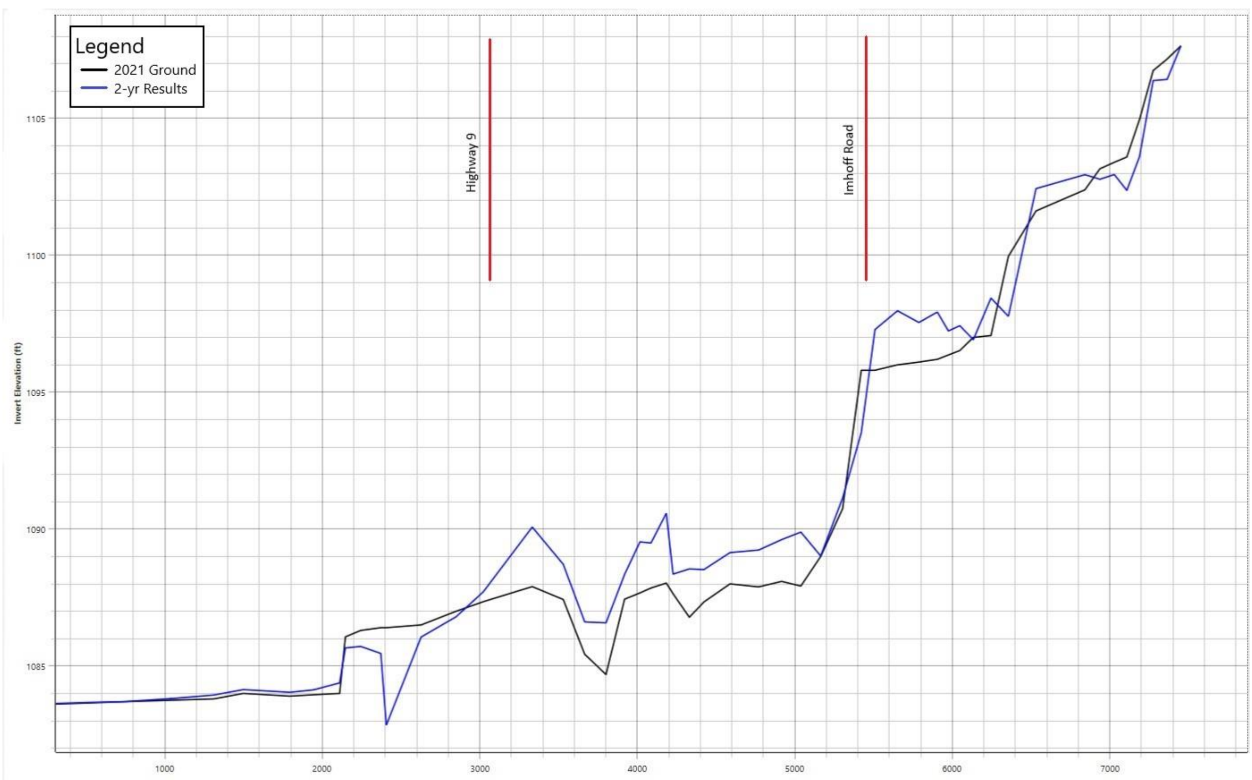

Figure 3-2: Sediment transport results for the 2-yr storm event

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The results show that the head cutting just downstream of the Imhoff Road structure is likely to continue moving upstream and undermine the existing Imhoff bridge structure. There is also additional head cutting occurring upstream of Highway 9, which will continue to erode upstream towards Imhoff Road over time.

3.3 Horizontal Analysis

3.3.1 Historical Observations

To estimate the historical horizontal movement of the channel, the 2015 and 2021 LiDAR were compared volumetrically, and profiles of several cross sections were evaluated. Figure 3-3 shows the two areas that were evaluated volumetrically, with Reach 1 in red and Reach 2 in orange. Table 3-1 shows the results of the volumetric analysis.

Figure 3-3: Area that was evaluated volumetrically

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Table 3-1: Volumetric erosion results

	Volume Lost (ft³)	Volume Lost (yd³)	Reach Length (ft)	Bank Height (ft)	Time (yr)	Annual Lateral Erosion (ft/yr)	Annual Lateral Erosion (in/yr)	Annual Volumetric Erosion (yd³/yr)
Reach 1	170,030	6,297.4	2,075.3	20	6	0.68	8.19	1,049.6
Reach 2	44,797	1,659.1	515.3	22.6	6	0.64	7.7	276.5

Figure 3-4 shows the locations of the evaluated cross sections, and Table 3-2 shows a summary of the yearly lateral movement of the toe and the top of the left bank to the east at each cross section.

