PRELIMINARY

WRS WATER RESOURCES SOLUTIONS

Independence Court Streambank Stabilization Feasibility Study

Prepared for the City of Leavenworth

Feb. 00, 2019

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WATER RESOURCES SOLUTIONS

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Feb. 15, 2019

Mike Hooper, PE
Public Works Department
City of Leavenworth
100 N 5th St
Leavenworth, KS 66048

Subject: Independence Court Streambank Stabilization Feasibility Study report

Dear Mike:

Water Resources Solutions is pleased to submit this draft report on our findings in the Independence Court Streambank Stabilization Feasibility Study.

Inside this report, you will find our recommendation of the most appropriate solution based on the City of Leavenworth's requirements, along with relative advantages and disadvantages of each proposed solution. Also included is a brief technical background, in order to help inform Leavenworth city staff and the city commission in their decision regarding the best option. Our report also includes the results of your requested tributary-wide investigation to evaluate the condition of the tributary, in order to prioritize possible projects in the future to prevent similar streambank failures that may be expected in other portions of the tributary.

If you have any questions, please contact me at 913-302-1030 or DBaker@wrs-rc.com.

Sincerely,
Water Resources Solutions, LLC

Donald W. Baker, P.E., D. WRE, CPESC

PRELIMINARY

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I. INTRODUCTION

This streambank stabilization alternatives feasibility study for the City of Leavenworth investigates contributors behind and possible solutions to a streambank failure on an unnamed tributary to Fivemile Creek adjacent to homes along Independence Court. This report will recommend the most appropriate solution based on the City of Leavenworth's requirements and relative advantages and disadvantages of each proposed solution. It will include a brief technical background in order to help inform Leavenworth city staff and the city commission in their decision regarding the best option. In addition, it will report the results of a tributary-wide investigation to evaluate the condition of the tributary and aid stakeholders in prioritizing possible projects in the future, in order to prevent similar streambank failures that may be expected in other portions of the tributary. This report and stream stability study includes a field assessment, a description of each reach and a score based on the American Public Works Association's channel condition scoring matrix, opinions of probable construction costs to stabilize all reaches of the tributary, concept-level design recommendations to stabilize the specific bank failure along the backyards of Independence Court, opinions of probable construction costs for the proposed alternatives, and recommendations.

II. SITUATION BACKGROUND

A. PROBLEM DESCRIPTION

An unnamed tributary to Fivemile Creek adjacent to homes along Independence Court is threatening private property and a sanitary sewer line owned by the City of Leavenworth. The property owner at 1421 Independence Court notified the city that a sinkhole had developed adjacent to a storage shed on the back portion of the property, which lies on the outside of a bend on the tributary. The property owner has stated her opinion that the creek lay further away from her yard and fenceline when she and her husband moved in many years ago than it does today, indicating a change in the creek's position. She also stated that recently the stream seemed to be eroding even more quickly. The City contracted with Water Resources Solutions (WRS) to investigate this situation and to propose options to stabilize the channel — referred to in this report as Reach 6 — along the backs of several homes adjacent to Independence Court. The city has also requested WRS prepare a stream stability study that evaluates the condition of the entire tributary.

B. DEVELOPMENT HISTORY

Lateral migration of a stream similar to the type threatening the residences along Reach 6 may be related to upstream development that results in increased stream flow volume. Therefore, the area's development history was investigated.

Based on historic aerial photography from 1947 to 2018 for the area, from 1947 to 1975, the area was rural and composed mostly of pasture, row cropland, and small farms, with little non-permeable surface area. Most of the basin development occurred from 1975 through 1990, consisting mainly of eighth-acre single-family residential homes. Some of the development areas were built close to the stream, such as the area along Independence Court. As the stream experienced additional flow volume and higher peak discharges from the upstream development runoff, its planform — the stream geometry as viewed from above — along the backs of the properties along Independence Court changed as follows:

- The channel became deeper.
- The channel became wider.
- The channel's "meanders," or the series of regular channel bends, became more exaggerated.

When compared to both the 1947 and 1960 aerial photos, the 2008 aerial photo shows the stream meanders exhibit greater amplitude. This change over time indicates the stream is lengthening to accommodate the additional flow, and it is that change in meander that accounts for the movement of the stream into the threatened residential yards. Additionally, the added flow has lowered, or incised, and widened the stream bed, in an attempt to reach equilibrium under the additional flow.

III. SOLUTION REQUIREMENTS

The city has requested WRS present solution alternatives that attempt to meet these requirements:

- Address the specific creek and bank stability issues leading to the undercutting and bank erosion along reach 6.
- Present alternatives that can be expected to prevent or reduce risk of further property loss related to those specific issues.
- Base alternative solutions on a concept level one-dimensional hydraulic model that determines the range of hydraulic forces accruing on the banks.
- Assess the wider instability issues along the entire tributary in order to protect residential property and city property throughout the tributary.
- Be capable of meeting permitting requirements.
- Provide and fit into potential phasing opportunities.

IV. TECHNICAL BACKGROUND

A. SITE VISIT FINDINGS

WRS Principal Don Baker, PE, visited the residence at 1421 Independence Court on Aug. 9, 2018, where he briefly interviewed owner Geneva Pressley. Baker observed holes and areas of settling appearing under and near a shed in the backyard. He concluded the holes were likely piping failures, a progressive development of internal soil erosion caused by backward erosion from the stream upward into the bank, until a continuous "pipe" is formed between the upstream area and the stream. Such continuous pipes are associated with bank failures. It was during this interview that Pressley also expressed her belief that the creek had moved closer to her yard in the years since she had first moved into the residence, and that recently the stream seemed to be eroding at a faster pace. Baker further confirmed that the neighboring residence to the west of Pressley's is experiencing similar levels of erosion and bank failure.

Figure 1. Suspected piping failure

A suspected piping failure associated with bank failure under the shed in the backyard of 1421 Independence Court.

Stream data for the tributary-wide stream stability study was collected by Bill Yord, PE, and Dan Rosas, EI, from WRS, on Dec. 18, 2018. Their site visit also confirmed the findings of Baker's previous site visit and documented several instances of bank undercutting, streambank slope failure, changes in stream meander, and failed attempts by individual property owners to mediate or prevent further erosive damage to property.

Figures 3 through 6 illustrate typical examples of these issues in Reach 6. Figure 2 maps the location of the figures.

