Feasibility Report

Bluff Creek Reach 5 Ecological Enhancement Plan

June 2022

Prepared for
Riley Purgatory Bluff Creek Watershed District

RILEY
PURGATORY
BLUFF CREEK
WATERSHED DISTRICT

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Appendix C Soil Test Results from Streambanks

Certifications

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the Laws of the State of Minnesota.

Scott Sobiech PE #: 41338

June 26, 2022

Date

1.0 Context and Goals for this Ecological Enhancement Plan

This document was written to guide enhancement and stewardship efforts of ecological resources within Reaches B5A-B5C of Bluff Creek (Project) as shown on Figure 1-1. A cooperative agreement between the RPBCWD and City will need to be developed for activities related to construction and maintenance of a resulting project. This Ecological Enhancement Plan documents the goals of the potential partnership for the Bluff Reach Restoration Project and establishes potential roles and responsibilities of Project partners for the estimated 20-year life of the agreement.

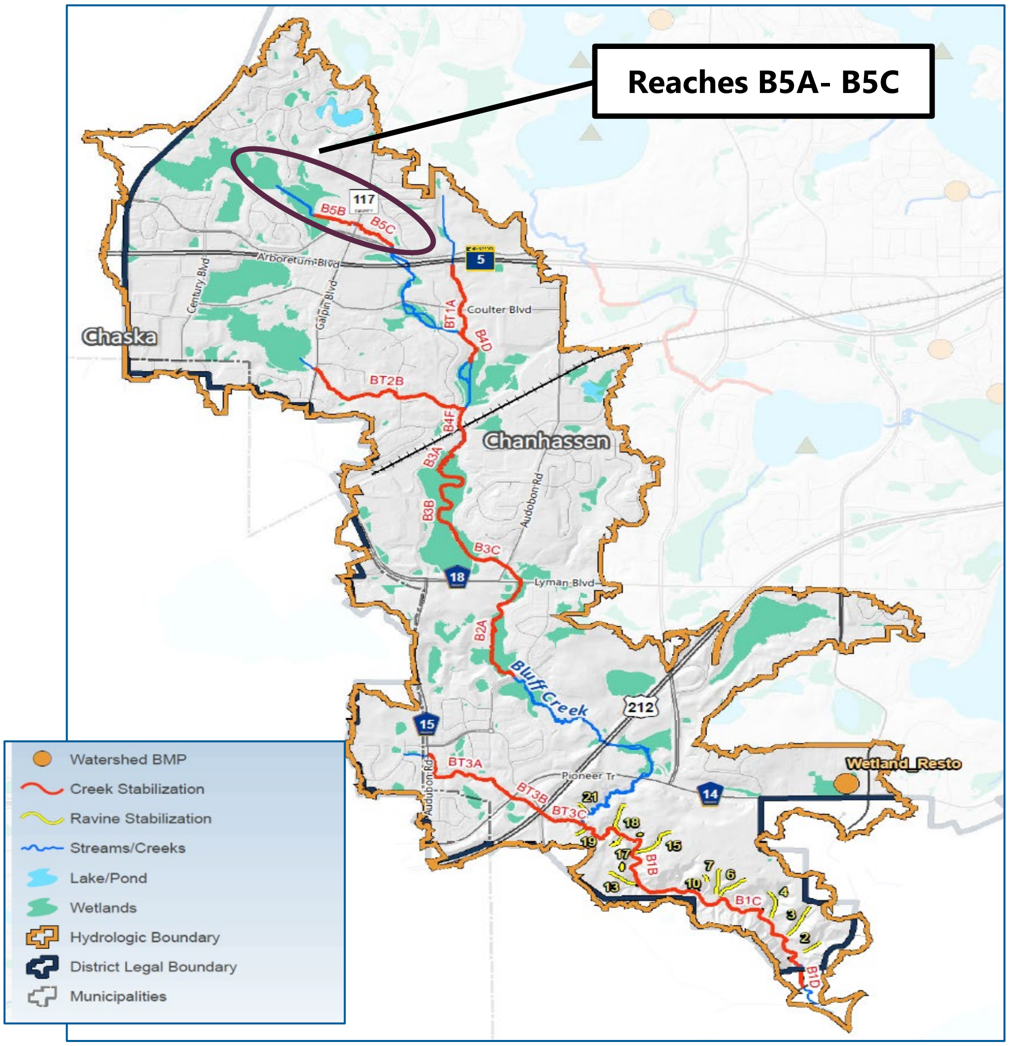

Figure 1-1 Location of Reach B5A-B5C of Bluff Creek Restoration Project

2.0 Vision, Goals, and Project Approach

Streams were identified in the 10-year plan public survey as being important to a majority of the citizens within the District. When ranking resource importance within the District, Bluff Creek was ranked seventh out of the 20 resources listed with nearly 30% of the respondents identifying the resource. In addition to the public survey, a watershed summit was held within each major watershed (Bluff Creek, Riley Creek, and Purgatory Creek). Comments related to erosion provided during the District's public engagement process include:

- Understanding the impact of shallow groundwater and development on bluff and steep slope stability
- Stabilizing streambanks and restoring channel meandering
- Reducing sediment loading to creeks, lakes, and wetlands

Concerns identified for Bluff Creek related to water quality and quantity as summarized in Table 2-1.

Table 2-1 Stakeholder Identified Streambank Issues

Creek	Water Resource Issue Category	Specific Issues
Bluff Creek	Water Quality (Erosion)	Areas of severe streambank erosion
	Water Quantity	Impact of development on streamflow in Bluff Creek

The District has several mechanisms to address the concerns presented in Table 2-1, including implementing its cost share program, capital projects, and regulatory program. The District's plan established goals intended to protect, restore, and enhance water resources. Table 2-2 provides a summary of how the Project aligns with these goals.

Table 2-2 Summary of Partner Goals and Project

Partner	Goals[1]	How Project Aligns with Goal
RPBCWD	Design, maintain, and implement Education and Outreach programs to educate the community and engage them in the work of protecting, managing, and restoring water resources. (EO 1)	The project will educate those living nearby and recreational users in the area about the project and inform them of stewardship ideas that they can implement.
	Include sustainability and the impacts of climate change in District projects, programs, and planning.	The District will use sustainable materials to the extent practicable as part of the project.
	Protect, manage, and restore water quality of District lakes and creeks to maintain designated uses. (WQual 1)	The project would restore the portions of Reach B5 of Bluff Creek and the associated headwater wetland.
	Preserve and enhance the quantity, as well as the functions and values of District wetlands. (WQual 2)	Restoration of the headwaters wetland to restore the wetland and creek hydrology as well as improve floodplain storage. The vegetation management will also support increased wetland functions and values.
	Preserve and enhance habitat important to fish, waterfowl, and other wildlife. (WQual 3)	The project will enhance the creek corridor, which includes both terrestrial and aquatic habitats. The project will enhance the aquatic habitats by stabilizing eroding streambanks. Furthermore, the project will reduce habitat fragmentation by reconnecting the creek with the terrestrial uplands. Restoration of the headwater wetland will also improve habitat.
	Protect and enhance the ecological function of District floodplains to minimize adverse impacts. (WQuan 1)	The project will reconnect the creek to the floodplain, which will also help increase of pollutant removal, promote infiltration, and enhance the ecological habitat.
	Limit the impact of stormwater runoff on receiving waterbodies. (WQuan 2)	The project will dissipate the energy of stormwater runoff entering the creek at several culvert outfalls within the creek reach. The wetland restoration will also reduce the flashiness of creek flows thereby enhancing channel stablity

[1]Based on Planning for the Next Ten Years, 2018-2027 document (1)

This plan intends to adopt an adaptive management approach to restoring this reach of Bluff Creek. An adaptive management approach evaluates the project performance following implementation and then determines if further actions are necessary to maintain the restoration.

This assessment looks to enhance the creek's and headwater wetland ecological values and functions, mitigate and prevent additional erosion of streambanks, and foster the use of natural materials and bioengineering principals for the restoration and maintenance of stream segments whenever feasible. Technical stakeholders, including the USACE and MnDNR, have expressed a preference for bioengineering over hard armoring for stream stabilization where possible. Bioengineering techniques maintain more of a stream's natural function and provide better habitat and a more natural appearance than hard armoring.

This study was completed to examine the feasibility of completing stream and wetland restoration projects on one segment of Bluff Creek within the City of Chanhassen, called B5. There are several factors that prioritized the assessment of this reach, summarized as follows:

- The 2018 Plan (Reference (1)) included this site a potential restoration location as part of the 10-year capital improvement program. The potential restoration was ranked using the District's prioritization metric which resulted in the score summarized in Table 2-3.

Table 2-3 Bluff Creek Reach B5 Project Benefit Score(1)

Goal Index	Sustainability Index	Volume Management Index	Pollutant Management	Stabilization	Habitat Restoration	Partnership	Education	Watershed Benefit	Total Benefit Score
3	7	1	1	7	7	1	3	7	**37**

Note:
(1) See Section 4 of 10-Year Watershed Management Plan for additional details about the RPBCWD prioritization methodology and associated descriptions for the variables used to assess multiple project benefits.

- Bluff Creek was identified as being impaired for turbidity along its entire length within the Riley Purgatory Bluff Creek Watershed District (District) (Reference (2)).

- The 2015 Creek Restoration Action Strategy Assessment (CRAS) (Reference (3)) prioritized stream segments within the District for stabilization. A subsequent 2020 update by RPBCWD staff further evaluated this reach of Bluff Creek. Reach B5C, included in this feasibility study, was identified as degraded and among the highest priorities for stabilization and/or restoration.

- The 2018 Plan (Reference (1)) includes a specific goal to preserve and enhance the quantity, as well as the function and value of wetlands. In addition, the citizens who reside within the District boundaries also place a high value on wetlands. Of the 408 respondents to the Riley Purgatory Bluff Creek Watershed District Community Survey, 176 of them considered wetlands to be one of the most valuable water resources. This was second most selected water resource among all choices.

The vision for this Project is to provide an ecologically diverse stream reach that significantly reduces streambank erosion, provides diverse habitat layers, improves the ecological functions, and enhances the public's access and their understanding of why stable stream systems are important while providing improved inspection and maintenance access. The following activities were performed during the development of this plan to identify feasible restoration alternatives:

- Identifying areas of erosion and prioritizing areas for restoration.
- Estimating erosion rates and potential for cost per pound of phosphorus reduction that could be achieved through a stabilization project.
- Fostering the use of natural materials and bioengineering principals for the restoration and maintenance of stream segments whenever feasible.
- Enhancing the creek's ecological values and functions as defined by the Stream Quantification Tool for Minnesota.
- Developing preliminary feasibility-level design concepts and opinions of probable cost to assist with future planning and restoration efforts.

3.0 Location and Land Use History

3.1 Location

Reach B5A encompasses the headwaters of Bluff Creek which originates in the wetland complex between Highway 41 and Galpin Boulevard (Figure 3-1) and is primarily contained on property owned by the City of Chanhassen. Reach B5B is near the headwaters of Bluff Creek and is composed of the channel approximately 985 feet immediately upstream of Galpin Boulevard and ends at Galpin Boulevard. The reach is on private property but is located in an outlot that has been placed in a conservation easement with the city of Chanhassen.

Reach B5C is composed of the channel between Galpin Boulevard and ends at West 78th Street. It has a watershed area of 454 acres and is located on city owned property. Reach B5C on property owned by the City of Chanhassen.

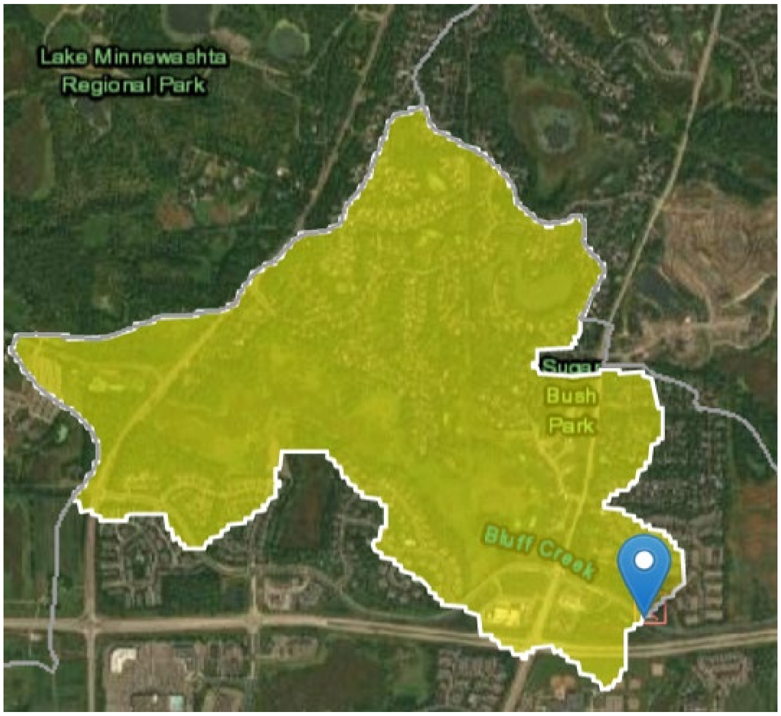

Figure 3-1 Bluff Creek Reach B5A-B5C watershed area

3.2 Land Use History

Prior to European settlement, the entire Bluff Creek watershed was located in an ecoregion known as the Big Woods, where oak woodland and maple-basswood forests were the dominant vegetation types. As settlement occurred, much of the landscape was initially converted to farmland. Between the early 1900's and late-1990's, the contributing watershed to Bluff Creek was primarily agricultural. The upper portions of the creek channel appear to have been straightened prior to 1945. Due to the quality of the 1937 photo it is difficult to conclusively determine if the channel was straightened prior to 1937.