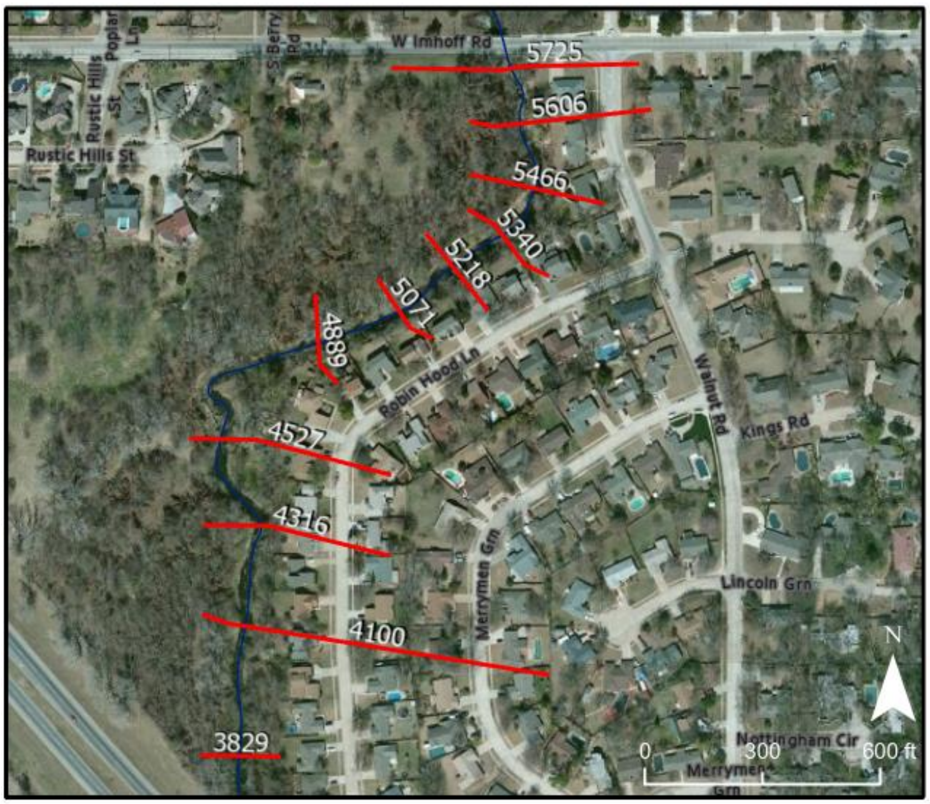


Figure 3-4: Locations of cross sections used to evaluate the lateral shift of the bank

Table 3-2: Lateral shift of the east bank

Cross Section	Lateral Shift of the channel toe to the east (feet per year)	Lateral Shift of the top of the east bank to the east (feet per year)
5725	.9	1.02
5606	1.9	0.48
5466	0	0
5340	.95	1.34
5218	1.3	0.41
5071	0	1.5
4889	0	1.02
4527	.49	1.1
4316	0	1.68
4100	0	1.01
3829	.46	0.41
Average	.49	0.9

3.3.2 Bank Stability and Toe Erosion Model

A USDA-ARS Bank Stability and Toe Erosion Model was used to simulate the lateral erosion at the toe and top of the left bank for three cross sections (5725, 5606 and 5340). The elevation of flow was input as the maximum water surface elevation of the 50 percent annual chance (2-year) storm event from the HEC-RAS unsteady flow model. A flow duration of 2 hours was used as that is how long the water surface elevation stays above the 2-year maximum elevation during a 10 percent annual chance (10-year) storm. The 10-year storm is equivalent to 5.53 in of precipitation, and it was assumed that this storm event would happen seven times a year based on the normal water year rainfall of 38.6 in for Cleveland County (Mesonet). Based on the geotechnical data available, all cross sections were evaluated with a soil profile of resistant stiff clay. The results of the toe erosion and bank stability model are summarized in Table 3-3 below.