Figure 2. Project area map

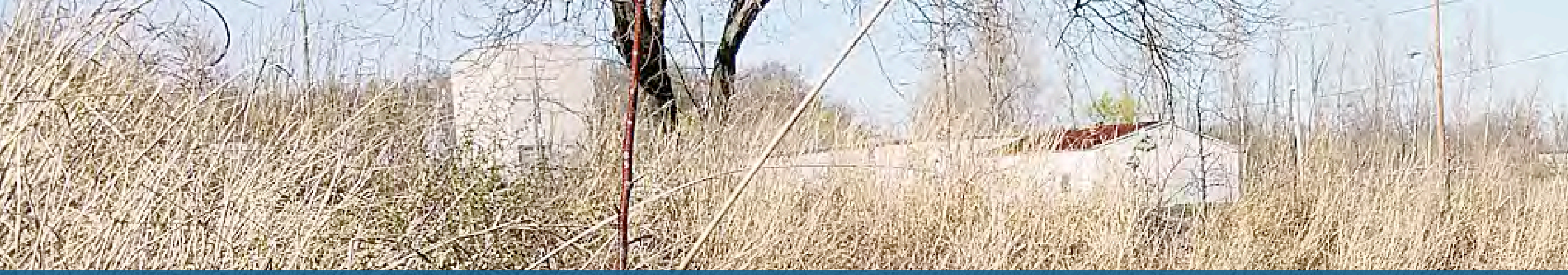
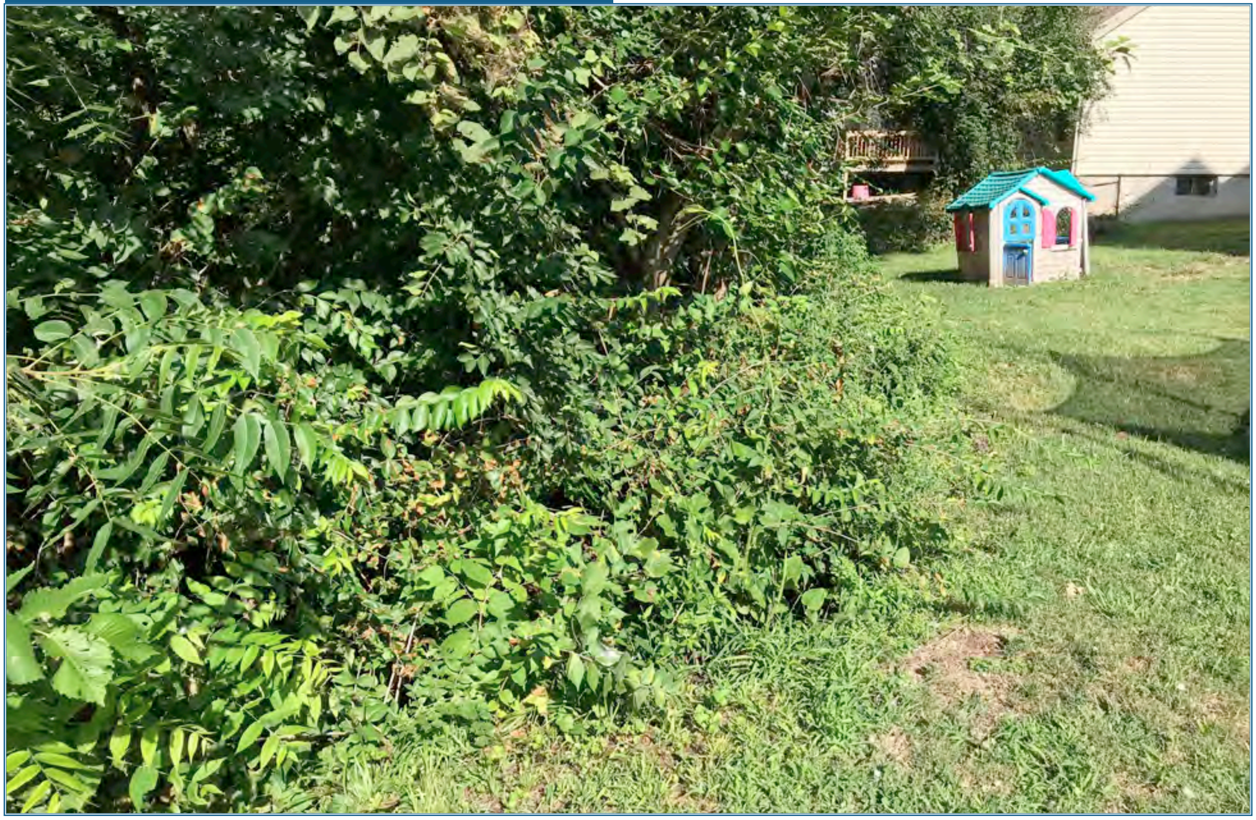


Figure 3. Meander encroaching on residential yard



The residential backyard being threatened by the changing meander of the tributary.

Figure 4. Bank undercutting and slope failure

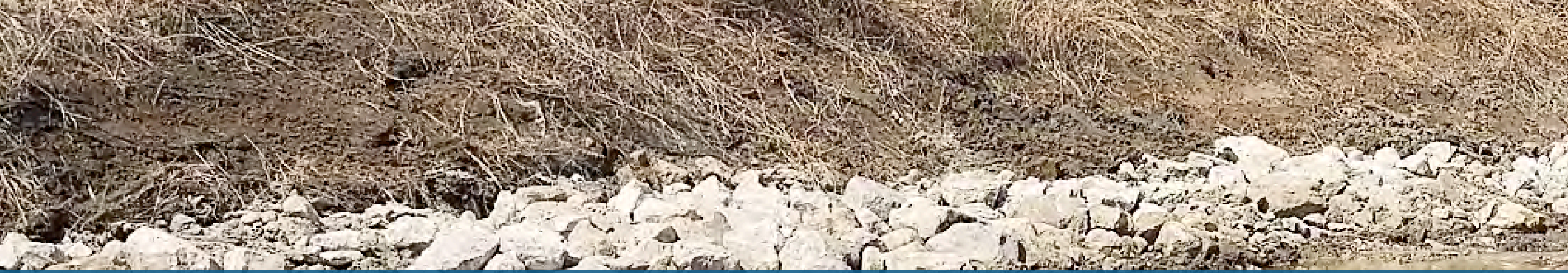
Severity of bank undercutting and slope failure adjacent to 1421 Independence Court.

Figure 5. Stream meander near project area start

Example of stream meander near the start of the project area. The bank on the left side of the photograph is vertical and approximately 15 feet high.

Figure 6. Failed repair attempt by property owner

Concrete slurry poured by property owner into bank hole. The concrete slurry went through the hole and into the stream.



B. SOILS

When proposing possible solutions to bank failures similar to that observed in this case, it is important to consider the erodibility of the existing soils. Soil information was obtained from the U.S. Department of Agriculture's Natural Resources Conservation Service Web Soil Survey. A percent-silt report based on the NRCS data and an analysis of this data indicates 60 percent of the soils in the basin that contains the tributary to Fivemile Creek consist of loam, an erodible soil type. See Table 1.

Table 1: Percent soil types and percent loam in Reach 6

Map Unit	Map Unit Name	Rating (Percent silt in soil type)	Percent of area composed of soil type	Percent of area that is loam soil
7051	Kennebec silt loam	70.0%	9.2%	6.4%
7211	Bremer silt loam	58.6%	4.1%	2.4%
7236	Elmont silt loam	58.3%	7.1%	4.1%
7250	Gosport-Sogn complex	42.0%	4.8%	2.0%
7285	Ladoga silt loam	63.9%	19.7%	12.6%
7291	Marshall silt loam	64.0%	3.2%	2.0%
7302	Martin silty loam	55.5%	6.3%	3.5%
7540	Sharpsburg silty clay loam	62.2%	5.8%	3.6%
7542	Sharpsburg silty clay loam	62.1%	19.9%	12.4%
7850	Judson silt loam	68.4%	0.1%	0.1%
7950	Gosport complex	42.0%	9.4%	3.9%
7955	Knox silt loam	66.6%	4.5%	3.0%
7958	Knox silty clay loam	66.1%	5.9%	3.9%
		Total	**100.0%**	**60.0%**

C. HYDRAULICS

A concept level one-dimensional hydraulic model was created for Reach 6 to determine the range of hydraulic forces accruing on the banks and to inform the choice of alternative solutions.

1. Method

The hydraulic model was created for Reach 6 using the U.S. Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS) software to provide information on the velocity and shear stress that is affecting the channel degradation occurring around 1421 Independence Court in Reach 6. The elevation and contour data were taken from the State of Kansas GIS Data Access and Support Center to create cross-sections at the reach of interest. The flow of the hydraulic model was estimated utilizing TR-55. Information from the Environmental Protection Agency was used to determine the sub-basin area information.

2. Results

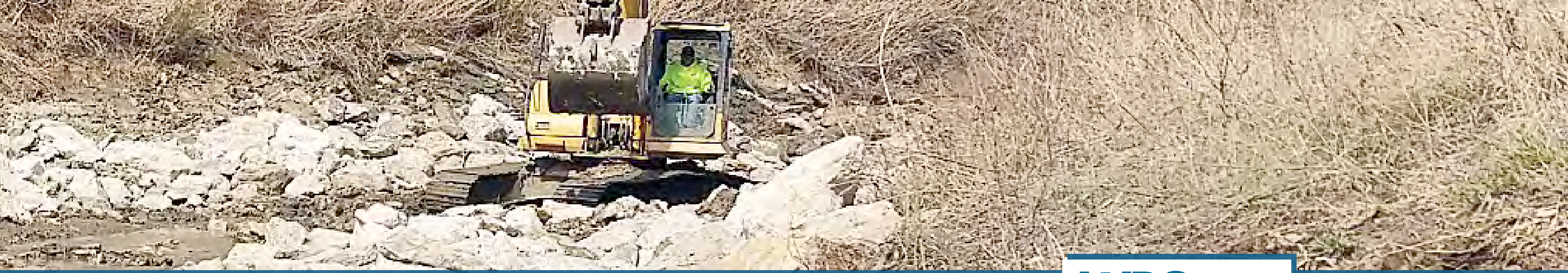
The results of the one-dimensional hydraulic model at River Station 1040, the elevation located closest