As urban development spread outwards from the Minneapolis core, areas of farmland then became converted to urban and suburban landscapes (see 1991, 2002 and 2020 photos in Appendix A). This conversion continues in some of the undeveloped areas of Bluff Creek watershed. The current land use in the contributing watershed is mostly single family residential, although there are also some areas of multi-family residential with a remnant forest along Reach B5C of Bluff Creek.

4.0 Assessment of Existing Conditions

Reach B5A was a wetland prior to ditch construction over a century ago. As part of this assessment, aerial photos, soil maps, and other data were examined to better quantify soil inputs from bank erosion throughout the system. Historical aerial photos, soil maps, and the Minnesota Restorable Wetland Inventory in Reach B5A were also examined to characterize wetland restoration potential for water storage benefits downstream.

There is some bank erosion along much of Reach B5B, however it appears to still be connected with its floodplain. The lower third of this reach has taller banks with more active erosion but the channel does not appear to be significantly incised. The erosion is primarily on the banks and appears to be a response to the confined nature of this portion of the channel, which has less access to its floodplain. The banks within this portion of the reach are 3 to 5 feet tall. There is agricultural debris located in the left overbank. The upper third of the reach includes banks that are 1- to 3-feet tall and has a wide, active floodplain. This portion of the reach has minor erosion but appears to be historically straightened since at least 1945 (see Figure 4-1). Meander patterns typically redevelop in reaches that have been straightened, and there is evidence that such a phenomenon is occurring in this reach as erosion locations alternate between each bank. The channel in this reach has an average slope of approximately 0.25%, which is a relatively low slope that helps keep velocities low.

Figure 4-1 Incised and straightened channel in Sub-Reach B5B

Reach B5C starts at a culvert through Galpin Road on the west end of the reach and ends at a bridge crossing on the southeast end of the reach. The stream is small, at less than one-half mile from the start of Bluff Creek in Reach B5A. The dimensions range from about 1 to 2 feet bankfull height with total bank heights of 2 to 6 feet and width of about 6 to 12 feet (see Figure 4-2). The channel slope was estimated at about 0.75% slope. It fits best into the Rosgen B5C type which is a moderately steep, slightly entrenched and low sinuosity stream (Rosgen 1996) (Reference (4)). The bed was a mixture of fine sediment, sand, and some gravel. The stream may have been a Type E5 prior to development. It likely evolved from increased runoff to become more entrenched with lower sinuosity. Currently the sinuosity is 1.2 while E type streams have greater than 1.5 sinuosity.

Currently there are sediment sources from four gullies entering on the north side of the stream from the apartment building area, as well as active bank erosion sources. The channel is slightly entrenched leading to higher bank heights than existed prior to development.

Figure 4-2 Bluff Creek typical section of Bluff Creek, Reach B5C, July 2021.

4.1 Creek Restoration Action Strategy (CRAS)

The 2015 CRAS Report (Reference 3), along with additional assessment by RPBCWD staff in 2020, evaluated segments of all creeks in the watershed by dividing the key categories for prioritizing restoration efforts into two tiers. The first tier was defined as consisting of categories that affect public health and safety, align with the goals in the District's Plan, and represent the key reasons why restoration projects are undertaken. These categories include: infrastructure risk, erosion and channel stability, ecological benefit, and water quality. Each category was assigned a score of 1, 3, 5, or 7 such that a score of 1 was best (i.e., no degradation) and a score of 7 was worst (i.e., significant degradation). The second tier of categories include those that provide supporting benefits to stream restoration, including watershed benefits, public education, partnership opportunities, and project cost per pound of phosphorus.

The 2015 CRAS report identified Reaches B5B and B5C as being in the top tier for prioritizing restoration projects with a Tier 1 score of 22 and 24 , respectively, of a possible 28 (see Table 4-1). Reach B5C was rated as "severe" for erosion/channel stability and water quality and "high" for risk to infrastructure and ecological benefits. Although the 2015 CRAS identified Reaches B5B and B5C as a degraded stream segments, the scope of the CRAS did not evaluate stream degradation causes or identify viable restoration alternatives. RPBCWD staff walked Reach B5C again in 2020 to further evaluate surface erosion, channel processes, and habitat. The updated field assessments yielded updated CRAS scores, which are also listed in Table 4-1. While there was a slight reduction in the Tier 1 score due to a change in water quality, the results continue to identify Reach B5C as serve suggesting this reach should continue to be high priority for restoration or stabilization.

Table 4-1 CRAS Tier I Scores for Reach B5C

Reach	Description	Infrastructure	Erosion/ Channel Stability	Ecological Benefits	Water Quality Summary	Tier I Score	Tier I Priority
B5A (2015)	Ridgeview Road Recreational Trail to 985 feet Upstream of Galpin Boulevard	1	1	7	7	16	Low
B5B (2016)	985 Feet upstream of Galpin Blvd to Galpin Blvd	3	5	5	7	20	High
B5C (2015)	Galpin Blvd to West 78th Street	5	7	5	7	24	Severe
B5C (2020)	Galpin Blvd to West 78th Street	5	7	5	5	22	Severe

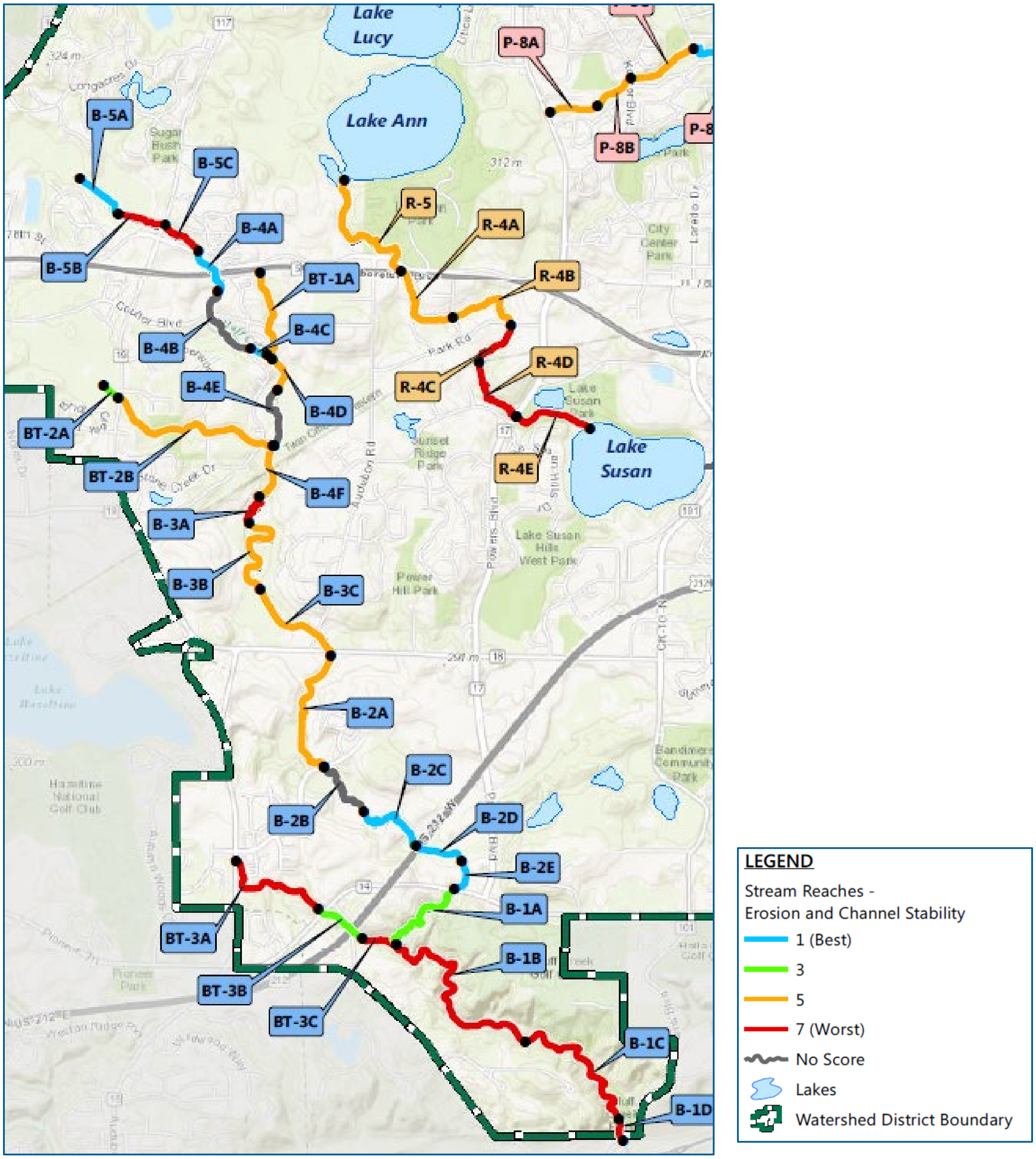

Figure 4-3 Bluff Creek erosion and channel stability rankings

Reach B5B and B5C had a channel stability rating of "worst" according to the 2015 CRAS report as indicated by the red color on Figure 4-3. Worst indicates that the channel is the most unstable compared to other stream reaches in the same watershed. The watershed upstream of this reach is a combination of partially drained wetland and residential subdivisions with little potential source for surface soil erosion suggesting a majority of the sediment in this reach originates from channel erosion.

4.2 Water Quality Impairments

States must develop a list of impaired waters that require total maximum daily load (TMDL) studies and routinely coordinate with the U.S. Environmental Protection Agency (USEPA) for study approval. A TMDL study identifies the maximum amount of a certain pollutant that a body of water can receive without violating water quality standards and allocates that amount to the pollutant's sources. The MPCA maintains a list of impaired waters for the state of Minnesota. A creek is considered impaired if it fails to meet one or more of the state's water quality standards presented in Table 4-2.

Table 4-2 MPCA Water Quality Standards for Creeks

Water Quality Parameter	MPCA Water Quality Standard
Total Phosphorus (summer average, µg/L)	100
Chlorophyll *a* (summer average, µg/L)	18
Secchi Disc Transparency (summer average, m)	NA
Total Suspended Solids (mg/L)[1]	30
Dissolved Oxygen (mg/L)	3.5
Biological Oxygen Demand (5 day) (mg/L)	2
Escherichia coli (# per 100 mL)	126
Chloride (mg/L)	230

[1]To achieve the MPCA total suspended solids (TSS) stream water quality standard, a stream may not exceed 30mg/L TSS more than 10% of the time.

The *Bluff Creek Total Maximum Daily Load (TMDL): Biological Stressor Identification* report (TMDL Report) (Reference (2)) identified multiple biological stressors on Bluff Creek, including Total Suspended Sediment (TSS) loads. High TSS loads to the creek can come from both watershed and near-channel sources. <u>The TMDL report identified near-channel sources as the primary source of sediment in upper Bluff Creek.</u>

RPBCWD placed an automated water-sampling unit on Bluff Creek at the culvert passing under Galpin Boulevard in 2019 (i.e., downstream end of B5B) and at the downstream end of Reach B5C in 2021, to better quantify rain event nutrient loading. The following water quality parameters were collected:

- Total phosphorus (TP; mg/L),
- Total dissolved phosphorus (TDP; mg/L),
- Total suspended solids (TSS; mg/L).

Based on the results of the district's recent monitoring efforts, as described below and summarized in Table 4-3 and Table 4-4, Reach B5C does not achieve the MPCA water quality standards (Table 4-4Table 4-2).As such, the creek discharges water with excess nutrient and suspended solids to downstream waterbodies. The 2021 data showed continued impairment for phosphorus and sediment as indicated by TSS data.

Table 4-3 2019 Bluff Creek Water Quality Sampling Summary at Galpin Boulevard (Downstream of Reach B5B) (5)

Parameter	Minimum	Maximum	2019 Average	MPCA Water Quality Standards
TP (mg/L)	0.154	1.77	0.525	≤ 0.1mg/L
TDP (mg/L)	0.025	0.237	0.135	-
Chl-a (ug/L)	3.34	24	11.562	≤ 18ug/L
TSS (mg/L)	5	800	84.625	≤ 30mg/L

Table 4-4 2021 Bluff Creek Water Quality Sampling Summary Downstream of Reach B5C

Parameter	Minimum	Maximum	2021 Average	MPCA Water Quality Standards
TP (mg/L)	0.08	1.80	0.26	≤ 0.1mg/L
TDP (mg/L)	0.03	0.20	0.09	-
Chl-a (ug/L)	1.00	75.00	7.16	≤ 18ug/L
TSS (mg/L)	1.00	88.00	9.83	≤ 30mg/L

The TDP and TP concentrations measured at the Galpin Boulevard crossing in 2019 are shown on Figure 4-4. The dashed line represents the MPCA's TP standard in Class 2B creeks (≤0.1 mg/L). The average TP across the 17 samples collected in 2019 was 0.525 mg/L. This level is about five times the MPCA eutrophication water quality standard for class 2B creeks (≤0.1 mg/L). As shown in Figure 4-4, none of the TP samples achieved the standard, and this reach of Bluff Creek is considered to be in poor health. These trends continued in 2021, though, the average concentration of TP was lower at 0.26 mg/L. Flow levels were lower than average possibly because it was a dry year. TDP represents a smaller faction of the TP, about 1/4 to 1/3, suggesting that most of the phosphorus is from sediment.