Table 3-3: BSTEM Results

Cross Section	Maximum Lateral Toe Retreat of East Bank (feet per year)	Lateral Retreat (top of bank) to a Stable Bank (feet)
5725	0.23	32.89
5606	2.78	45.94
5340	1.15	61.16

4.0 Emergency Repair

4.1.1 Wingwall Failure

The Imhoff Road bridge was inspected in October of 2019 by Oklahoma Department of Transportation (ODOT) and rated scour critical. The inspection noted severe scour up to 1 ft at the upstream end with up to 1.5 ft of undermining and 2.25 ft of scour with up to 0.5 ft of undermining at the downstream end. Scour at the southeast wingwall was up to 4 ft with up to 3.3 ft of undermining. Figure 4-1 below shows the scour at the downstream end of the box, and Figure 4-2Figure 4-2 shows the undermining of the southeast wingwall. In September of 2021 the southeast wingwall failed, as shown in Figure 4-3.

Figure 4-1: Scour at the south end of the structure at Imhoff Road

Figure 4-2: Undermining of the southeast wingwall of the structure at Imhoff Road

Figure 4-3: Failure of the southeast wingwall of the structure at Imhoff Road

An emergency repair is underway, replacing all four wingwalls and adding new aprons on the upstream and downstream end of the structure. Figure 4-4 below shows the location of the emergency apron on the downstream end of the structure, with a 4 ft drop at the structure face and a 6 ft sheet pile wall at the end of the 42.5 ft long apron.