Table 2: Velocity and shear stress, River Station 1040 for various storms

Flow Year	Discharge	Velocity, ft/s	Shear Stress, lb/ft^2
1-yr	245.40	6.00	0.81
2-yr	412.97	6.56	0.94
5-yr	736.50	6.71	0.96
10-yr	1022.90	7.01	1.03
25-yr	1325.62	7.31	1.09
50-yr	1595.82	7.59	1.16
100-yr	1960.11	7.99	1.26

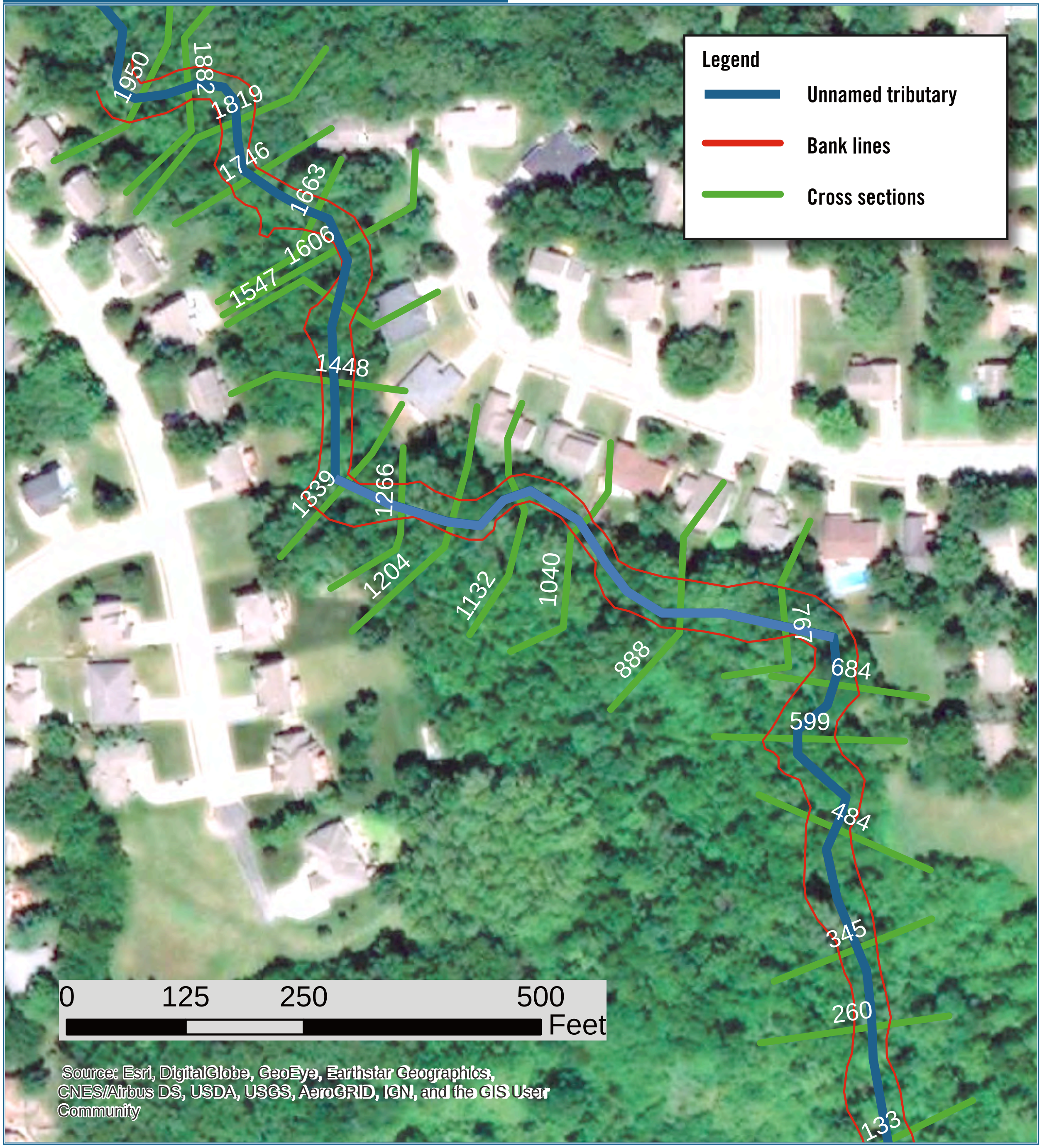
Table 3: Velocity and shear stress, River Station 1132-888, 1- and 2-year storms

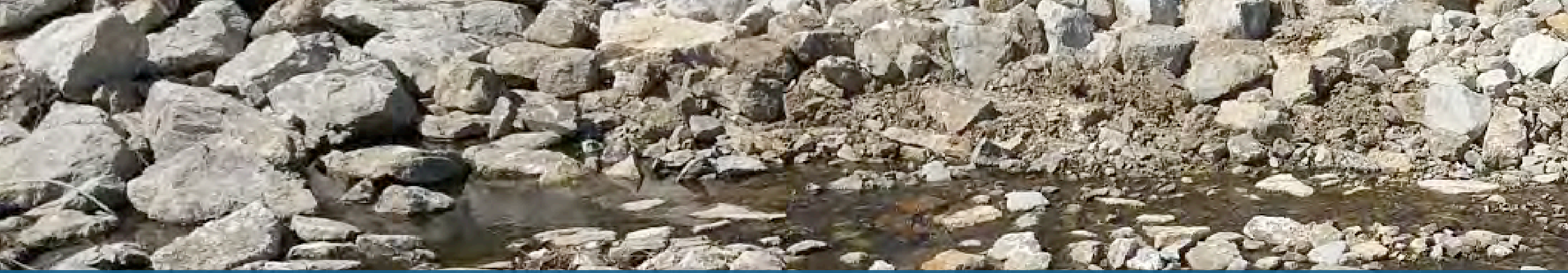
River Station	Flow Year	Average Velocity (ft/s)	Shear Stress (lb/ft^2)
1132	1-year	4.63	0.58
1040	1-year	6.00	0.81
888	1-year	6.90	1.47
1132	2-year	5.85	0.88
1040	2-year	6.56	0.94
888	2-year	7.73	1.71



to the 1421 Independence Court bank failure, are detailed in Table 2. The model shows that during the 1-year and 2-year storms, a high velocity and shear stress is scouring the left bank at the river stations shown in Table 3. The results of the analysis show that the stream condition is poor and unstable. The velocity of stream forming condition showed to be around the 1- to 2-year flow. The velocity was 6.00 to 6.56 feet per second. The shear stresses the stream experiences are 0.81 and 0.94 pounds per square

Figure 7. Stream Reach 6 cross sections





foot. Because of the type of soil and constant wetting of the toe of the embankment, mass wasting has taken place along the backs of these properties. Additionally, the city indicated that the channel may have been re-directed because of debris load at some time in its history. Based on historic aerial phots from 1947 to present, it appears the stream meander has increased in amplitude in Reach 6 and, as a result, is threatening the backs of the properties along Independence Court.

D. PERMITTING REQUIREMENTS

The City of Leavenworth has set out the requirement that proposed solutions must be permittable under current regulatory requirements. WRS conducted an assessment of permit requirements.

Based on the length of the proposed project and the construction within the ordinary high-water mark, it is expected that option No. 1 within Reach 6 presented in this study would be permitted by the U.S. Army Corps of Engineers under a Nationwide Permit 13 – Bank Stabilization. Consultation with the Kansas City District Permitting Branch should take place early in any subsequent project to verify that expectation. Some of the criteria for a Nationwide Permit 13 are listed below.

- No material is placed in excess of the minimum needed for erosion protection.
- The activity is no more than 500 feet in length along the bank, unless the district engineer waives this criterion by making a written determination concluding that the discharge will result in no more than minimal adverse environmental effects. An exception applies to bulkheads. The district engineer cannot issue a waiver for a bulkhead greater than 1,000 feet in length along the bank.
- 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, unless the district engineer waives this criterion by making a written determination concluding the discharge will result in no more than minimal adverse environmental effects.
- The activity does not involve discharges of dredged or fill material into special aquatic sites, unless the district engineer waives this criterion by making a written determination concluding the discharge will result in no more than minimal adverse environmental effects.
- 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.
- 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.
- Native plants appropriate for current site conditions, including salinity, must be used for bioengineering or vegetative bank stabilization.
- The activity is not a stream channelization activity.
- The activity must be properly maintained, which may require repairing it after severe storms or erosion events. The permit authorizes those maintenance and repair activities if needed.