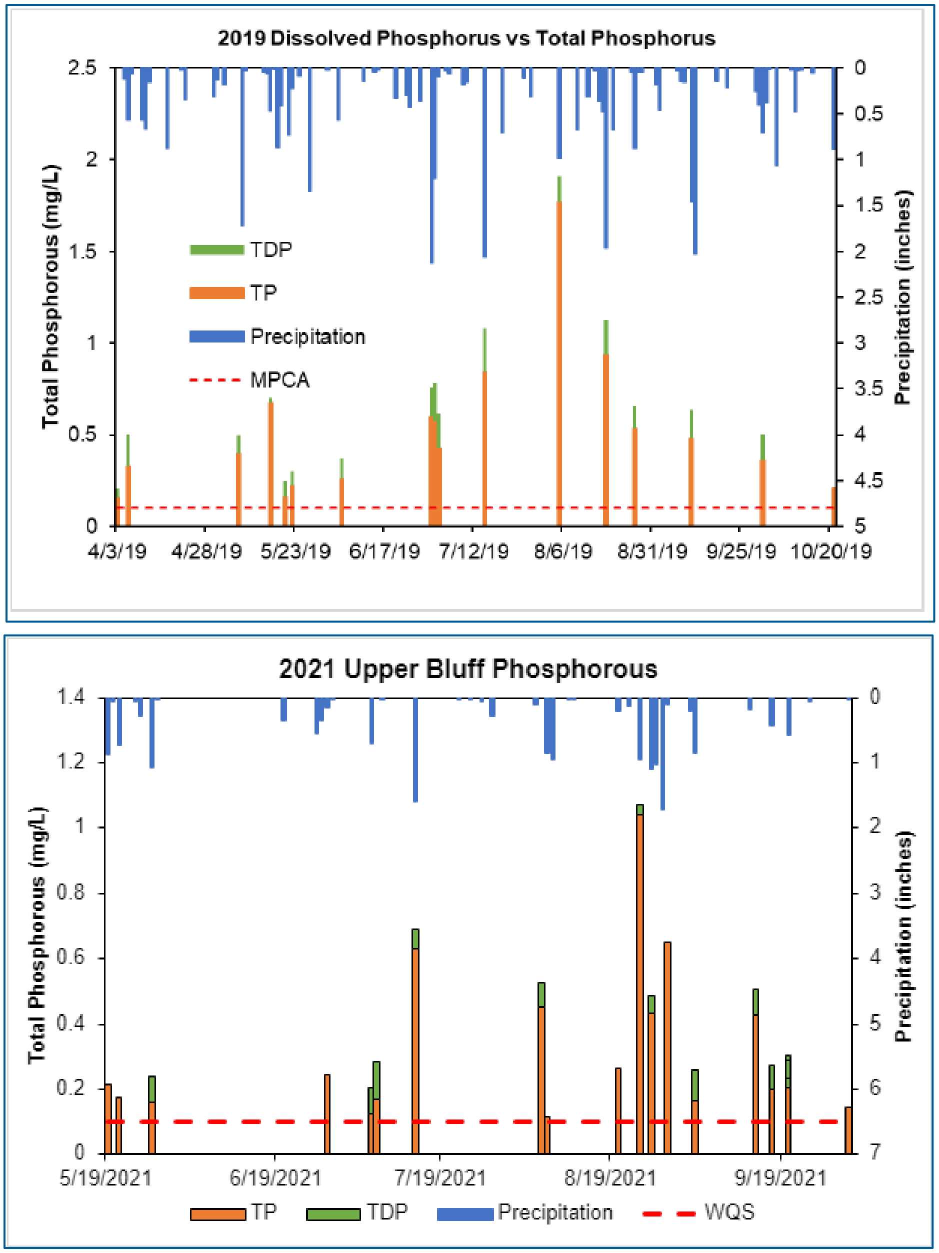

Figure 4-4 Bluff Creek TP and TDP Measurement at Galpin Avenue (2019) and 78th Street (2021) (5)

TSS concentrations measured at the Bluff Creek/Galpin Boulevard crossing in 2019 are summarized in Figure 4-5. The dashed line represents the MPCA's standard for TSS in Class 2B creeks (≤30 mg/L TSS no more than 10% of the time). Roughly 50% of the 17 samples taken in 2019 fell below the 30 mg/L TSS standard, thus confirming the creek reach upstream of Galpin Avenue is in poor health. In 2021, TSS also exceeded the standards more than 50% of the time, indicating poor water quality from high levels of sediment in the stream.

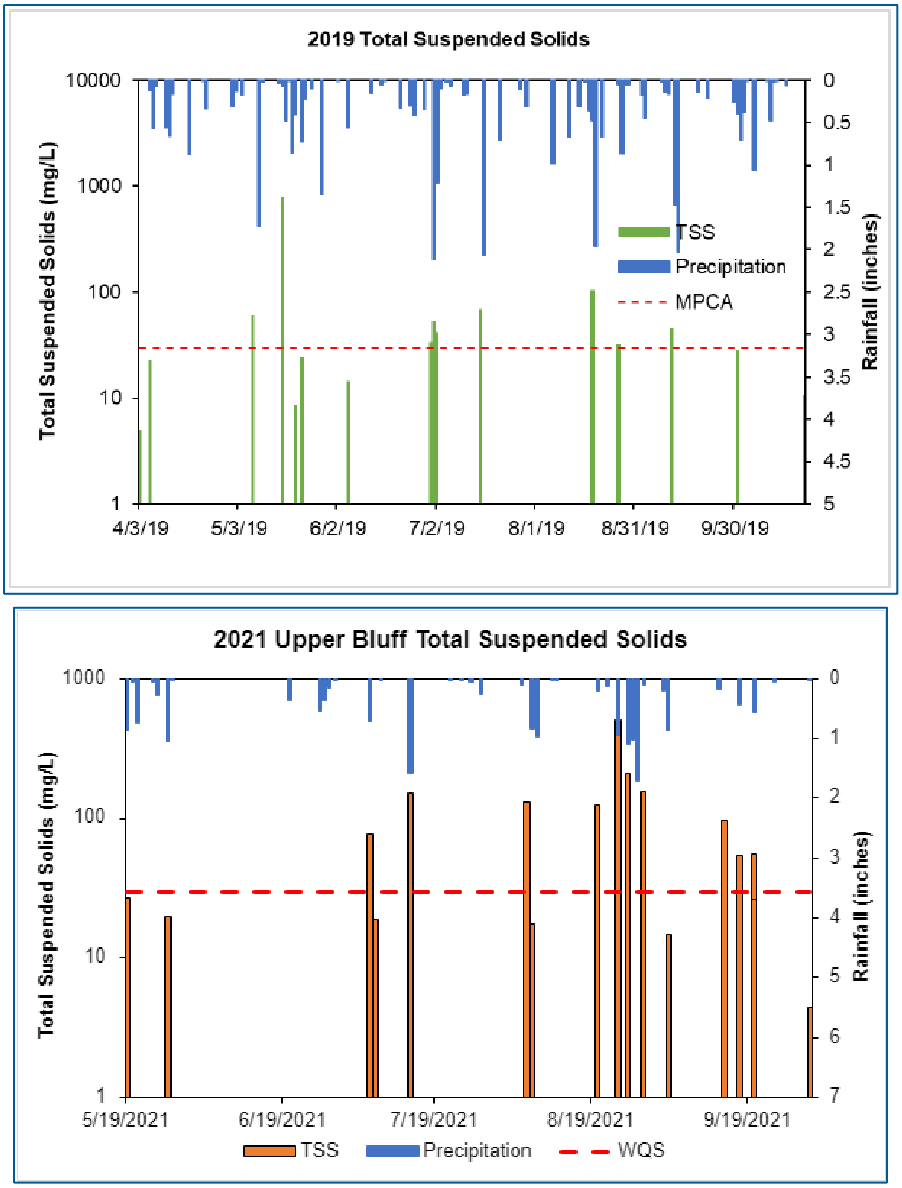

Figure 4-5 Bluff Creek TSS Measurements at Galpin Boulevard (2019 above and 2021 below)

4.3 Habitat

The habitat conditions of the reach were assessed by RPBCWD with the Minnesota Stream Habitat Assessment (MSHA) protocol developed by the MPCA. MSHA provides a worksheet for collecting data on watershed land use, riparian quality, bank erosion, stream substrate type and quality, in-stream cover, and several channel morphology characteristics of an identified reach (MPCA, 2014) (Reference (6). Each reach is assigned a score out of 100 points based on these characteristics. The lower the habitat rating, the more degraded the habitat was in a particular sub-section, resulting in greater potential benefit that could be gained from a restoration project. Ecological benefit scoring criteria are included in Table 4-5.

Table 4-5 CRAS Ecological Benefit Scoring Criteria

CRAS Score	MSHA Score	Habitat Quality
1	76-100	Excellent
3	51-75	Good
5	26-50	Fair
7	1-25	Poor

RPBCWD Staff assessed the habitat conditions based on the Minnesota Stream Habitat Assessment (MSHA) protocol developed by the MPCA, and the rating was poor to fair. In general, these reaches scored well on shade and cover in the channel, including large woody debris in the channel which creates excellent habitat; and they scored poorly on bank erosion and bed substrate lacking a diverse mix of sizes of sediment. The sediment was dominated by clays, silts, and other fine materials which are not good for a diverse in-stream fauna population. Adjacent land-use included a forested buffer through the valley with a housing development with lawn grass to the north about 50 yards. Table 4-6 summarizes the MSHA rating.

Table 4-6 MSHA habitat ratings for each sub-reach

Reach	Description	Habitat Quality	MSHA Score	CRAS Score
B5A	Ridgeview Road Recreational Trail to 985 feet Upstream of Galpin Boulevard	Fair	31.5	5
B5B	985 Feet upstream of Galpin Blvd to Galpin Blvd	Poor	21.5	7
B5C	Galpin Blvd to West 78^{th} Street	Fair	44.6	5

An electroshocking survey was done by Barr in 2015 for approximately 1 hour in Reach B5C. Fish species found in the electroshocking survey of Reach B5 on July 7, 2015 included three common native stream fishes, brook stickleback, fathead minnow, and creek chub. Reach B5C is not flowing more than 80% of the time, though small pools may remain to support fish and they move at high flows The findings suggest that there is minimal aquatic life diversity (only three species). This is likely due to the intermittent flow conditions, potentially poor connectivity to more permanent waters and poor bed conditions, dominated by fine sediments with a lack of gravel/cobble bed supporting fish and invertebrate habitat. The findings from the fish survey support the Creek Restoration Action Strategy score for Ecological Benefits of restoration since there were only three fish species, this suggests a strong need for habitat restoration.

4.4 Stream Geomorphic Assessment

Sediment delivery from the watershed to a stream is a natural process that occurs in all watersheds; however changes to the watershed change the dynamics of sediment delivery to and through the stream system. The basic processes driving sediment loading to a stream can be broken down into three categories: surface erosion processes, hydrologic processes, and channel processes. Each of these processes is summarized in this section.

4.4.1 Surface Erosion Processes

Surface erosion comes directly from the land surface and includes sediment that comes from both natural and impervious surfaces. It also includes mass wasting of hillslopes that contribute a significant amount of sediment directly into a drainage way or stream. While there is streambank erosion along Bluff Creek, the nature of the erosion is consistent with channel processes rather than mass wasting of a slope.

Surface erosion on natural surfaces is dependent on the watershed slope and the vegetation. Areas of a watershed that are unvegetated or poorly vegetated (e.g., fallow fields, development sites) will erode more and contribute more sediment than areas that are well vegetated. The watershed tributary to Reach B5C is relatively flat and well vegetated, with seemingly minimal natural erosion from hillslopes.

The contributing watershed can play both a direct and indirect role in sediment delivery from surface erosion to the channel. Direct sediment delivery primarily includes sediment carried in runoff from impervious surfaces or eroded from land surfaces (usually unvegetated or poorly vegetated slopes) in the watershed. Direct sediment delivery can also include other sources, such as construction activities or agricultural land uses. Parking lots which are sanded in the winter can also contribute large quantities of sediment to the stream if they are not appropriately treated with best management practices (BMP).