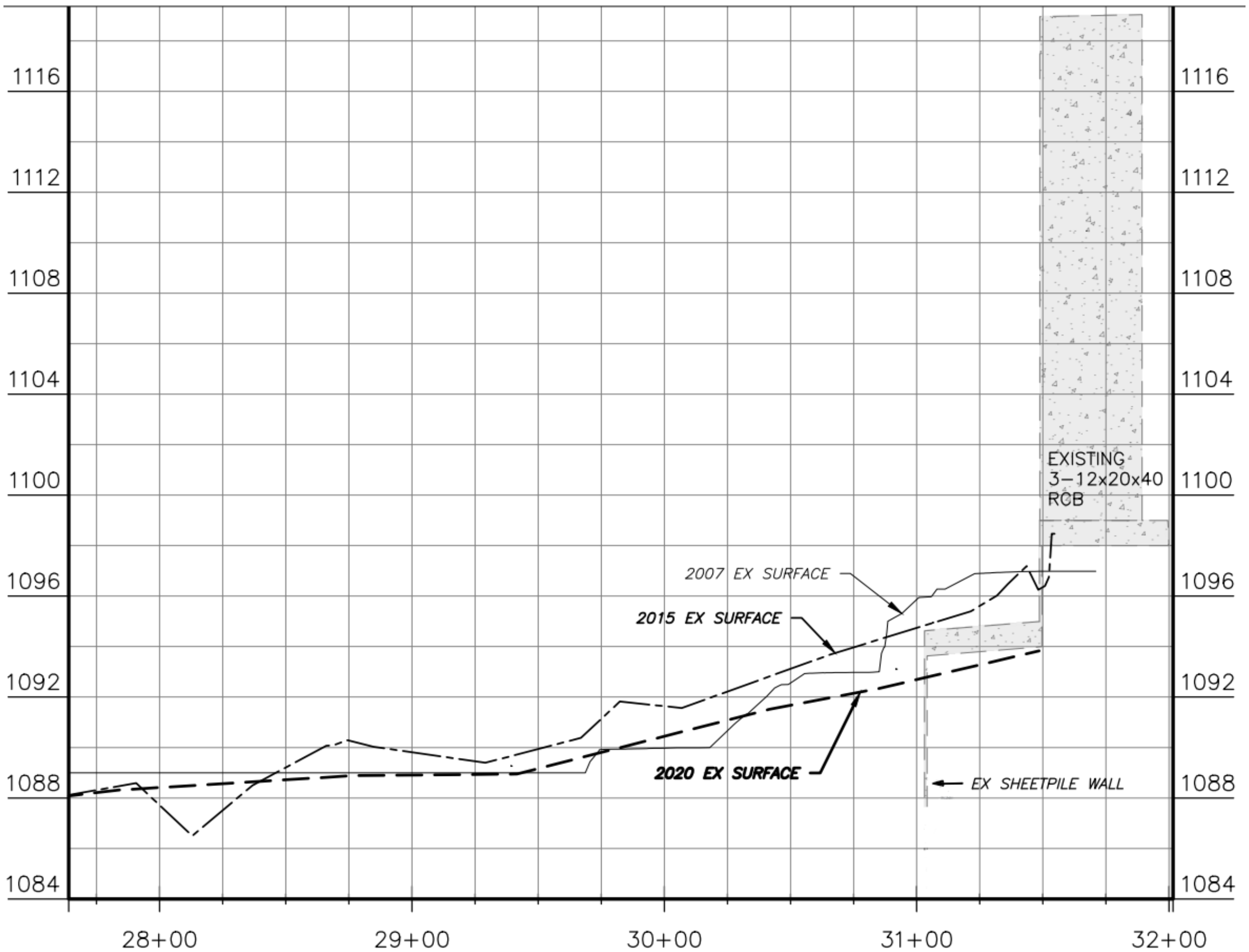


Figure 4-4: Profile view of downstream emergency repair

4.1.2 HEC-RAS Model

A comparison between current existing conditions and the emergency repair was done to determine the repair's effect on the stream flow and erosion. Figure 4-5 shows the increase in velocity due to the emergency repairs. While the velocity through the structure slightly decreased, the velocities increased 20-50% just downstream of the apron.