E. FIELD ASSESSMENT METHODOLOGY

During the site investigations, it become obvious the bank instability issues at 1421 Independence Court were not an isolated event for this one yard. The neighbor to the west is experiencing similar levels of erosion and bank failure.

Instead, the streambank failures appear to be systemic in nature. Most or all of the tributary most likely is adjusting to changed hydrology in the watershed due to the development. The stream appears to be incising and increasing its meander in order to flatten its slope to minimize energy. If tributary-wide improvement is left unaddressed, additional properties along the stream will begin experiencing similar types of erosion and streambank failures. As a result, individual property owner efforts at bank stabilization are at best a temporary and costly solution.

In order to address this issue, a long reach of stream will need to be stabilized. This stabilization would likely take the form of grade controls along the long reach to manage energy and streambank stabilization in certain areas to mitigate the unstable slopes that have developed during the stream changes that have occurred. The solution would need to be applied to approximately 3,000 to 4,000 feet of stream.

Because of that need for a systemic evaluation, the City of Leavenworth requested WRS conduct a field assessment of the entire tributary to evaluate its stability.

A field assessment using a refined version of the protocol developed by Johnson, Gleason, and Hey (1999) for the Federal Highway Administration was completed. This modified protocol includes the chan-

nel condition scoring matrix (CCSM) shown in Table 5605-2 in the Kansas City Metropolitan Chapter of the American Public Works Association Section 5600 Design Guidance Document for Storm Drainage Systems and Facilities (2006).

The CCSM provides a quantitative evaluation system for stream reaches to provide an unbiased assessment and comparison of stream conditions. It is based on the scoring or assessment of 15 channel stability indicators. A score of "good" receives 1 point, "fair" receives 2 points, and "poor" receives 3 points. The Stability Indicators from the CCSM are listed in Table 4.

1. Data collection

The stream data for the study reach of the unnamed tributary to Fivemile Creek was collected by Bill Yord, PE, and Dan Rosas, EI, from WRS, on Dec. 18, 2018. The field data was collected using a Trimble GeoHX GPS data collector with hand field notes and pictures. The data input into the Trimble GeoHX GPS was collected using the NAD 1983 (US feet) State Plane Kansas North FIPS 1501 coordinate system. Some of the channel scoring criteria for the CCSM for the reaches were determined using the aerial photography and GIS information provided to WRS by the city.

2. Channel condition rating and ranking

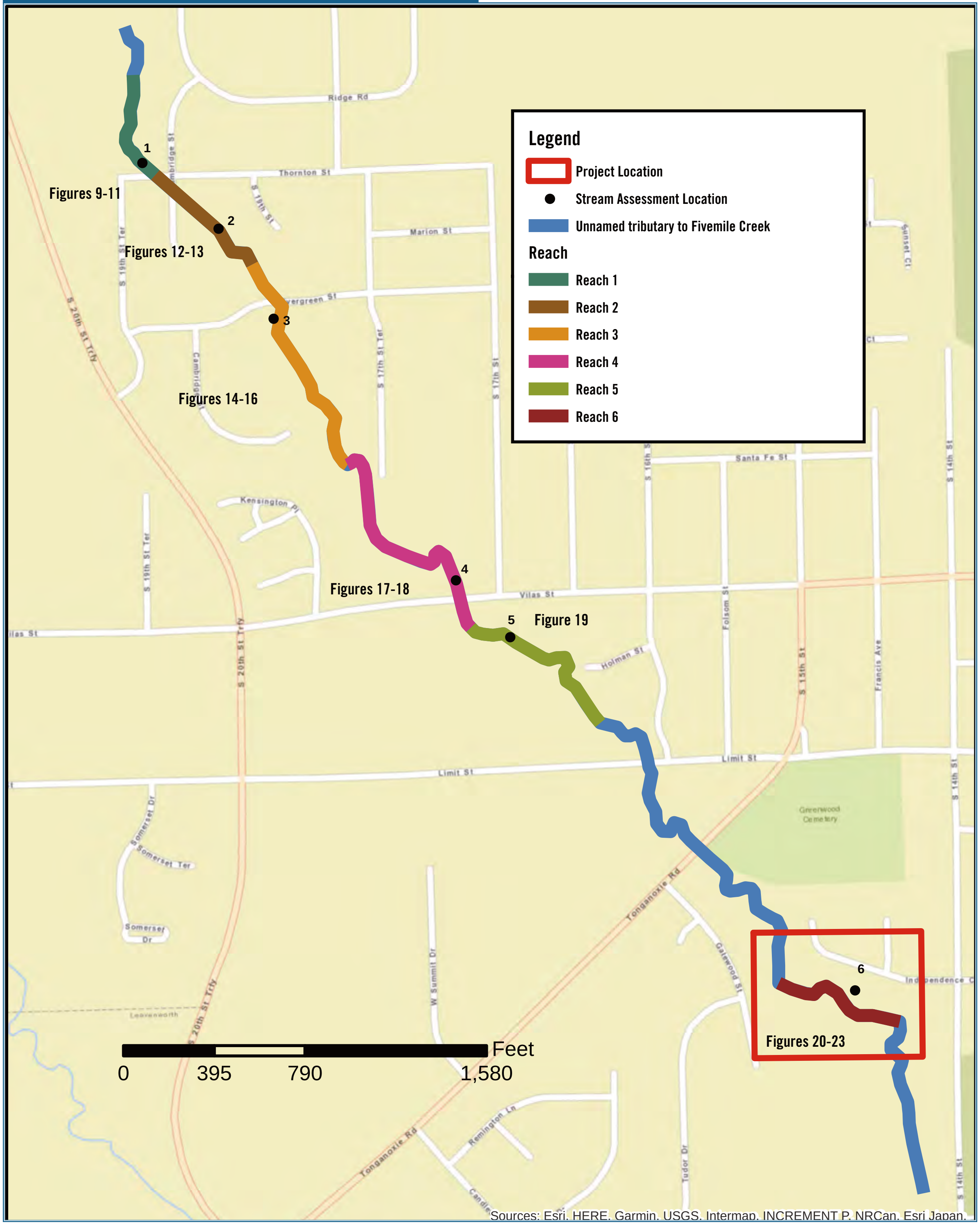
Each of the stability indicator scores described in the previous section was multiplied by a weighting factor that produces a numeric rating for each indicator. The weighting factor is a decimal value ranging from 0.2 to 0.8, which establishes the relative importance of the indicators to stream stability. The weighting factors for the matrix add to a total of 9.8.

The stability indictor ratings are then added together to produce a total ranking. As a result, the upper limit of total ranking for a stream reach to be ranked "good" would be 9.8 (1 x 9.8). The upper limit for a stream reach to be ranked "fair" is 19.6 (2 x 9.8). Similarly, the upper limit of the total ranking for a stream reach to be ranked "poor" is 29.4 (3 x 9.8). Figure 8 illustrates the location for each of the rated stream reaches.

Table 4: CCSM Stability Indicator List

Stability indicator	Explanation and relevance
Bank soil texture and coherence	The texture of the soil and how well it remains cohesive in order to resist erosion
Average bank slope angle	The steepness of one or both banks; the shallower the banks, the better the hydraulic energy dissipates without causing erosion
Average bank height	The height of one or both banks; the lower the height, the less potential to erode
Vegetative bank protection	The width, age, type, diversity and density of trees, shrubs and plants whose root systems help hold bank soil in place
Bank cutting	The number and height of "raw" banks, or those with exposed, bare dirt
Mass wasting	The amount of scalloping, undercutting and slumping of chunks of soil along the banks
Bar development	The size and indication of freshness of shoals built by deposited materials
Debris jam potential	The existence of or potential for logjams and other floating debris to accumulate
Obstructions, flow deflectors (walls, bluffs) and sediment traps	Frequency and stability of natural or man-made obstructions to streamflow that cause sediment to accumulate or the stream channel to erode
Channel bed material consolidation and armoring	Size, degree of packing, overlapping, and interlocking of rock or other material resistant to erosion in the bottom of the stream; may contribute to increased erosion along the banks
Sinuosity	The height and depth of the curves formed by a stream's natural flow pattern when viewed from above; the bigger the curves, the more stable the stream
Ratio of radius of curvature to channel width	The sharpness of stream bends in comparison to the stream's width
Ratio of pool/riffle spacing to channel width at elevation of 2-year flow	The relative frequency of the natural combination of rapids and calm pools indicating stability of sediment erosion and deposition
Percentage of channel constriction	The percentage of the normal channel width choked off to water flow
Sediment movement	The amount and size of sediment suspended in the flowing water

Figure 8. Stream reaches map



F. FIELD ASSESSMENT RESULTS

1. Reach 1 – CCSM score: 19.2

Reach 1 is the length of stream from north of Thornton Street to the outlet of the existing 48-inch pipe on the south side of Thornton Street. The area surrounding the stream on the north side of Thornton Street is wooded, with development predominantly on the east side of the stream.