The P8 Urban Catchment model was used to understand the total loading of sediment and phosphorus from watershed sources of phosphorus. The modeling results were compared to values from the MPCA Stormwater Manual (Reference (7))and estimated from monitoring data provided by the RPBCWD watershed district. The drainage area of the site at Bluff Creek at the downstream end of Reach B5C at 78th Street is 0.67 square miles (454 acres) while at the wetland outlet at Galpin the watershed is 0.53 square miles

In 2011, a P8 model was developed as a component of the *Bluff Creek Total Maximum Daily Load (TMDL): Biological Stressor Identification* report (TMDL Report) (Reference (2)) using rainfall and precipitation data from 1990 to 2008. To understand the current loading and existing conditions of Bluff Creek, the P8 model was updated using rainfall and precipitation data from 2011 to 2021.

P8 modeled loading results can be viewed as the contribution from the subwatershed runoff. Loading results were first analyzed for Bluff Creek Reach B5C, defined as the stretch of creek between Galpin Venue (upstream) and 78th Street (downstream). P8 results indicate an existing total phosphorus loading of approximately 42 pounds per year (lbs/yr) and total suspended solids loading of 12,800 lbs/yr (6.4 tons) from this reach. P8 modeling results also indicated that the total watershed loading to creek at 78th Street (downstream end of Reach B5C) is 164 lbs/yr of total phosphorus and 26,000 lbs/yr (13.0 tons/yr) of total suspended solids, thus 122 lbs/yr of phosphorus appear to be conveyed to the creek from areas upstream of Galpin Avenue (i.e., Reach B5A and B5B).

P8 was also used to estimate the watershed loading leaving the wetland along Reach B5A. It is important to note that P8 simplifies the complex processes in a wetland to estimate pollutant removal based solely on the settling dynamics of the inflowing sediment and is best used as a tool to compare relative differences rather than absolute values unless extensive calibration is conducted. P8 results indicate that the wetland is estimated to receive 161 lbs/yr of phosphorus and could potentially remove 51 lbs/yr of phosphorus. Therefore, the wetland, which was historically ditched, is estimated to remove approximately 30% of the annual total phosphorus load. For total suspended solids, P8 results indicate that the wetland receives 39,170 lbs/yr of total suspended solids (19.5 tons/yr) and removes 27,300 lbs/yr of total suspended solids. Therefore, the wetland has a predicted annual total suspended solids removal rate of 70%.

In comparison, the MPCA's MN Stormwater Manual (Reference (7) indicates a typical phosphorus-loading value for low-density residential is 1.1 lbs/acre/year while native grass averages a phosphorus load of 0.1 lbs/acre/year. The watershed area at the wetland outlet is 340 acres, with 50% residential and 50% native cover. This results in an estimated phosphorus loading 200 lbs/yr (±30 lbs), which was slightly more than the P8 model estimates. Phosphorus loading was also estimated using the water quality data collected by RPBCWD (Figure 4-4 and Figure 4-5) and flow duration predictions from Streamstats. This comparison method yielded an estimated load of 160 to 330 lbs/year of phosphorus. Because these comparison values are higher than the P8 model estimates, it suggests loading from streambank erosion since P8 models only watershed loading.

4.4.2 Hydrologic Processes

Indirect influences of sediment delivery include increases in the volume and/or rate of runoff reaching the stream. As described in more detail in the following sections, there are multiple ways runoff volume and/or rates can increase, including:

- Changes in land use – natural → agricultural → urban/suburban development.
- Increased impervious surface within the watershed.
- Modified watershed boundaries due to grading during development and installation of storm sewer systems.
- Increased efficiency of runoff delivery to streams due to the use of storm sewers.
- Climatological shifts that results in changes in the precipitation depth and intensity of storms.

Increases in the volume and/or rate of runoff contributing to a stream results in degradation of the stream bed and banks with transport of the eroded sediment downstream.

4.4.2.1 Flood Frequency and Magnitude Primer

Prior to the introduction of agriculture and grazing practices, these segments of Bluff Creek were likely in dynamic equilibrium with its watershed and were able to convey storm runoff without significant change in its shape, pattern, or profile. Transforming the landscape to one dominated by agriculture likely made fundamental changes to the hydrology by changing the dominant vegetation (both in the watersheds and adjacent to the creek), improving the rate of drainage from fields, and altering the sediment load to the creek (see Figure 4-6). Relatively rapid fundamental changes to the hydrology can disrupt the dynamic equilibrium and result in erosion as the creek gradually moves toward a new balance with the hydrology and sediment supply to the creek in a process that can take years or decades to play out. When the watershed began to urbanize, a similar process likely began again as sediment supply, drainage patterns, and runoff rates and volumes changed in response to increased imperviousness (see Appendix A for images of suburban development from 1991-2020).

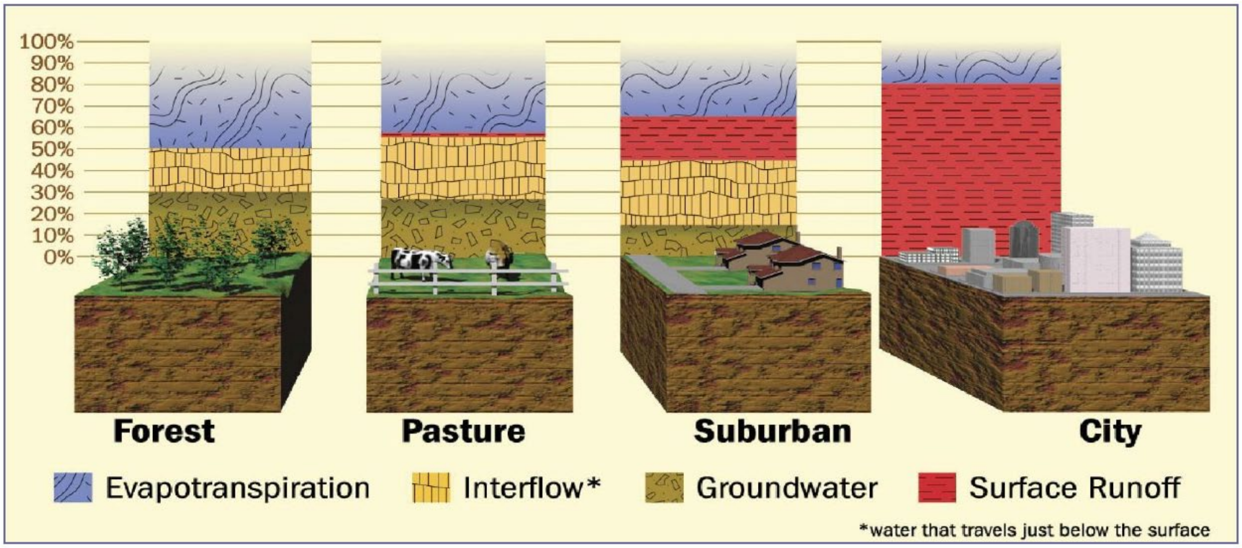

Figure 4-6 Regional Impact of Urbanization on Stormwater Flows (8)

The most significant change associated with urbanization, as far as the creek is concerned, is an increase in runoff from the watershed. With urbanization, the rate and volume of runoff generally increases, as shown on Figure 4-7. assuming mitigating measures are implemented. Flows in the upstream reaches of Bluff Creek are intermittent. Urbanization also reduces baseflow through groundwater recharge, so stream flow is reduced at low flow, between stormwater runoff events.

The shape, pattern, and profile of the creek channel are directly related to the bankfull discharge. When the creek is in equilibrium with its environment, the shape, pattern, and profile are such that the creek can convey the bankfull discharge without significant change in those parameters. With urbanization, the frequency of bankfull discharge typically increases depending on the amount of impervious area in the watershed as illustrated on Figure 4-8.

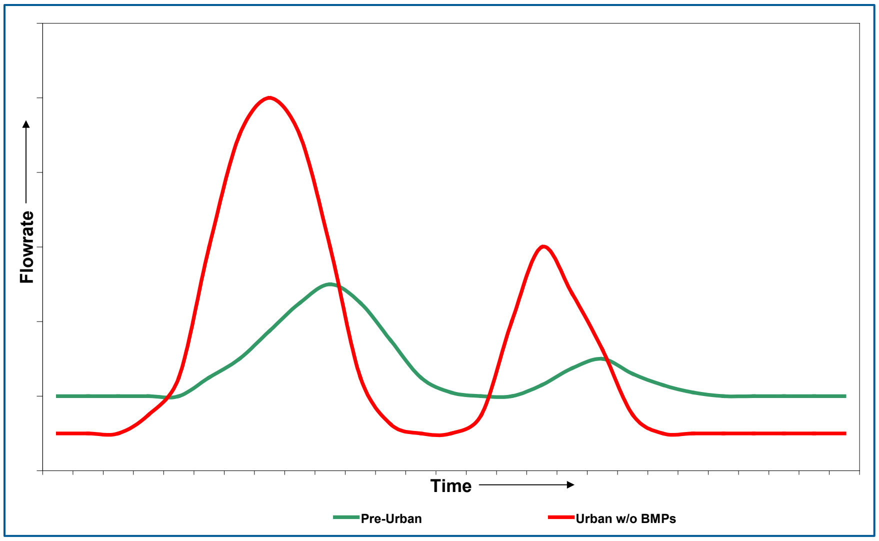

Figure 4-7 Example change in Streamflow Due to Urbanization (9). Note this is a general example, not based on flow data from Bluff Creek

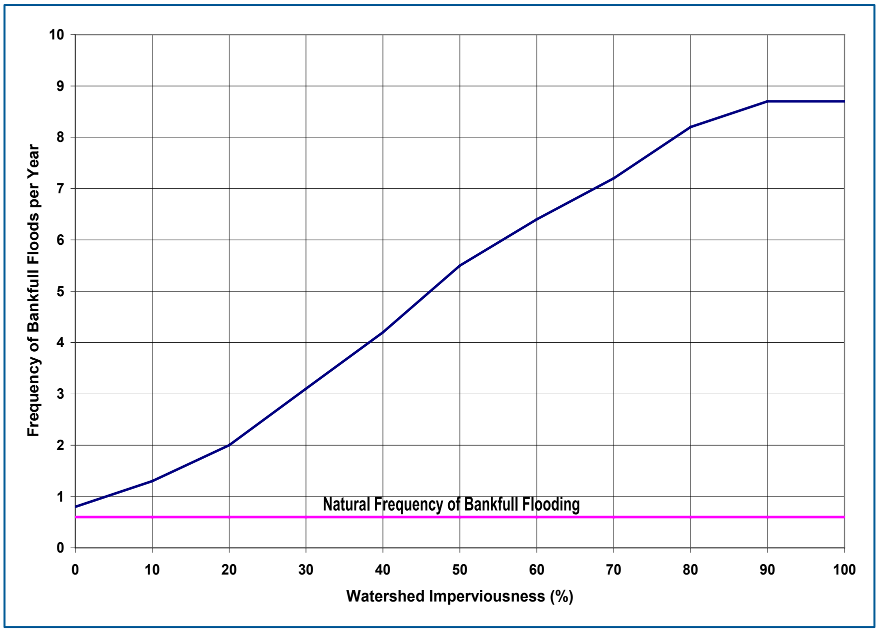

Figure 4-8 Conceptual Frequency of Bankfull Flooding as a Function of Imperviousness (9)

The increase in the frequency of pre-development bankfull discharge means that there is a different, larger flow that occurs at the same frequency as the pre-development bankfull discharge frequency, and over time, the channel will adjust its dimensions to accommodate the larger flow that occurs at a frequency more consistent with a typical range of bankfull flow frequencies. The channel can adjust its dimensions through either deepening or widening by eroding and transporting the resulting sediment downstream. This is currently occurring in portions of Bluff Creek.

In urban areas, detention ponds are often constructed to slow the rate of storm water flow to the creek, and thus attempt to maintain a more natural rate of flow to the creek. By increasing storm water detention volume available it may be possible to approach the pre-urbanized peak runoff rates to the creek. Infiltration practices such as rainwater gardens are even more beneficial, because they reduce not only the rate of runoff but also the volume.

Because it is usually impractical to store enough runoff to eliminate increases in the amount of runoff to the channel, the creek must respond to the flow increases. The natural creek channel tends to widen and deepen to convey the greater frequency and volume of discharge. Even if peak flows are sufficiently attenuated through stormwater detention, an increase in the total runoff volume may also impact stream geomorphology. The impacts are dependent on watershed characteristics and are less in watersheds with a lot of natural storage in lakes and wetlands, compared to those with little natural storage, because the channel is already adjusted to a longer hydrograph.

The MPCA's Stormwater Manual Wiki (7) also contains information on how to mitigate the impacts of development (i.e., land use or storage changes) on streambank stability. The Stormwater Manual states, *"The purpose of channel protection criteria is to prevent habitat degradation and erosion in urban streams caused by an increased frequency of bankfull and sub-bankfull stormwater flows. Channel protection criteria seek to minimize downstream channel enlargement and incision that is a common consequence of urbanization (Schueler and Brown, 2004)."* (https://stormwater.pca.state.mn.us/index.php?title=Channel_protection_criteria_(Vcp)) . According to the manual, channel protection measures have been adopted by the States of Georgia, Maryland, New York, Vermont, and Washington. The MPCA's channel protection analysis findings and recommendations are summarized below. In addition, Table 4-7 summarizes the MPCA's recommended channel protection criteria recommended in the manual based on waterbody types.