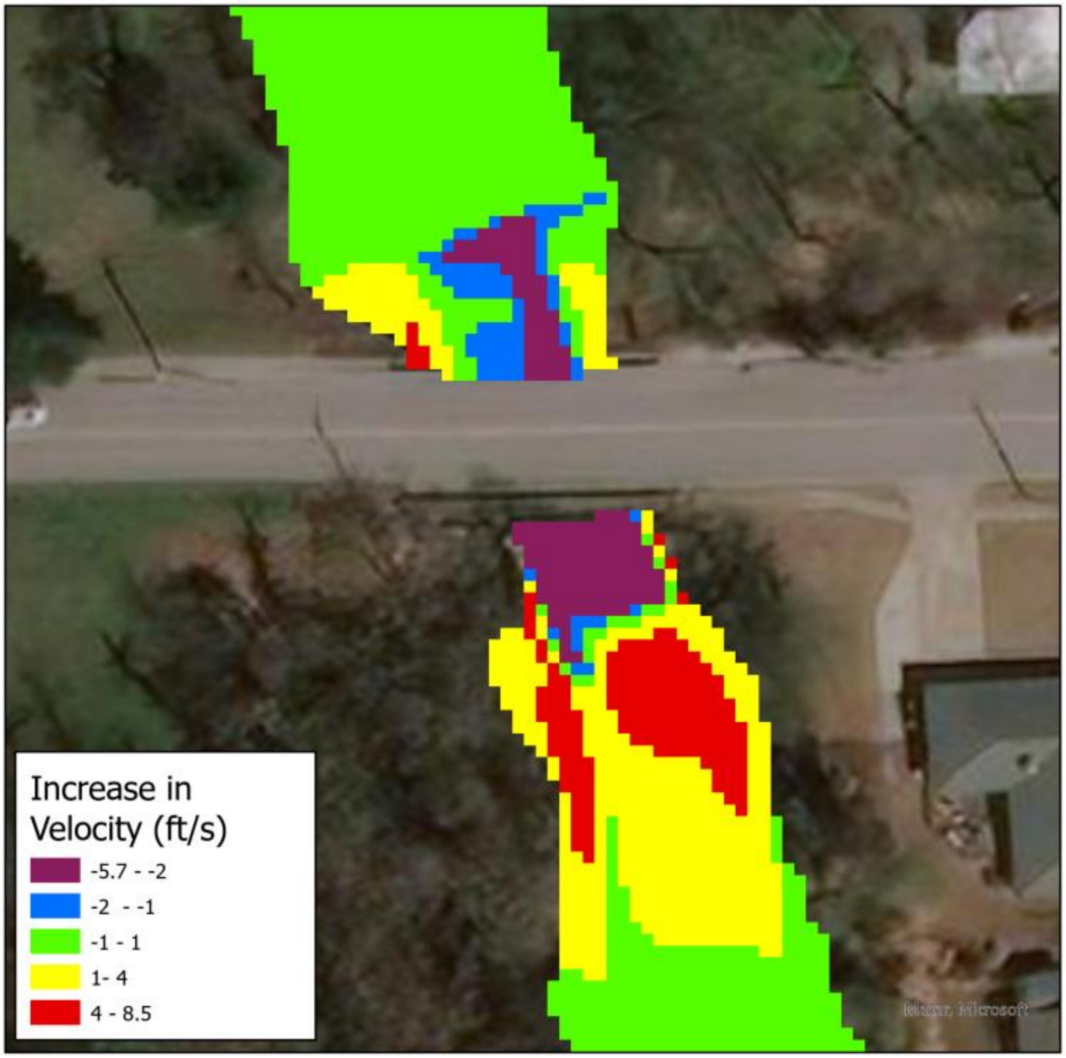


Figure 4-5: Increase in velocity due to the emergency repair

The increase in velocity will increase the rate of erosion in the area. Assuming the increased velocities will increase the rate of the head cut migration toward the Imhoff bridge structure by approximately 30%. Once the streambed head-cut reaches the bridge structure and the newly installed 6' sheet pile wall at the end of the apron, the bridge structure may be compromised in approximately 23 years. The engineer of record for the emergency bridge repairs estimates the life expectancy of those repairs to be approximately 15 years.