The sides of the channel are well vegetated, and the channel bottom has rock exposed, which helps armor the stream along the reach. The stream flows into an existing 48-inch reinforced concrete pipe (RCP) with an end section on the north side of Thornton. Debris load was present in the end of the RCP, which filled the end with about 2.3 feet of sediment, leaving only about 1.7 feet of open area at the end of the culvert.

Bank cutting and some mass wasting were present along the banks in some areas of the stream in this reach. Because of limited development immediately adjacent to the banks, room exists for the channel to adjust without endangering property or infrastructure. Additionally, because of the surrounding wooded area, additional protection of the stream is present.

Figure 9. Rock in stream bottom in Reach 1

Figure 10. Debris filling pipe in Reach 1

Rock in the stream bottom (Figure 9) helps armor the channel in Reach 1. Debris in the RCP at Thornton (Figure 10) has choked the space to about 43%.

Figure 11. Evidence of mass wasting in Reach 1

Some evidence of stream instability in Reach 1 includes mass bank wasting (Figure 11).

2. Reach 2 – CCSM score: 25.4

Reach 2 is the length of stream from the outlet of the existing 48-inch RCP on the south side of Thornton Street to the inlet of the existing 60-inch RCP on the north side of Evergreen Street. Development has encroached on the existing stream, with landscaping, retaining walls, fencing, and other features typically found in single-family areas. Rock revetment, a facing of stone meant to protect the bank placed in the channel downstream of existing storm sewer outlets, has moved. Scour is present at the ends of these systems. Trees are falling into the channel, causing constrictions and possibly serving as a source of debris. The straightening of the stream resulted in an increased slope which created the velocity and shear stress conditions for increased scour.

Figure 12. Vertical cut bank in Reach 2

Vertical cut bank and mass wasting (Figure 12) indicates stream instability in Reach 2.

Figure 13. Displaced rock revetment, Reach 2

Rock revetment placed in the stream (Figure 13) to protect the bank has moved, leading to scour downstream.

Figure 14. Separated 60-inch RCP end, Reach 3

Figure 15. Vertical cut bank, Reach 3

Instability indicators in Reach 3 include separation in a 60-inch RCP due to scour (Figure 14), mass bank wasting (Figure 15), and bank scouring (Figure 16).

Figure 16. Scour at end of 10-inch RCP, Reach 3

3. Reach 3 – CCSM score: 22.4

Reach 3 is the length of stream from the outlet of the existing 60-inch RCP on the south side of Evergreen Street to the south end of South 17th Terrace. The end section at the south end of the existing 60-inch RCP has become separated from the pipe due to erosion and a scour hole that has developed on the south-west side of the pipe outlet. Because of residential development adjacent to the stream, added flow and shear stress has led to erosion along the banks of the stream along the west side of South 17th Terrace. Once the stream moves south of the south end of South 17th Terrace, it is within a wooded area and has more room to move within its natural floodplain.

4. Reach 4 – CCSM score: 19.2

Reach 4 is the length of stream from the south end of South 17th Terrace to the culvert outlet on the south side of Vilas Street. The surrounding area is wooded, and the stream has room to move within its floodplain. Because of this room, less stream degradation along the banks and stream bottom is present; however, small debris load upstream of Vilas Street was left in the stream from a recent flow event. Concrete revetment was present in the channel downstream of Vilas Street.

Despite offering more room in its floodplain for the stream to move, Reach 4 demonstrates some potential instability, including debris load (Figure 17) and concrete revetment (Figure 18).

Figure 17. Debris at Vilas Street, Reach 4

Figure 18. Concrete revetment, Reach 4

5. Reach 5 – CCSM score: 21.2

Reach 5 is the length of stream from the culvert outlet on the south side of Vilas Street to the culvert under Limit Street. This area is wooded around the stream and, like Reach 4, offers more space for the stream to naturally move within its floodplain. Rock was also present, which may serve as a natural armor for the stream bottom. Because this armoring prevents the stream from deepening, it is widening, which is leading to bank erosion. Large trees continue to fall into the channel, caused by the erosion of the banks.

Rock armors the stream channel bottom in Reach 5, leading to stream widening and erosion, threatening trees along the bank (Figure 19).

Figure 19. Trees falling into channel, Reach 5

Figure 20. Cut bank behind residences, Reach 6

Figure 22. Piping failure under shed, Reach 6

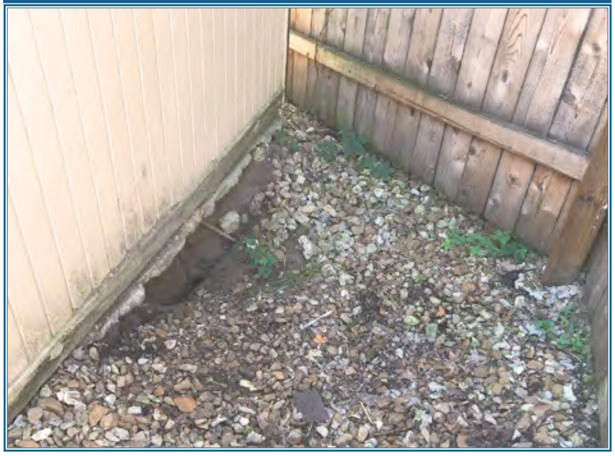


Figure 21. Bank slide failure behind residences, Reach 6

Figure 23. Bank slide failure behind residences, Reach 6

Extensive mass bank wasting in Reach 6 includes a 15-foot cut bank behind 1421 Independence Court (Figure 20), bank slide failure (Figures 21 and 23), and piping failure in the yard at 1421 Independence Court (Figure 22).

6. Reach 6 – CCSM score – 24.6

Reach 6 is the length of stream from the south side of Tonganoxie Road through the proposed project area adjacent to 1421 Independence Court. Evidence exists of extensive mass wasting along this reach that has caused piping to take place in the backyard of 1421 Independence Court. The property owner has attempted to fix the failure by pouring concrete into the hole that has developed next to the existing shed at the back of the property. The cut bank adjacent to this area is approximately 15 feet high. The city also indicated the stream may have been diverted by debris upstream of this location at some point in its history.

As Table 5 shows, all but two of the stream reaches were assigned a "poor" ranking. The CCSM ratings range between 19.2 and 25.6, indicating a stream condition range between fairly stable and significantly unstable. In general, the CCSM rating is negatively impacted by development of the basin. The detailed individual field assessment reports for each of the assessed reaches are found in the appendix to this report.

Table 5: Stream reach rating and ranking

Stream reach	Total rating	Ranking
1	19.2	Fair
2	25.4	Poor
3	22.4	Poor
4	19.2	Fair
5	21.2	Poor
6	24.6	Poor

V. DESCRIPTION OF OPTIONS

The options presented in this study are offered in two sets:

1. **Tributary improvements**: A prioritized list of general streamwide stabilization efforts by reach; and,
2. **Reach 6 improvements**: A set of options for specifically addressing the bank failure along Independence Court.

It was beyond the scope of this study to compare the feasibility of pursuing option set 1 or 2 in an either/or framework.

A. TRIBUTARY IMPROVEMENTS PRIORITIZATION

Based on the CCSM scores, WRS has developed a priority list which will allow the city to systematically phase possible future projects along the tributary. Table 6 presents a prioritization based on the opinions of probable construction cost and project cost. The costs are based on the following:

- $360 per foot of stream for restoration cost plus a 25% contingency for construction cost.
- An additional 25% for engineering and construction administration for project cost.