- Many communities require 2-year peak control by seeking to keep the post-development peak discharge rate at or below pre-development rates. While the intention is to limit flows in the creek, research suggests 2-year rate control may lead to bank erosion because of the extended duration of higher than predevelopment flows and velocities.

- There are currently no state requirements to provide channel protection for regular waters. However, channel protection is also highly recommended for trout streams and certain discharge situations to lakes and wetlands.
- The recommended channel protection criterion is to use extended detention techniques to store and slowly release the runoff generated from the 1-year, 24-hour design storm over a 24-hour period. This will likely limit the critical erosive velocities in downstream channels so they are not exceeded over the entire storm hydrograph.

Table 4-7 MPCA's recommended channel protection criteria by receiving water type

Receiving Water Type	MPCA's Recommended Channel Protection Criteria
Regular Waters	No current state requirement. It is recommended that communities adopt a criterion for either 24-hour extended detention of the 1-year, 24-hour design storm or one-half of the 2-yr, 24-hr pre-development peak flow when revising or adopting local stormwater ordinances for peak flow control (and eliminate two-year peak discharge requirements).
Construction General Permit Special Waters	One- and two-year design storm peak discharge and volume control required in four special water categories (wilderness, trout lakes, lake trout lakes, and scientific and natural areas).
Other Sensitive Receiving Waters	12-hour detention of water is recommended as the most for discharge to trout streams (to prevent heating), while other sensitive receiving waters should maintain the 24-hour minimum.

According to the MN Stormwater Manual, *"Continuous simulation models are important when assessing the downstream effects of a stormwater discharge. For example channel erosion protection needs to be based more on continuous simulations of more frequent storms to properly represent the duration of erosive periods, particularly if detention used to control peak rate of runoff with limited volume control (WEF, 2012)."* (10)

An emerging approach to managing the impact of development or storage changes (e.g., wetland restoration) is to require that post-development flow duration curve match the pre-development or even pre-settlement duration curve. A flow duration curve is a plot of flow rate against the percentage of time that the flow rate is exceeded. Flow duration analysis can be used to determine the changes in the duration of all flows regimes and assess the impact of the changes in hydrograph shape on downstream erosion potential. Many counties and municipalities in California are required to develop hydromodification management plan (HMP) as part of their National Pollutant Discharge Elimination System (NPDES) MS4 permit. Hydromodification is the modification of the runoff hydrograph's timing, peak discharge and volume because of land alterations and the resulting impacts on receiving waters, such as erosion, habitat degradation, and sedimentation. The goal of the HMP is to protect the physical, chemical, and biological functions of streams in urbanizing areas. Many of the HMP yield performance standards based on a flow duration approach. In fact, the Santa Clara Valley Urban Runoff Pollution Prevention Program HMP report reviewed three measures for controlling the adverse impacts of hydromodification (flow duration control, volume control, and single event hydrograph matching). The report concluded that volume control or hydrograph matching would not provide adequate protection against stream erosion and a flow duration control design approach was the most effective in controlling erosive flows (Reference (11)). Of the HMPs reviewed, they seem to include some form of flow duration matching to mitigate both the duration and magnitude of flows within a prescribed range. To avoid the erosive effects of extended low flows, the maximum rate at which runoff is discharged is set below the erosive threshold, a critical flow rate (Qcp) that generates critical shear stress on the channel bed and banks. The critical flow is a function of site-specific soils, cross sectional shape, channel slope, bed and bank roughness.

4.4.2.2 Hydraulic Analysis Summary

Research suggests the more frequent small to moderate flows have the largest influence on erosion potential (Reference (11)). The smaller events have been found to do a significant proportion of the work leading to erosion in urban streams because of how frequently they occur (Reference (12)). Therefore, increasing the duration of the lower flow rates could potentially have an adverse impact on erosion unless flows are control to some low threshold that will not initiate stream bed or bank erosion. This low flow threshold depends on the stream channel characteristic and is known has the critical flow (Qc). As long as flows remain less than this threshold erosion is unlikely to occur.

The methodology used to establish a lower threshold critical flow is based on the approach outlined in Santa Clara Valley Urban Pollution Prevention Program's Hydromodification Management Plan, Final Report (Reference (11)) and addressing the urban stream disturbance regime (Reference (13)). The critical flow approach builds several simple but well-established river hydraulics concepts. These concepts include shear stress and conveyance hydraulics (Reference (13)). The shear stress represents the force the flow water place on the streambed and bank materials. Before the critical flow can be estimated, the shear stress that induces sediment movement must be determined (known as the critical shear stress). Examples of published threshold criteria are presented in Table 4-8.

Table 4-8 Published threshold values for selected soil types

Soil type	Allowable Velocity (fps)	Allowable Shear Stress (lbs/ft^2)
Sandy loam soil[a]	1.75-2.25	0.045-0.05
Stiff clay[a]	3-4	0.26

a – (14)

Native soil along portions of upper Bluff Creek (assuming sandy loam) can withstand peak velocities of 1.75 to 2.25 feet per second (fps) and maximum shear stresses of 0.045 to 0.05 pounds per square foot (lbs/ft^2).

RPBCWD developed a detailed PCSWMM hydrologic and hydraulic model of Bluff Creek in 2016. This model includes existing watersheds and land use to determine the rate and volume of runoff conveyed in Bluff Creek. Modeling results for the 2-, 10-, and 100-year flows are presented in Table 4-9. These results indicate flow velocities regularly exceed the threshold values and that erosion will occur under existing conditions.

Table 4-9 Flow Characteristics for Reach B5B and B5C predicted by PCSWMM

	2-yr Flow				10-year Event				100-year Event			
Reach	Flow (cfs)	Velocity (ft/sec)	Depth (ft)	Shear Stress (lb/ft3)	Flow (cfs)	Velocity (ft/sec)	Depth (ft)	Shear Stress (lb/ft3)	Flow (cfs)	Velocity (ft/sec)	Depth (ft)	Shear Stress (lb/ft3)
B5B	43	2.2	2.7	0.6	83	1.3	4.2	0.9	123	1.5	6.9	1.5
B5C	43	2.9	2.5	0.1	83	4.1	3.3	0.1	123	4.7	4.4	0.1

4.4.3 Channel Processes

Sediment transport is an important function of the creek. It forms the shape of the channel, including the pools and riffles which are so important to aquatic life. Sediment transport consists of suspended sediment, which is distributed throughout the water column, and bed load sediment, which moves along the creek bed. Suspended sediment generally consists of finer particles, while bed load sediment consists of larger, heavier particles. With larger flows, bed load sediment particles may become suspended as the power of the creek increases. Bed load sediment occupies from 5 to 50 percent of the total sediment load of a creek; suspended sediment occupies the remaining larger fraction. In streams with fine-sediment beds such as Bluff Creek, bed load is on the lower end of that fraction.

The general progression of suspended sediment transport with a single storm typically begins with a low suspended sediment load at low creek flows. As flow increases, the sediment load also increases, until the flow reaches a maximum. The rising sediment load is typically a combination of wash load from the watershed and near channel sources, including mobilization of bed material. Near-channel sources of sediment can also include, but are not limited to, scour around fallen trees and bank slumps that have occurred between floods. As the flood recedes, the sediment load is lower than for similar discharges on the rising limb of the hydrograph for a few reasons. Wash load from the watershed is decreased as runoff has stopped already or easily movable sediment has already been washed into the creek. Removal of slumped bank material and scour around in-creek obstruction decreases mostly because lower velocities can no longer transport sediment from these sites. Velocities in the channel are also lower on the tail of the hydrograph compared to the same flow on the rising arm of the hydrograph because flows are no longer increasing and tailwater created by the flood help slow velocities; and lower velocities are less capable of eroding the channel and transporting sediment.

Activities such as roads crossing the creek, channel straightening, and concentration of flow at culvert crossings can also have negative impacts on the creek. These activities alter the stable pattern and profile of the channel. Areas of disturbed natural vegetation along the creek banks and floodplain also result in greater erosion potential, although Reach B5C runs through a patch of remnant forest that is fairly intact for this watershed.

4.4.3.1 Streambank Erosion Potential

The instability within Bluff Creek is likely caused by the gradual increase in runoff volume and increased peak runoff rates generated by a developing watershed. Bank erosion ratings, near bank stress, and modified Pfankuch channel stability rating worksheets were completed for along Reach B5C based on site walks. A detailed engineering survey of the segment was part of this feasibility effort.

As shown on Figure 4-9, the Bluff Creek streambed is about 2 to 3 feet higher than below it. The road acts as a check dam against channel incision moving upstream from Reach B5C as is evident by the streambed upstream of Galpin Road being at roughly Elevation 950 feet and downstream at about Elevation 945-946. Reach B5C is likely entrenched about 2 to 3 feet compared to pre-development or pre-agriculture conditions. Entrenchment increases the bank heights, making them more prone to erosion, subsequent collapse and sediment loading to Bluff Creek.

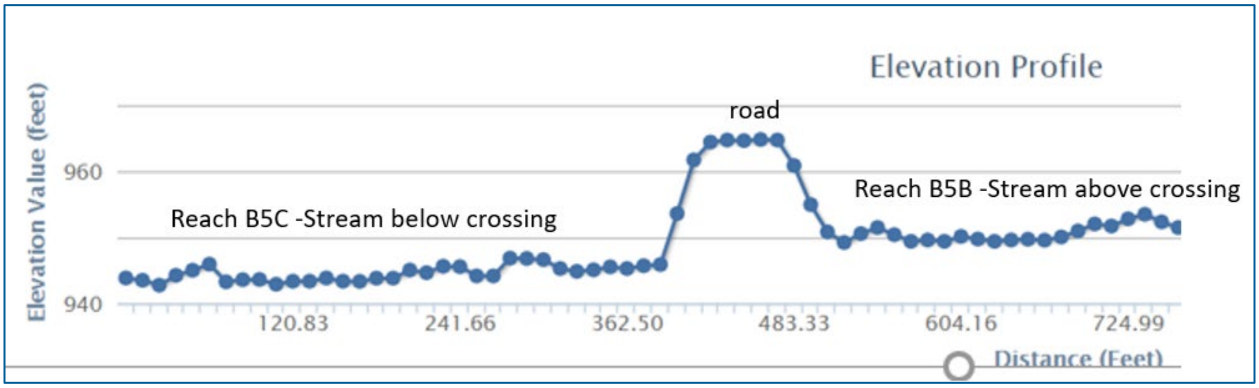

Figure 4-9 LiDAR data for Bluff Creek streambed elevation showing elevation of stream bed for Reaches B5C and B5B.

Modified Pfankuch Channel Stability Ratings

The Pfankuch assessment assigns channel stability rating based on a series of qualitative questions to predict creek stability. The method evaluates stability in the upper banks, lower banks, and stream bed by looking at mass wasting potential adjacent to the channel, detachability of bank and bed materials, channel capacity, and evidence of excessive erosion and/or deposition. A higher rating score indicates greater channel instability. The final score is adjusted based on the Rosgen stream classification (Reference (15)).

Reach B5C rated as unstable on the Pfankuch assessment for the whole reach for a B5 stream type (even when broken down into the upper, middle, and lower portions of the reach) (see Table 4-10). It should be noted that this stream segment has intermittent flow with stagnant water and no flow which tends to lower Pfankuch scores.

Table 4-10 Modified Pfankuch Channel Stability Rating

Reach	Description	Pfankuch Rating	Existing Stream Type	CRAS Score
B5B	985 Feet upstream of Galpin Boulevard to Galpin Boulevard	Fair	B5	7
B5C (Upper)	Upstream third of the reach starting at Galpin Road-County Road 117 and heading downstream towards West 78th Street-County Road 16	Poor	B5	7
B5C (Middle)	Middle third of the reach between Galpin Road-County Road 117 and heading downstream towards West 78th Street-County Road 16	Poor	B5	3
B5C (Lower)	Downstream third of the reach from that extends from Galpin Road-County Road 117 and heading downstream towards West 78th Street-County Road 16	Poor	B5	5

Bank Erosion Potential Ratings

Streambank erosion rates predicted by CRAS range from 0.005 ft/year to 0.5 ft/year (Table 4-11). The survey needed to complete a full near bank stress analysis was not completed for this phase of assessment, so a moderate rating was assumed for all reaches because there was not sharp meanders, mid-channel bars or other factors that promote high shear stress on the streambanks.