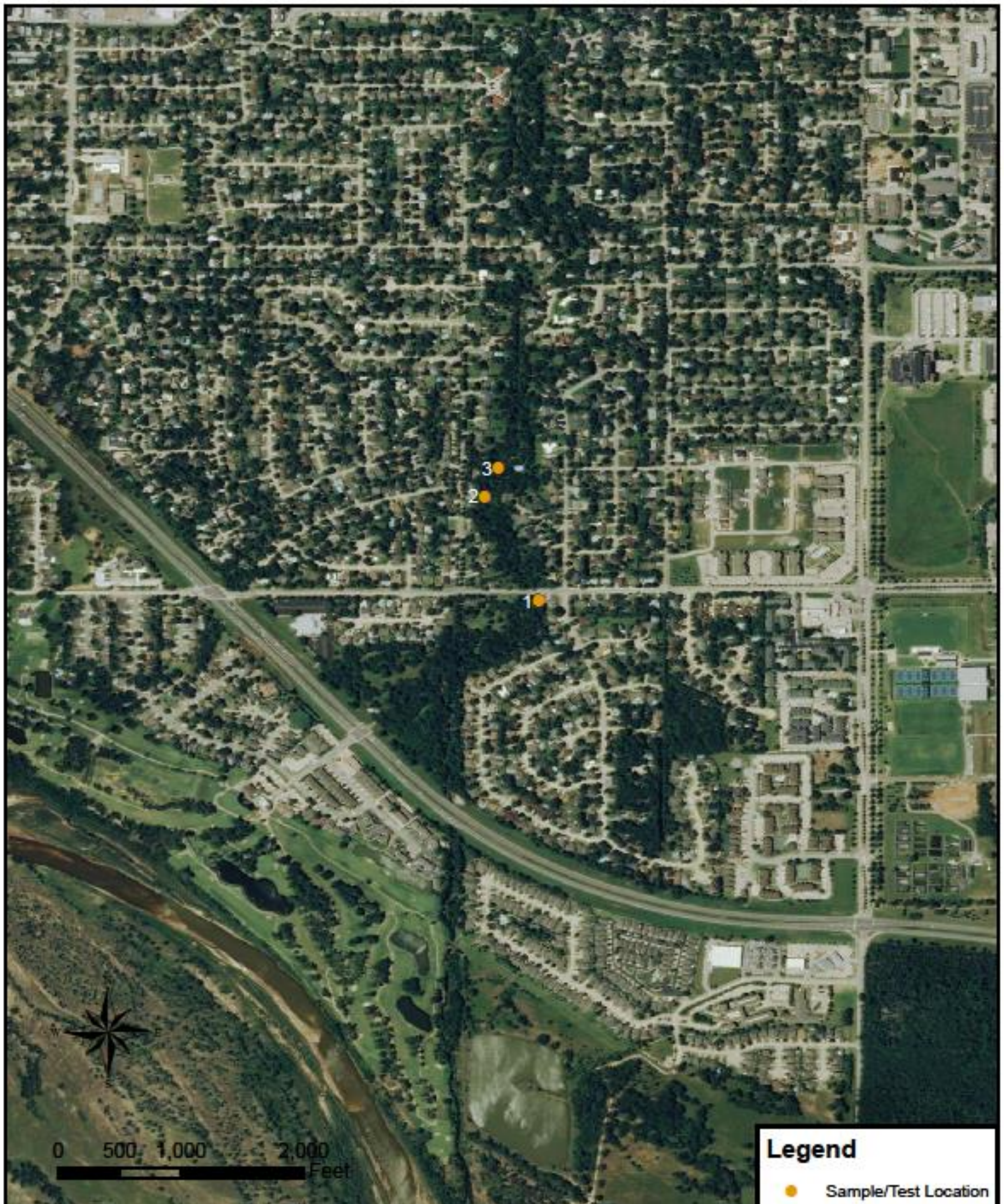
5.0 Erosion Analysis Conclusion

The goal of the erosion analysis is to quantify the future erosion and impacts to critical infrastructure along Imhoff Creek between Imhoff Road and Highway 9. The rate of erosion in the area is highly variable due to differences in channel geometry, bank and channel material, channel slope, flow velocities and shear stress throughout the reach. If no mitigation strategies are employed, the erosion will continue to head cut upstream and undermine the bridge structure at Imhoff Road in approximately 23 years. The east bank will continue to erode further to the east, threatening the residential properties and sanitary sewer infrastructure along the creek.

Assuming the average annual lateral rate of erosion of 0.7 feet per year from historical observations, Figure 5-1Figure 5-1 below shows the current top of bank line, and the estimated top of bank line in 10 years and 20 years. The predicted future banks threaten two houses and five sewer lines in the next ten years. The degradation of the structure at Imhoff Road puts an additional sewer line at risk if the structure fails.

Figure 5-1: Future top of bank lines due to erosion

6.0 Appendix A: Geotechnical Analysis (2016)



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Page 1 of 1 | Date: 06/01/2016

Sample and Field Test Location Plan
Imhoff Creek
Norman, Oklahoma

Source: ESRI, Inc.

SUMMARY OF LABORATORY TEST RESULTS

PROJECT: Imhoff Creek

PROJECT NO.: 8275000239

DATE: 01-June-2016

BORING NUMBER	SAMPLE NUMBER	SAMPLE TYPE	DEPTH* (FT.)	NATURAL MOISTURE (%)	PERCENT GRAVEL (%)	PERCENT SAND (%)	PERCENT SILT /CLAY (%)	SPECIFIC GRAVITY	ATTERBERG LIMITS			UNIFIED SOIL CLASSIFICATION	OTHER TESTS **	SOIL DESCRIPTION
									LIQUID LIMIT	PLASTIC LIMIT	Plasticity Indes			
	1A	Grab	9'	11.9	14	39	47		20	12	8	SC		Clayey Sand, brown
	1B	Grab	19'	19.0	0	14	86		34	14	20	CL		Lean Clay, brown
	1C	Grab	21'	19.7	0	46	54		25	12	13	CL		Lean Clay, sandy, reddish brown
	2A	Grab	15'	15.2	0	32	68		22	16	6	CL-ML		Silty Clay, sandy, dark brown
	2B	Grab	21'	10.6	0	56	44		NV	NP	NP	SM		Silty Sand, reddish brown
	2C	Grab	25'	17.3	0	42	58		29	12	17	CL		Lean Clay, sandy, brown
	3A	Grab	10'	7.6	0	18	82		23	17	6	CL-ML		Silty Clay, with sand, brown
	3B	Grab	18'	17.4	0	32	68		27	15	12	CL		Lean Clay, sandy, reddish brown

* ST-SHELBY TUBE, SS-SPLIT SPOON / SPLIT-BARREL SAMPLER, B-BAG / BULK, C-CORE

** C- Consolidation Test | P-Proctor | O-Fractional Organic Carbon | pH-acidity

S-Sieve or Grain Size Analysis | D-Direct Shear | CBR-California Bearing Ratio | K - Permeability

U-Unconfined Compression Test | T-Triaxial Compression Test | H-Hydrometer

R-Relative Density | SL-Shrinkage Limits | G-Specific Gravity

RE-Resistivity

Notes: * Depth is from top of bank

DATA CHECKED BY NCL

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Summary of Pocket Penetrometer Field Testing
Imhoff Creek - Norman, Oklahoma

Test Location	Depth* (ft)	Pocket Penetrometer Readings (tsf)
1	9	1.5 - 2.0
	19	3.5 - 4.5
	21	4.5+
2	15	1.5 - 2.2
	21	1.5 - 2.2
	25	2.5 - 3.5
3	10	4.5
	18	3 - 4.5

* Depth is from top of bank

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