Because alternatives specific to the Reach 6 project area will be considered separately from the tributary-wide improvement prioritization, the length of the Reach 6 project area has been removed from the total length for Reach 6 in calculating these cost opinions.

Table 6: Opinion of probable construction and project cost

Priority	Reach	Length (ft)	Construction Cost	Project Cost
1	2	275	$ 123,750	$ 154,688
2	1	450	$ 202,500	$ 253,125
3	6	530	$ 238,500	$ 298,125
4	3	685	$ 308,250	$ 385,313
5	5	800	$ 360,000	$ 450,000
6	4	900	$ 405,000	$ 506,250
		Totals	**$ 1,638,000**	**$ 2,047,501**

B. REACH 6 OPTION 1

Option 1 to specifically address the Reach 6 bank failure involves three components:

- Longitudinal peaked stone toe protection (LPSTP) along two bends to protect and restore the bank. LPSTP is a row of stone placed at the bottom of the slope, running parallel with the stream. It armors the vulnerable toe of the bank against further erosion and supports the bank above it while helping stabilize the slope by allowing sediment to deposit behind the stone and rebuild the upper bank over time. The upper bank above the stone toe protection gradually slumps to a stable slope.
- Native vegetative plantings along the banks and stream to stabilize the channel by restoring the root system that helps resist erosion.
- A series of four riprap grade controls in the stream to reduce channel slope and water velocity in the project area and rebuild the scoured banks.

Figure 25 shows the proposed locations of the improvements in Reach 6, Figure 26 shows a typical section drawing of a LPSTP installation, and Table 7 details the opinion of probable construction cost for option 1.

Figure 24. Peaked stone toe protection example

LPSTP has been successfully used to control bank failure in the past at Threemile Creek in 2017 (Figure 24).

Figure 25. Proposed locations of option 1 improvements

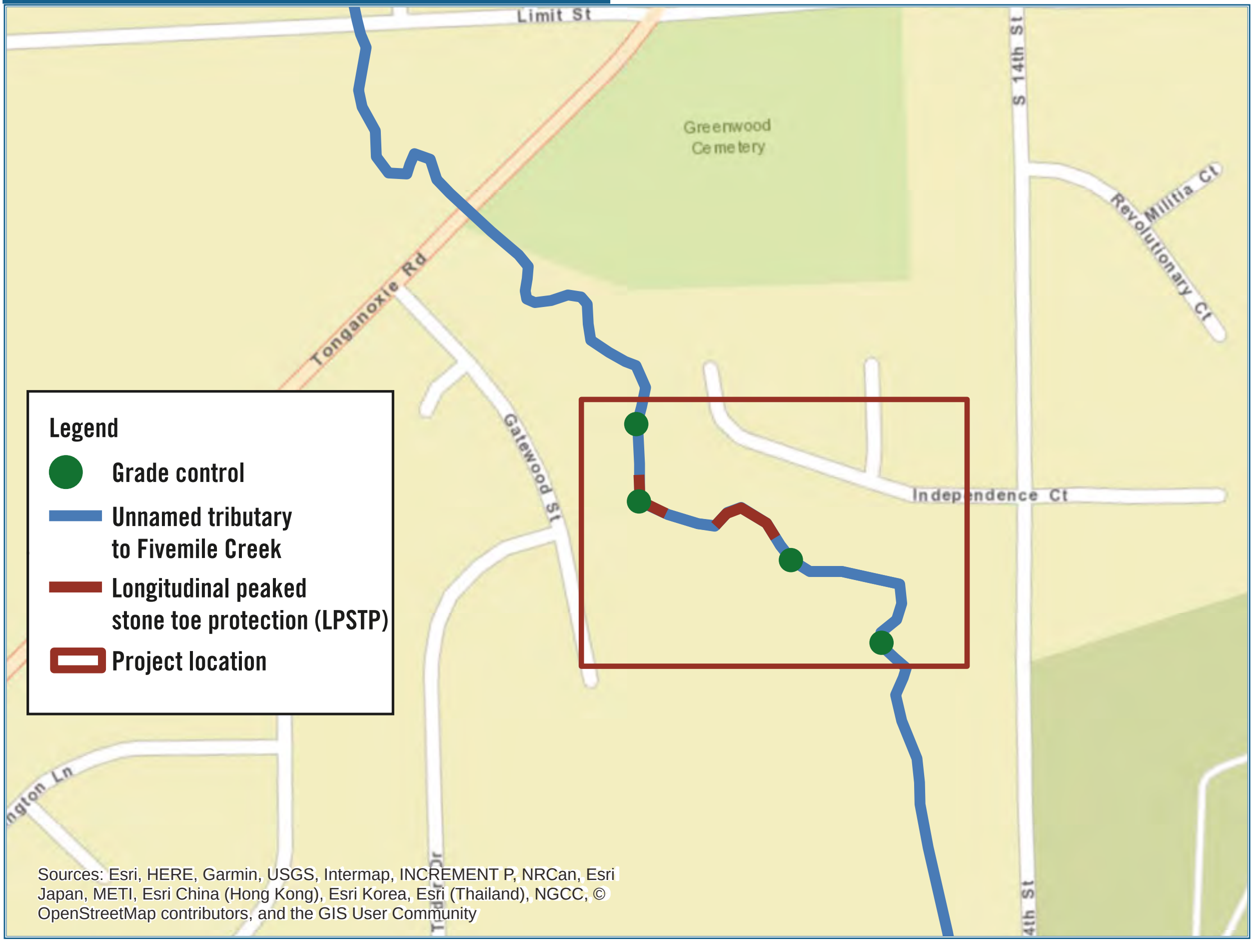


Figure 26. Typical section drawing of LPSTP installation

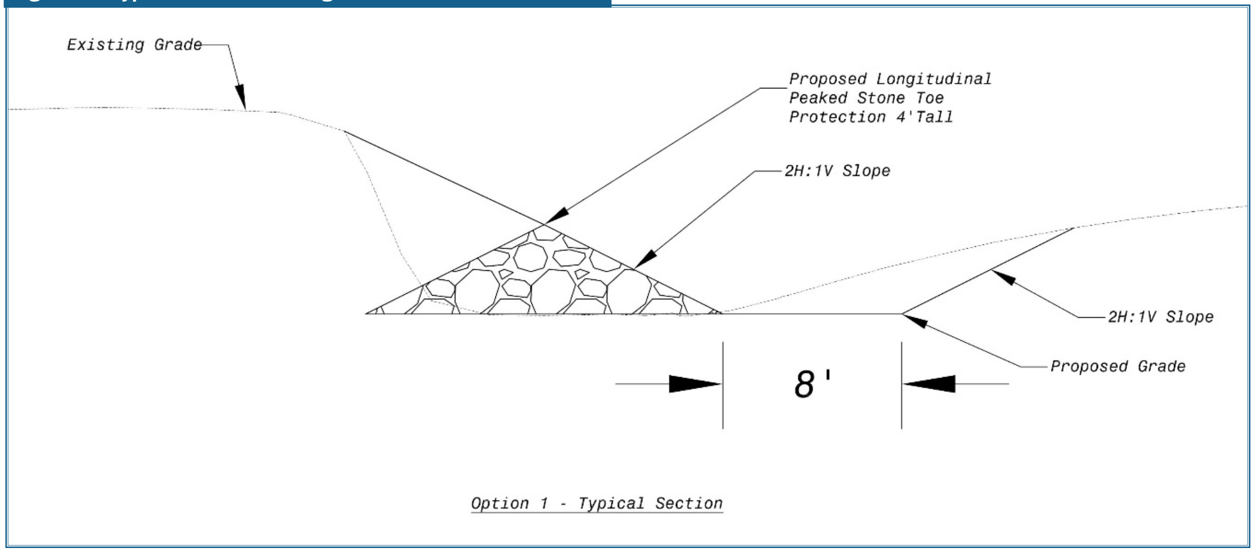


Table 7: Opinion of probable construction and project cost option 1

Item No.	Item Description	Unit	Quantity	Unit Cost		Total Cost	
1	Mobilization	LS	1	$	35,000	$	35,000
2	Clearing, grubbing and demolition	LS	1	$	30,000	$	30,000
3	Erosion and sediment control	LS	1	$	10,000	$	10,000
4	Excavation	CY	400	$	10	$	4,000
5	Embankment	CY	5,000	$	15	$	75,000
4	Longitudinal peaked stone toe protection (LPSTP)	CY	450	$	100	$	45,000
5	Grade control	EA	4	$	30,000	$	120,000
6	Landscaping	SY	8,500	$	7	$	59,500
		Subtotal				**$**	**378,500**
		25% Contingency				**$**	**94,625**
		Design/Consultancy fee (20% of construction)				**$**	**94,625**
				Total		**$**	**567,750**

C. REACH 6 OPTION 2

Option 2 will re-align the stream throughout Reach 6 to an ideal natural meander, or the normal course of curves and loops a stream takes from side to side as it flows across its floodplain. Realignment will keep the stream in equilibrium and reduce further erosion similar to that which is threatening the at-risk properties.