Table 4-11 Bank Erosion rate prediction using bank erosion categories from the CRAS

Erosion category	CRAS Erosion & channel stability score	Erosion rate range (ft/year)	Description of banks
Slight	1	0.005 – 0.025	Some bare banks, but little active erosion is apparent
Moderate	3	0.026 – 0.10	Banks mostly bare with some rills and vegetative overhang
Severe	5	0.11 – 0.25	Banks are bare, with rills and severe vegetative overhang. Exposed tree roots and some fallen trees
Very severe	7	0.26 – 0.50	Banks are bare, with gullies and severe vegetative overhang. Many fallen trees. Obvious bank erosion is common

In addition to creek assessments, RPBCWD staff also installed bank pins (i.e., rebar embedded horizontally into a bank) at monitoring location B5 in 2015. The bank pins were installed at "representative" erosion sites to evaluate erosion rates for each reach. Since the bank pins were installed, RPBCWD annually measured the amount of exposed bank pin, or sediment accumulation if buried, between 2016 through 2021. These measurements, summarized in Table 4-12, produce a representative average lateral bank recession rate of between 0.005-0.19 feet per year within Reach B5. In 2020, one of the three bank pins installed on the left creek bank was not found. Similarly in 2021, one of the bank pins on the right bank was not found. The loss of the bank pins indicates sufficient erosion to completely dislodge the pin and as a result the measured recession rated could be underestimated. The lower left bank pin on the left bank routinely experienced deposition of material resulting in a negative recession rate.

Table 4-12 Measured Bank Recession Rate at B5

Date	Top/ Bottom of pin	Right Bank (RB) Lateral Recession (inches)					Left Bank (LB) Lateral Recession (inches)				
		# of Pins	Upper Pin	Middle Pin	Lower Pin	Average	# of Pins	Upper Pin	Middle Pin	Lower Pin	Average
6/15/15		3	Install	Install	Install		3	Install	Install	Install	
6/14/16	Top	3	4.4	4.75	2	3.72	3	2.4	2	2.8	2.40
6/13/17	Top	3	1.78	4.75	-1	1.84	3	2.25	2	-2.25	0.67
7/11/18	Top	3	0	0.25	0.75	0.33	3	0.75	0.5	-7	-1.92
7/11/18	Bottom	3	0	3	0.75	1.25	3	0.75	1.28	-7	-1.66
7/15/19	Top	3	0.5	1.13	2.94	1.52	3	2	4.25	-5.5	0.25
7/15/19	Bottom	3	6.13	5.38	2.94	4.81	3	2.88	4.25	-5.5	0.54
6/23/20	Top	3	0.25	2.5	5	2.58	2	0.2	No pin	-1	-0.40
6/23/20	Bottom	3	3.88	2.75	0.25	2.29	2	2.13	No pin	-1	0.56
6/15/21	Top	2	0	No pin	0	0	2	0	No pin	0	0.00
6/15/21	Bottom	2	9	No pin	0	4.5	2	0.25	No pin	0	0.13
Average (in/yr)			2.59	3.06	1.36	**2.29**		1.36	2.38	-2.65	**0.06**
Average (ft/yr)			0.22	0.26	0.11	**0.19**		0.11	0.20	-0.22	**0.005**

4.4.4 Bank Erosion Rates

A total volume of eroded sediment is obtained by taking the lateral erosion rates multiplied by bank height and length. Soil density was used from the Natural Resources Conservation Service (NRCS) web soil survey to convert soil volumes to soil mass, in tons per year.

Based on the average measured bank recession rate in Reach B5 the sediment load from streambanks was estimated at approximately 26.3 tons/year in Reach B5B and 26.7 tons/yr in Reach B5C. The phosphorus load from streambanks was estimated at approximately 33 lbs/yr of phosphorus from each reach, or 66 pounds of phosphorus per year for the combined reaches.

In addition to streambank erosion, Minnesota Board of Water & Soil Resources' (BWSR's) Gully Stabilization Estimator (V2.1) was used to approximate the sediment load to Bluff Creek from the four gullies along Reach B5C. It is presumed that the gullies formed when the tributary areas was used for agriculture. Based on field observations the erosion appears to continue headcutting at the upstream end of the gullies under current land use conditions. BWSR's calculator provides a rough approximation of the gully erosion of 1.7 tons/year/gully. This results in an estimated sediment load from all four gullies of about 6.8 tons/year.

Much of the coarse sediment eroded from stream channels is not transported all the way down to the Minnesota River but is deposited along the way in adjacent wetland, on floodplains or point bars. In this case, the Lester and Kilkenny Loam type soils are on average about 40% sand, so an estimated 13.7 tons would be deposited in the stream or floodplain, with 60% (mostly silt and clay) being transported downstream and leading to resource impairments.

4.4.5 Comparison of sediment from Reach B5C to lower parts of Bluff Creek

In the 2015 CRAS report (Reference (3)), Reach B5C was rated as "Severe" for bank instability, the worst rating available. However, while the Reach B5C is unstable, it has low bank height and smaller cross-sectional area than lower reaches of Bluff Creek. Because of the adjacent soils and the creek's location at the headwaters, Reach B5B and B5C have the potential to deliver the eroded materials to downstream wetlands, floodplains, and points bars, thereby impacting those downstream resources. These reaches would have a lower sediment delivery rate to the Minnesota River, meaning that less eroded sediment is transported out of the watershed. Banks in lower Bluff Creek can exceed 20 feet when the bank meanders into steep ravine walls. Compared to the maximum bank height in Reach B5C of about 8 feet. While more data would be needed to confirm the quantitative estimates, the same pattern has been found throughout the Minnesota River basin. Ravines contribute disproportionate amounts of sediment to the sediment load in the Minnesota River basin (Day et al. 2013) (Reference (16)) and the load to the Minnesota River tends to be greater from streambanks in the lower creek reaches (Lauer et al. 2017) (Reference (17)).

According to the prioritization process developed the 10-year plan, Reach B5 received a score of 37 (see Table 4-13). While B3 and BT3 scored higher, the logistical factors considered during the plan development placed the restoration of Reach B5 ahead of B3 and BT3. A couple of primary considerations included efforts to maintain a consistent operating budget and the location of the reach in the watershed. Reach BT3A was restored by the district in 2019-2022.

Table 4-13 Bluff Creek Restoration Project Prioritization Scores from RPBCWD's 10-Year Plan

Reach	Project Description	Goal Index[1]	Sustainability Index[1]	Volume Management Index[1]	Pollutant Management[1]	Stabilization[1]	Habitat Restoration[1]	Partnership[1]	Education[1]	Watershed Benefit[1]	Total Benefit Score[1]
BT3A	Creek Restoration and Stabilization	3	7	1	1	7	5	7	5	7	**43**
BT3	Creek Restoration and Stabilization along SW Branch, excludes BT3A	3	7	1	1	7	5	7	1	7	**39**
B3	Creek Restoration and Stabilization	3	7	1	1	7	7	1	7	5	**39**
B4	Creek Restoration and Stabilization	3	7	1	1	5	5	1	7	7	**37**
B5	Creek Restoration and Stabilization	3	7	1	1	7	7	1	3	7	**37**
BT1	Creek Restoration and Stabilization	3	7	1	1	5	7	1	3	7	**35**
B2	Creek Stabilization	3	7	1	1	5	5	1	7	3	**33**
B1	Creek Stabilization	3	7	1	1	7	5	7	1	1	**33**
BT2	Creek Restoration and Stabilization	3	7	1	1	5	3	1	3	7	**31**

5.0 Strategies for Ecological Enhancement and Management

There are a variety of stabilization and ecological restoration measures that may be used in streams, rivers and side tributaries such as ravines. Once installed, restoration projects require ongoing management to ensure their long-term success. This section describes the initially proposed restoration techniques and outlines a management program.

5.1 Restoration Measures

Some common restoration techniques applicable to Reach B5B and B5C are summarized in Table 5-1.

Table 5-1 Stabilization Techniques

Design Element	Purpose	Ecological Benefit
Rock Riffles 	Gravel or cobble-sized material installed in the stream bed to create natural flow patterns and to control stream bed elevations.	The variety in flow and channel substrate size provides habitat diversity for aquatic species.
Cross Vanes 	Boulders buried in the stream bed and extending partially (“vanes”) or entirely across the stream (“cross vanes”) to achieve one or more of the following goals: re-direct flows away from banks, encourage sediment deposition in selected areas, and control stream bed elevations.	Scour pools develop over time near the vane, which provide habitat diversity for species that prefer pools to faster flowing in-channel habitat.
Root Wads 	Tree trunks with the root ball attached, installed either singly (root wads) or in conjunction with additional large woody debris and toe wood to Increase bank roughness and resistance to erosion, re-direct flows away from banks, and provide a bench for establishment of riparian vegetation	Creates undercut/overhanging bank habitat features.

Design Element	Purpose	Ecological Benefit
VRSS/Toe Wood Bank Stabilization 	Soil lifts created with a combination of root wads and long-lasting, biodegradable fabric and vegetated to stabilize steep slopes and encourage establishment of root systems for further stabilization.	Creates undercut/overhanging bank habitat features.
Rock Wood Composite 	Allows stormwater to outlet at an elevation more proximately to the channel elevation. This, along with placement of a material to dissipate flows, reduces potential for in-channel scour.	When flows are appropriately dissipated, there is less sedimentation and associated turbidity in the waterway.
Floodplain Connectivity 	Active floodplain/vegetated bench—modifications made to the stream cross section to increase floodplain connectivity and decrease erosive stress during flood flows; for this project, constructed by raising the channel bed.	Provides a smooth transition between in-channel, riparian, and upland habitat.
Vegetation/Buffer 	Established along a stream bank or overbank area to stabilize bare soils and increase resistance to fluvial erosion.	Using trees, shrubs, and a seed mix of grass and forbs provides a diverse array of vegetation strata and habitat types. Allows for more naturalized aesthetics, with emphasis on native species. Project would be designed to comply with District buffer rules.

Several concept restoration designs with cost estimates were completed for each reach and are described in more detail below. The concept designs were developed based on field-based measurements and estimates of channel dimensions from lidar and aerial photos. A topographic survey must be completed for final design. The district's hydrologic and hydraulic model was used to develop an understanding of existing conditions in both reaches; however additional hydraulic modeling should be completed for final design. Final design may differ from the concepts included below once a topographic survey and hydraulic modeling is complete, and the final design should utilize published erosion threshold information, such as that in Table 5-2, to the extent possible.

Table 5-2 Published threshold values for selected stabilization techniques

Stabilization Technique	Allowable Velocity (fps)	Allowable Shear Stress (lbs/ft^2)
Sandy loam soil[a]	1.75-2.25	0.045-0.05
Stiff clay[a]	3-4	0.26
Vegetated soil with short native grasses[a]	3-4	0.7-0.95
Vegetated turf reinforcement mat[a]	8-21	8
Vegetated Reinforced Soil Slopes (VRSS) – immediately after installation[b]	3-5	5-9
Vegetated Reinforced Soil Slopes (VRSS) – after 1-2 years of growth[b]	8	14
Riprap (12-in D_{50})[a,c]	10-13	5.1
Riprap (24-in D_{50})[a,d]	14-18	10.1

a – from Reference (14)

b – Sotir and Fischenich (2003) (Reference (18)

c – for use in constructed riffles and grade control

d – for use in rock vanes

As shown in Table 5-2, a sandy loam soil can withstand peak velocities of 1.75 to 2.25 feet per second (fps) and maximum shear stresses of 0.045 to 0.05 pounds per square foot (lbs/ft^2). The soils along this reach of Bluff Creek are a little more resistant to erosion as the silty clay loams are more cohesive. Hydraulic model results for Bluff Creek indicate peak velocities and shear stresses during the 2-year event are near these limits for Reach B5B and the velocities exceed these limits for the upper half of Reach B5C, as shown in Table 4-9., thus restoration measures appear warranted.

5.1.1 Engineer's Opinion of Probable Cost Development

The engineer's opinions of probable costs for design, permitting, and construction were developed for each conceptual design (See Appendix B). These opinions of costs, project reserves, contingency, documentation, and discussion are intended to provide background information for feasibility alternatives assessment, analysis purposes and budget authorization by the RPBCWD. Industry resources for cost estimating (AACE International Recommended Practice No. 18R-97, and ASTM E2516-06 Standard Classification for Cost Estimate Classification System) provide guidance on cost uncertainty, depending on the level of project design developed. The opinion of probable cost for the alternatives evaluated generally corresponds to a Class 4/5 estimate characterized by completion of limited engineering and use of deterministic estimating methods. As summarized in Figure 5-1 as the level of design detail increases, the level of uncertainty is reduced.