The planform geometry for the option was determined based on studies and summarized in Sour and Thorne (2001). It has been shown that the dimensions of stable natural channels are proportionally related to the stream discharge, and the dimensions of the channel are inter-related. Using HEC-RAS in combination with indicators such as bar height and lower limit of woody vegetation, the bankfull discharge was

Figure 27. Typical section drawing of streambed, option 2

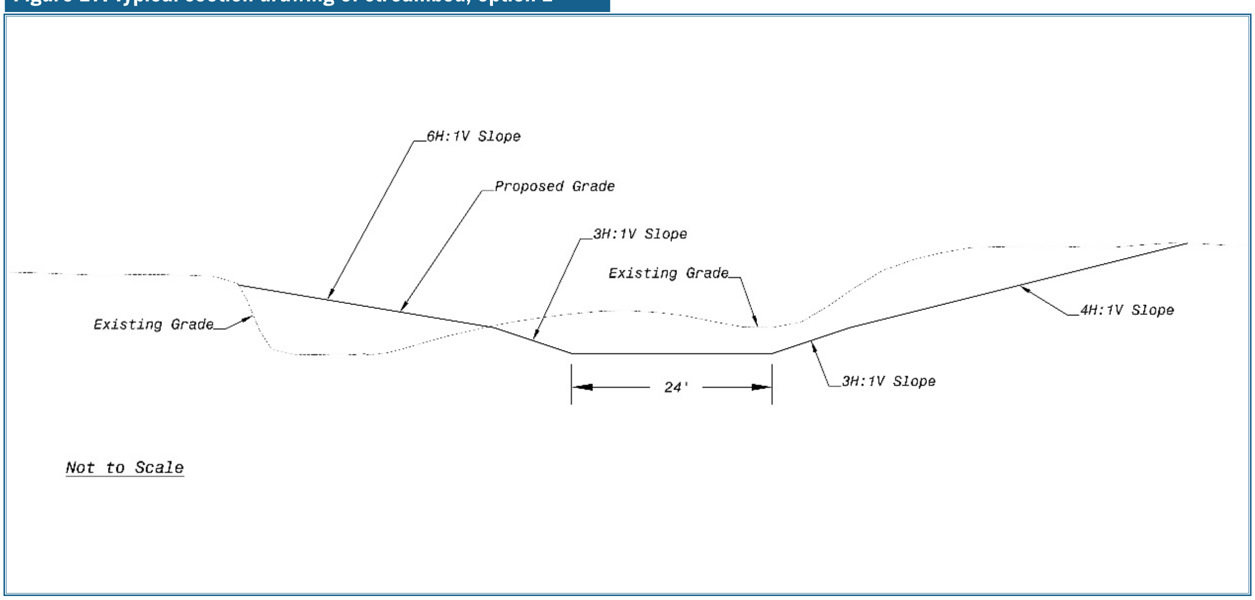


Figure 28. Proposed streambed realignment for option 2

determined to be approximatelyh 2 feet. The stream forming flow at that flow depth was determined to be 350 cubic feet per second. Using the stream chart and aerial photos, an improved stream alignment can be proposed from those figures. Table 8 shows the results of the calculation for the ideal width, length, and radius of curvature for the re-aligned stream meander pattern.

Option 2 will also install four rip-rap grade controls to reduce channel slope and velocity in the project area and rebuild the scoured banks. Vegetative plantings along the banks and stream to help stabilize the channel are also recommended. Figure 28 shows the proposed planform and grade control locations, and

Table 8 : Predicted and observed planform geometry

Variable	Predicted	Observed
W	34’	26'
L	428’	150’
	474’	206'
R_c	85’	50’
	95’	80’

Table 9 details the opinion of probable construction cost.

Table 9: Opinion of probable construction and project cost, option 2

Item No.	Item Description	Unit	Quantity	Unit Cost	Total Cost
1	Mobilization	LS	1	$ 60,000	$ 60,000
2	Clearing, grubbing and demolition	LS	1	$ 50,000	$ 50,000
3	Erosion and sediment control	LS	1	$ 15,000	$ 15,000
4	Excavation	CY	30,000	$ 10	$ 300,000
5	Embankment	CY	15,000	$ 15	$ 225,000
6	Grade control	EA	4	$ 30,000	$ 120,000
7	Landscaping	SY	20,000	$ 7	$ 140,000
		Subtotal			**$ 910,000**
		25% Contingency			**$ 227,500**
		Design/consultancy fee (20% of construction)			**$ 227,500**
		Total			**$ 1,365,000**

VI. RECOMMENDATIONS

This section provides recommendations for the project.

A. EVALUATION OF ALTERNATIVES

The following section discusses the evaluation of each alternative.

1. Tributary improvements prioritization

The analysis of the stream indicates systemic instability is occurring at from 60% to 80% of this tributary that shows bed lowering, bank widening, and mass wasting. Table 6 presents a prioritization for future stream reach improvements based on the opinions of probable construction cost and project cost, ranging from a low of $154,688 to a high of $506,250 for reach 2 and reach 4, respectively.

2. Reach 6 option 1

Option 1 to specifically address the Reach 6 bank failure would install longitudinal peaked stone toe protection (LPSTP) along two bends to armor and restore the failing banks, include vegetative plantings along the banks and stream to stabilize the channel, and install a series of grade controls in the stream to reduce channel slope and water velocity in the project area and rebuild the scoured banks. Option 1 would provide a complete solution to protect the private and public property currently at risk in the project area, at an estimated cost of $567,750.

3. Reach 6 option 2

Option 2 would re-align the stream throughout Reach 6 to an ideal natural meander, to keep the stream in equilibrium and reduce further erosion similar to that which is threatening the at-risk properties. It would provide a complete solution to protect the private and public property currently at risk in the project area, at an estimated cost of $1,365,000. It may require more involved permitting under an individual 404 permit.

B. RECOMMENDED ALTERNATIVE

1. Tributary improvements prioritization

Consideration should be given to those reaches where property and infrastructure may be at risk because of stream instability. Additionally, it is recommended the city clean the 48-inch RCP north of Thornton and repair the 60-inch outlet south of Evergreen.

2. Reach 6 options

In Reach 6 the channel degradation needs intervention to protect private property and city infrastructure. In order to protect the at-risk property, option 1 is the recommended alternative. Although option 2 would provide a more holistic approach, option 1 is a more targeted solution that would provide a complete solution to the project problem, at a cost of 41.5 percent of option 2.

VII. REFERENCES

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VIII. APPENDIX

Reach 1

Stability Indicators	Score	Weight	Rating
Bank Soil Texture and Coherence	1	0.6	0.6
Average Slope Angle	3	0.6	1.8
Average Bank Height	2	0.8	1.6
Vegetation Bank Protection	2	0.8	1.6
Bank Cutting	3	0.4	1.2
Mass Wasting	2	0.8	1.6
Bar Development	1	0.6	0.6
Debris Jam Potential	2	0.2	0.4
Obstruction, Flow Detectors, and Sediment Traps	1	0.2	0.2
Channel Bed Material Consolidation and Armoring	1	0.8	0.8
Sinuosity	3	0.8	2.4
Ratio of Radius of Curvature to Channel Width	2	0.8	1.6
Ratio of Pool-Riffle Spacing to Channel Width at 2-Year Flow Elevation	2	0.8	1.6
Percentage of Channel Constriction	2	0.8	1.6
Sediment Movement	2	0.8	1.6
		Total:	**19.2**

Reach 2

Stability Indicators	Score	Weight	Rating
Bank Soil Texture and Coherence	3	0.6	1.8
Average Slope Angle	3	0.6	1.8
Average Bank Height	2	0.8	1.6
Vegetation Bank Protection	2	0.8	1.6
Bank Cutting	3	0.4	1.2
Mass Wasting	3	0.8	2.4
Bar Development	3	0.6	1.8
Debris Jam Potential	3	0.2	0.6
Obstruction, Flow Detectors, and Sediment Traps	3	0.2	0.6
Channel Bed Material Consolidation and Armoring	3	0.8	2.4
Sinuosity	3	0.8	2.4
Ratio of Radius of Curvature to Channel Width	1	0.8	0.8
Ratio of Pool-Riffle Spacing to Channel Width at 2-Year Flow Elevation	3	0.8	2.4
Percentage of Channel Constriction	2	0.8	1.6
Sediment Movement	3	0.8	2.4
		Total:	**25.4**

Reach 3

Stability Indicators	Score	Weight	Rating
Bank Soil Texture and Coherence	3	0.6	1.8
Average Slope Angle	2	0.6	1.2
Average Bank Height	2	0.8	1.6
Vegetation Bank Protection	2	0.8	1.6
Bank Cutting	2	0.4	0.8
Mass Wasting	3	0.8	2.4
Bar Development	3	0.6	1.8
Debris Jam Potential	2	0.2	0.4
Obstruction, Flow Detectors, and Sediment Traps	2	0.2	0.4
Channel Bed Material Consolidation and Armoring	3	0.8	2.4
Sinuosity	3	0.8	2.4
Ratio of Radius of Curvature to Channel Width	1	0.8	0.8
Ratio of Pool-Riffle Spacing to Channel Width at 2-Year Flow Elevation	2	0.8	1.6
Percentage of Channel Constriction	2	0.8	1.6
Sediment Movement	2	0.8	1.6
		Total:	**22.4**

Reach 4

Stability Indicators	Score	Weight	Rating
Bank Soil Texture and Coherence	3	0.6	1.8
Average Slope Angle	2	0.6	1.2
Average Bank Height	2	0.8	1.6
Vegetation Bank Protection	2	0.8	1.6
Bank Cutting	3	0.4	1.2
Mass Wasting	2	0.8	1.6
Bar Development	1	0.6	0.6
Debris Jam Potential	2	0.2	0.4
Obstruction, Flow Detectors, and Sediment Traps	2	0.2	0.4
Channel Bed Material Consolidation and Armoring	2	0.8	1.6
Sinuosity	1	0.8	0.8
Ratio of Radius of Curvature to Channel Width	3	0.8	2.4
Ratio of Pool-Riffle Spacing to Channel Width at 2-Year Flow Elevation	1	0.8	0.8
Percentage of Channel Constriction	2	0.8	1.6
Sediment Movement	2	0.8	1.6
		Total:	**19.2**

Reach 5

Stability Indicators	Score	Weight	Rating
Bank Soil Texture and Coherence	3	0.6	1.8
Average Slope Angle	3	0.6	1.8
Average Bank Height	3	0.8	2.4
Vegetation Bank Protection	2	0.8	1.6
Bank Cutting	3	0.4	1.2
Mass Wasting	3	0.8	2.4
Bar Development	2	0.6	1.2
Debris Jam Potential	2	0.2	0.4
Obstruction, Flow Detectors, and Sediment Traps	2	0.2	0.4
Channel Bed Material Consolidation and Armoring	1	0.8	0.8
Sinuosity	3	0.8	2.4
Ratio of Radius of Curvature to Channel Width	2	0.8	1.6
Ratio of Pool-Riffle Spacing to Channel Width at 2-Year Flow Elevation	1	0.8	0.8
Percentage of Channel Constriction	1	0.8	0.8
Sediment Movement	2	0.8	1.6
		Total:	**21.2**

Reach 6

Stability Indicators	Score	Weight	Rating
Bank Soil Texture and Coherence	3	0.6	1.8
Average Slope Angle	3	0.6	1.8
Average Bank Height	3	0.8	2.4
Vegetation Bank Protection	3	0.8	2.4
Bank Cutting	3	0.4	1.2
Mass Wasting	3	0.8	2.4
Bar Development	3	0.6	1.8
Debris Jam Potential	3	0.2	0.6
Obstruction, Flow Detectors, and Sediment Traps	3	0.2	0.6
Channel Bed Material Consolidation and Armoring	2	0.8	1.6
Sinuosity	1	0.8	0.8
Ratio of Radius of Curvature to Channel Width	3	0.8	2.4
Ratio of Pool-Riffle Spacing to Channel Width at 2-Year Flow Elevation	1	0.8	0.8
Percentage of Channel Constriction	2	0.8	1.6
Sediment Movement	3	0.8	2.4
		Total:	**24.6**

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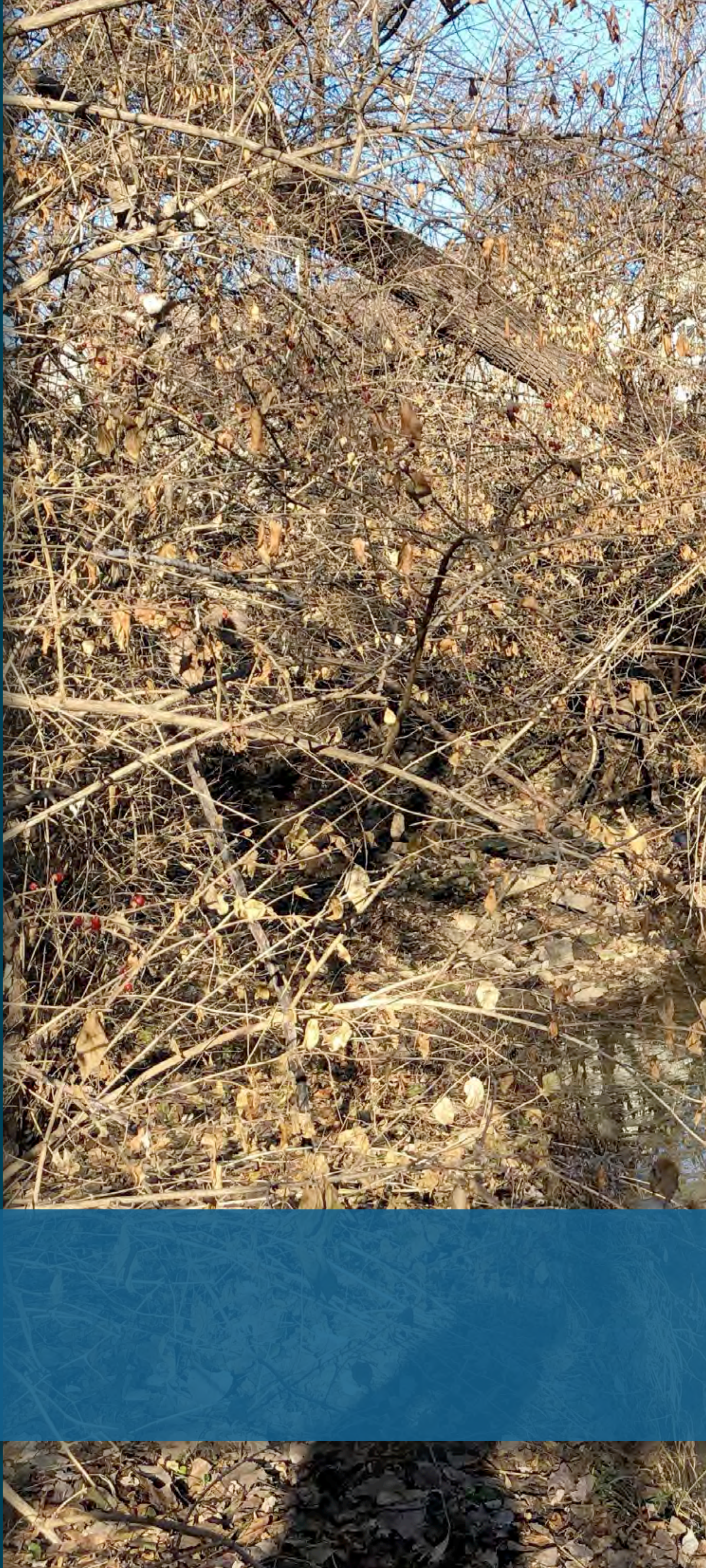

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