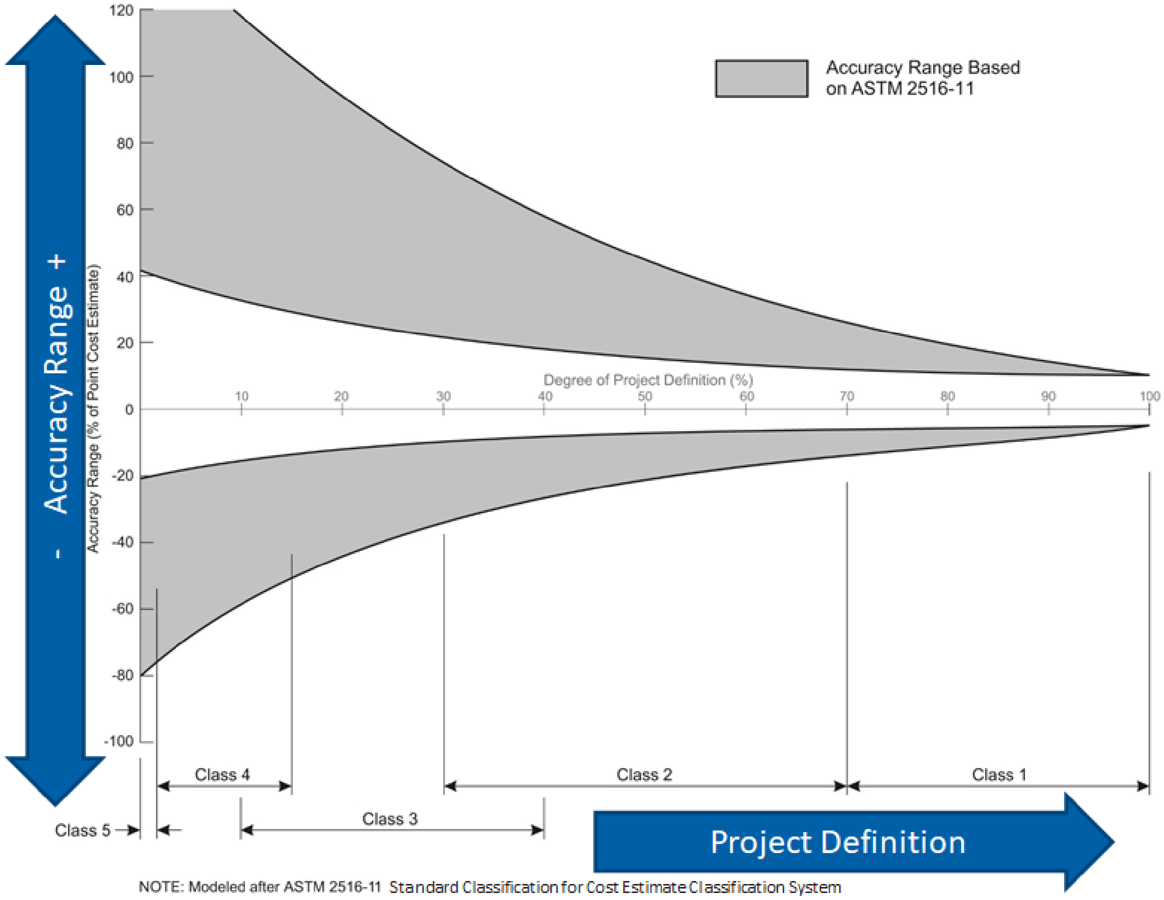

Figure 5-1 Variability in Opinion of Probable Cost (OPC) based on Project Definition Level

The opinion of probable cost provided in this engineer's report is made on the basis of Barr Engineering Co.'s experience and qualifications and represents our best judgment as experienced and qualified professionals familiar with the project. It is acknowledged that additional investigations and additional site-specific information that becomes available in the next stage of design may result in changes to the proposed configuration, cost and functioning of project features. Developing opinions of cost are very challenging in 2022 given the volatility in the construction industry, including but not limited to fuel cost and material supply constraints.

5.1.2 Summary of Restoration Concepts

Table 5-3 and Table 5-4 summarize the potential project costs and pollutant reduction benefits associated with the concepts considered. Descriptions of each of the concepts are included in the sections below along with figures and detailed cost estimates are included in Appendix B.

Table 5-3 Summary of Opinion of Probable Cost and Annual Maintenance Costs

Reach	Concept	Project Cost Estimate (1)	Annualized Maintenance Cost (2)
B5A	Wetland Hydrology Restoration	$240,400 ($216,400-$336,600)	$4,808 ($4,328-$6,732)
B5B	Concept A-Remeander	$442,700 ($398,400-$619,800)	$8,854 ($7,968-$12,396)
B5B	Concept B – Restore In-place	$348,900 ($314,000-$488,500)	$6,978 ($6,280-$9,770)
B5C	Concept A – Low	$162,000 ($145,800-$226,800)	$3,240 ($2,916-$4,536)
B5C	Concept B – Moderate	$213,300 ($192,000-$298,600)	$4,266 ($3,840-$5,972)
B5C	Concept C - High	$365,700 ($329,100-$512,000)	$7,314 ($6,582-$10,240)

(1) A Class 4/5 screening-level opinion of probable cost, as defined by the American Association of Cost Engineers International (AACI International), has been prepared for these alternatives. The opinion of probable construction cost provided in this table is based on Barr's experience and qualifications and represents our best judgment as experienced and qualified professionals familiar with the project. The cost opinion is based on project-related information available to Barr at this time and includes a conceptual-level design of the project. Includes 30% project contingency, 30% for planning, engineering, and design, and 10% for construction administration. Lower bound assumed at -10% and upper bound assumed at +50%.

(2) Assumed to be 2% of the total project cost

Table 5-4 Summary of Cost Estimates and Pollutant Loading Reduction

Reach	Concept	Alternative Description	Ecological Enhancement Area (ac)	Project Opinion of Probable Cost [(1)]	Annualized Cost [(2)]	TP Loading		TSS Loading	
						Load Reduction (lb/yr)[(3)]	Cost/lb Reduced[(4)]	Load Reduction (lb/yr)[(3)]	Cost/lb Reduced[(4)]
B5A	A	Restore Wetland Hydrology	7.9	$240,400	$16,828	31	$543	8,255	$2.04
B5B	A	Remeander channel to create a stable, natural channel	0.5	$442,700	$30,989	26	$1,182	42,000	$0.74
B5B	B	Stabilize channel with series of cross vanes	0.5	$348,900	$24,423	26	$931	42,000	$0.58
B5C	A	Stabilize Gullies and Riprap Culvert Outlet	0.1	$162,000	$11,340	11	$1,033	17,600	$0.65
B5C	B	Stabilize Gullies, Install grade control	0.3	$213,300	$14,931	21	$712	33,500	$0.45
B5C	C	Stabilize Gullies, Install grade control, Restore Bank	0.6	$365,700	$25,599	38	$681	60,200	$0.43

(1) A Class 4/5 screening-level opinion of probable cost, as defined by the American Association of Cost Engineers International (AACI International), has been prepared for these alternatives. The opinion of probable construction cost provided in this table is based on Barr's experience and qualifications and represents our best judgment as experienced and qualified professionals familiar with the project. The cost opinion is based on project-related information available to Barr at this time and includes a conceptual-level design of the project. Includes 30% project contingency, 30% for planning, engineering, and design, and 10% for construction administration. Lower bound assumed at -10% and upper bound assumed at +50%.

(2) Assumed to be 2% of the total project cost for annual maintenance plus the initial project cost distributed evenly over a 20 year project lifespan.

(3) Reductions reflect the estimated load decrease from the proposed project element and exclude any ancillary benefits that reduced flows would have on further reducing erosion, scour, and pollutant transport from downstream reaches.

(4) Annualized cost divided by estimated annual pollution load reduction.

5.1 Reach B5A Wetland Restoration Concept

Stream channel morphology and dynamics can be preserved by managing the water budget of a developed site and restoring prior impacted wetlands so that it is as similar as possible to the pre-urban conditions. Reach B5A is a wetland to the west of County Highway 117 that had been historically ditched and drained. Though not the primary objective of this study, restoration of Reach B5A has potential to reduce peak flows in Bluff Creek helping to decrease erosion and downstream sediment loads. The stream could be re-meandered to slow down the flow and restore natural channel geometry. Alternatively, the area could be restored as a wetland mimicking its structure prior to construction of the ditch in the early 1900s. Figure 5-2 shows the potential wetland extents as shown in the Minnesota Restorable Wetland Index. The Minnesota Restorable Wetland Index was developed by the Natural Resources Research Institute in collaboration with the Minnesota Department of Natural Resources.

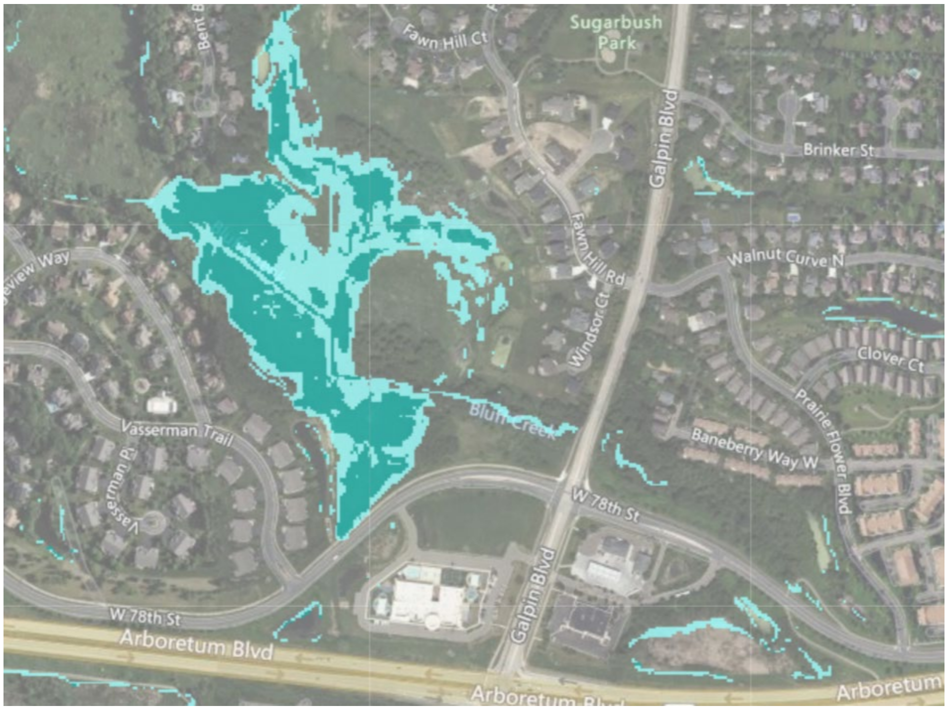

Figure 5-2 Reach B5A contains a restorable wetland on the Restorable Wetland Index, shown in blue and aqua

Wetland restoration would also sequester carbon and provide greater ecological benefits than re-meandering a ditch including nutrient removal and ecological benefits. Restoration of roughly 8 acres of wetland bordering Bluff Creek in Reach B5A would raise the water level by approximately 1 to 2 feet in the partially drained wetland, which is currently classified as a PEM1D (a drainage-impacted, emergent wetland according to the National Wetland Inventory).

The district's hydraulic modeling was used to estimate the critical flow rate that produced the critical velocities below the erosion threshold. The modeling results suggest the critical flow is on the order of 2 to 5 cfs for the upper portion of Bluff Creek. Restoring the wetland hydrology by constructing a multi-tiered extended detention outlet structure with a narrow v-notch weir at Elevation 953 could reduce the flow velocities for the 2-year even to less than the thresholds listed in Table 5-2, thus helping reduce erosion in downstream creek reaches and increasing the robustness of the overall system. It may also be possible to fill portions of the ditch with a low flow pipe to achieve a similar restoration of the hydrology. The conceptual outlet design would be further evaluated, modified, and optimized during the final design process. While restoring the wetland hydrology has the added benefit to reducing downstream erosion potential, modeling suggests the peak water surface elevations could be increases based on the preliminary outlet configuration. It will be necessary to consider these potential impacts and mitigate any increases to flood risk during the final design of a project along upper Bluff Creek.

Example of a stage weir from the *Minnesota Wetland Restoration Guide* by the Minnesota Board of Water and Soil Resources (BWSR)

Table 5-5 Potential Hydraulic impact of Wetland Restoration in Reach B5A

Storm Event	Approximated Pre-settle			Existing Condition			Restored Wetland Hydrology		
	Peak Water Elevation	Flow (cfs)	Velocity (fps)	Peak Water Elevation	Flow (cfs)	Velocity (fps)	Peak Water Elevation	Flow (cfs)	Velocity (fps)
1	952.3	15.4	2.3	952.8	29.1	2.9	954.5	1.1	1.0
2	952.7	24.4	2.7	953.0	43.3	3.3	954.9	2.0	1.3
10	953.2	66.7	3.9	953.7	83.1	4.1	955.5	40.0	3.2
100	955.6	114.0	4.5	956.2	122.9	4.7	956.7	125.9	4.7

The calibrated P8 model from the Bluff Creek TMDL was used to assess the potential pollutant reduction by restoring the hydrology of the wetland. The results suggest an additional estimated to be 4.1 tons of sediment per year, which is equivalent to approximately 8,255 pounds of TSS per year and approximately 31 pounds of TP per year could be removed (see Table 5-6). The estimated reductions in Table 5-6 reflect the estimated load decrease from only the wetland restoration. The restored wetland also has the potential to reduce the stream flow velocities to slightly larger than 1 fps for the frequent storm events. Because the anticipated post-restoration velocity for the 2-year event is less than the allowable for the given the soil type (approximately 2 fps), the wetland restoration would provide ancillary benefits of reducing erosion, scour, and pollutant transport in downstream channel reaches. If the wetland restoration moves forward, it will be important to collect and test the soils that will be inundated to balance the potential for release of phosphorus from the sediment with the additional pollutant removal from watershed runoff.

Table 5-6 Summary of Wetland Restoration TSS and TP Reductions

Pollutant of Interest	Existing Load Reduction (lbs/yr)	Restored Wetland Load Reduction (lbs/yr)	Change (lbs/yr)
Total Suspended Solids (TSS)	27,300	35,555	8,255
Total Phosphorus (TP)	51	82	31

The recently published Wetland Restoration Effectiveness Tool (WRET), was used to predict nutrient removal by the wetland. This tool developed by The Nature Conservancy and University of Minnesota predicts nutrient removal using watershed vs. wetland area and a few other simple variables. The WRET predicted nutrient reduction benefits would include an additional 70 lbs/yr (±50%) of nitrogen removal. Rewetting the upper 2 feet of organic soils could also stop or greatly reduce CO_2 emissions which occur from drained organic matter. This could help prevent the loss of 70,000 tons of organic matter over time containing about 40,000 tons of carbon, equivalent to about 150,000 tons of CO_2 emissions over a time scale of decades.

The engineer's opinion of probable cost for restoring the wetland hydrology in Reach B5A is $240,400, including construction costs, engineering, design, permitting and construction management. The anticipated range for costs is between $216,400 and $336,600. The costs summarized in Table 5-3 reflect the restoration of the wetland hydrology and presume an adaptive management approach would be pursued for vegetation management. Initially limited vegetation restoration would occur to allow the system to acclimate to the restored hydrology and potentially allow the vegetation to recover naturally. Future effort at an additional cost could include localized vegetation restoration in high visible areas adjacent to public access areas or a phased approach to managed vegetation within the entire wetland complex over several years.

Based on the estimated pollutant reduction and the opinion of probably cost, the cost per pound of TP and TSS load reductions are $543 and $2.04, respectively. The costs per pound of load reduction are summarized in Table 5-4.

5.2 Reach B5B Restoration Concepts

Two concepts were evaluated for the restoration of Bluff Creek Reach B5B. Concepts aim to provide cost effective ways to reduce sediment loading in the creek while increasing stream ecological function.

5.2.1 Concept A – Remeander

This concept includes restoring eroding banks on the downstream portion of the reach and construction of a new channel with an appropriate meander pattern to replace the section that was historically straightened (see Figure 5-3).

One significantly complicating factor for this reach is the presence of old farm equipment near stream banks. There is a reasonable risk of soil contamination within this area, which will require investigation and clean-up. The need for the clean-up and possible extent and cost of such a clean-up are largely uncertain. A cost for completing this work is included in the cost estimate, however actual costs of the investigation and clean-up may change significantly.

The pollutant reduction by stabilizing this reach, including the side ravine between the main channel and the wetland to the south, is estimated to be 26 tons of sediment per year, which is equivalent to approximately 42,000 pounds of TSS per year and approximately 26 pounds of TP per year.

The engineer's opinion of probable cost for this reach is $442,700, including construction costs, engineering, design, permitting, and construction management. The anticipated range for costs is between $398,400 and $619,800. These costs are summarized in Table 5-3.

Based on the estimated pollutant reduction and the opinion of probably cost, the cost per pound of TP and TSS load reductions are $1,182 and $0.74, respectively. The costs per pound of load reduction are summarized in Table 5-4.

The costs above are focused only on Reach B5B. If the project were extended to Reach B5A with the same approach as described in this concept to create a more complete project that addresses similar issues, then the total project cost is expected to *increase* by approximately $261,000.

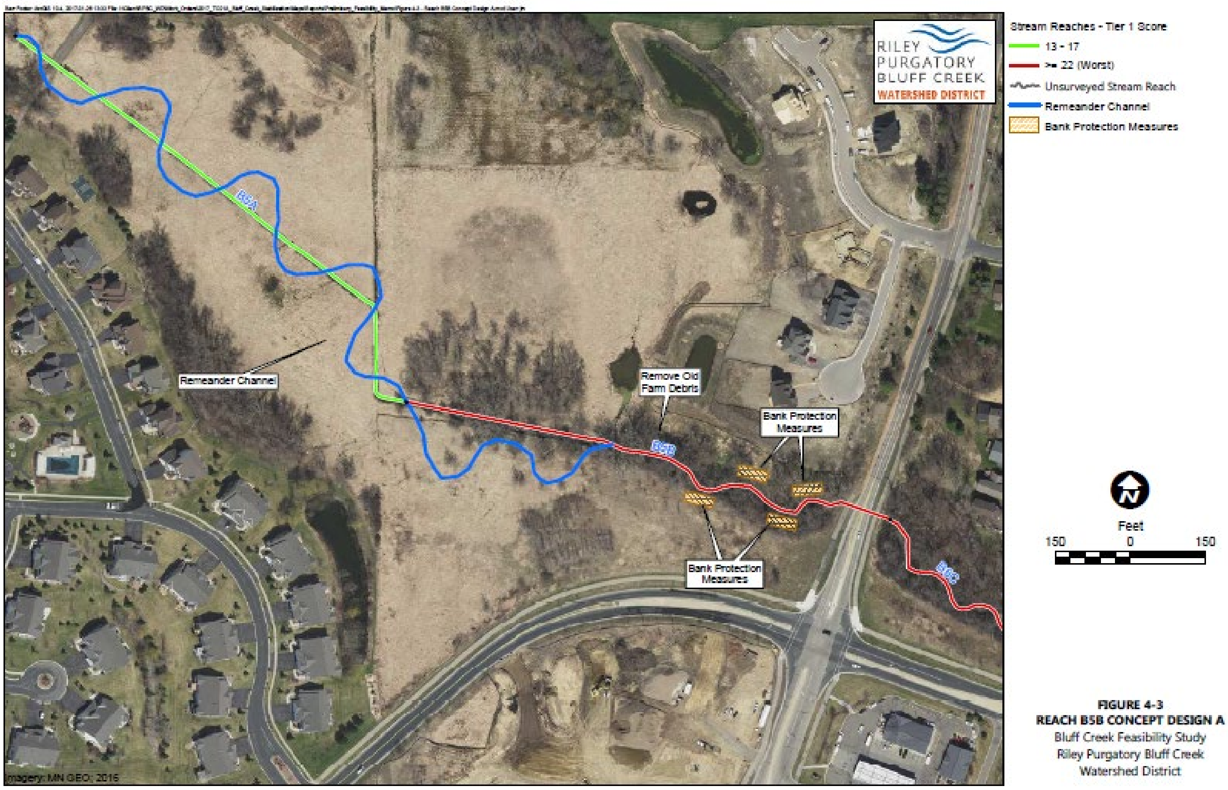

Figure 5-3 Concept A: Restoration of Reach B5B by Remeandering

5.2.2 Concept B –Restore In-Place

Concept B for Reach B5B would be to stabilize eroding banks in place on the downstream portion of the reach and install a series of cross vanes in the straightened portion of the reach (see Figure 5-4). The cross vanes would help to concentrate higher velocities in the center of the channel to reduce erosive pressures on the banks and reduce the tendency of the stream to attempt to recreate a meander pattern.

As noted above, one significantly complicating factor for this reach is the presence of old farm equipment near stream banks. There is a reasonable risk of soil contamination within this area, which will require investigation and clean-up. The need for the clean-up and possible extent and cost of such a clean-up are largely uncertain. A cost for completing this work is included in the cost estimate, however actual costs of the investigation and clean-up may change significantly.

The pollutant reduction by stabilizing this reach, including the side ravine between the main channel and the wetland to the south, is estimated to be 26 tons of sediment per year, which is equivalent to approximately 42,000 pounds of TSS per year and approximately 26 pounds of TP per year.

The engineer’s opinion of probable cost for this reach is $348,900, including construction costs, engineering, design, permitting, and construction management. The anticipated range for costs is between $314,000 and $488,500. These costs are summarized in Table 5-3.

Based on the estimated pollutant reduction and the opinion of probably cost, the cost per pound of TP and TSS load reductions are $931 and $0.58, respectively. The costs per pound of load reduction are summarized in Table 5-4.

The costs above are focused only on Reach B5B. If the project were extended to Reach B5A with the same approach as described in this concept to create a more complete project that addresses similar issues, then the total project cost is expected to *increase* by approximately $167,000.

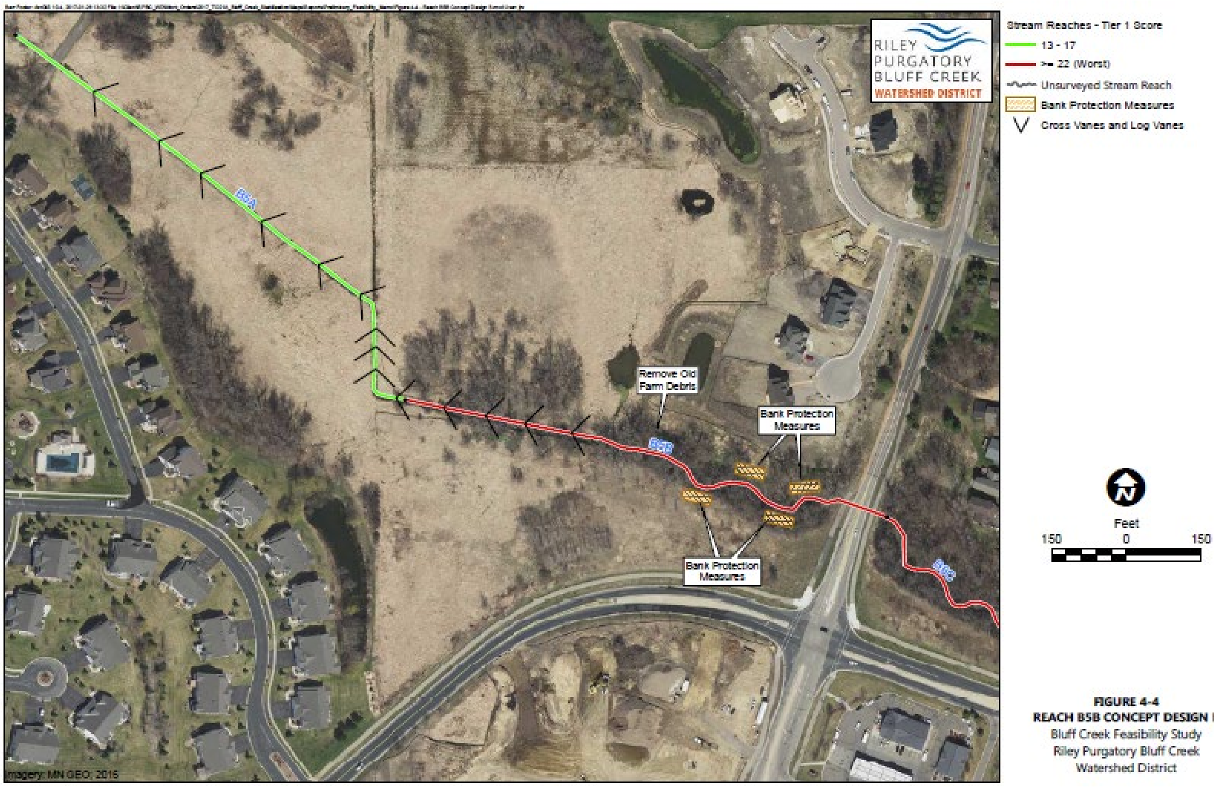

Figure 5-4 Concept B: In-place Restoration of Reach B5B

5.3 Reach B5C Restoration Concepts

Three concepts were evaluated for the restoration of Bluff Creek Reach B5C. Concepts aim to provide cost effective ways to reduce sediment loading in the creek while increasing stream ecological function.

5.3.1 Concept A – Low intervention: protect infrastructure

Concept A within Reach B5C would address areas where infrastructure or homes could be impacted: erosion. The areas targeted in Concept A are shown on Figure 5-5. Structures or buildings being threatened by erosion in Reach B5C include the culvert at the upstream end of the reach at Galpin Boulevard; identified as a problem by the district in 2015 and shown on Figure 5-6.

Drainage from the apartment buildings to the north of the reach have caused three gullies to form in the woods adjacent to the apartment lawn. There is another gully forming on the north side of the reach, just east of Galpin Avenue. This gully is wider and more dished than the gullies near the apartment buildings. One of the gullies is shown in Figure 5-7.

Gully stabilization practices would include grading back to a stable slope, placement of riprap at the top of the gully where there is active erosion and placement of erosion control fabric on the bare soil surfaces with seeding for revegetation. The culvert would be stabilized by replacing the riprap and the apron as needed. All strategies should include removal of buckthorn and planting of native shrubs and understory species to replace the invasives and increase groundcover. This not only improves the ecological value of the forest but can reduce understory erosion.

Figure 5-5 Concept A: Low Concept Restoration of Reach B5C

Figure 5-6 Culvert at upstream end of Reach B5C, July 2021 photo

Figure 5-7 Gully cutting into apartment yards north of Bluff Creek (2015 photo from RPBCWD)

The pollutant reduction by stabilizing this reach, including the side ravine between the main channel and the wetland to the south, is estimated to be 8.8 tons of sediment per year, which is equivalent to approximately 17,600 pounds of TSS per year and approximately 11 pounds of TP per year.

The engineer's opinion of probable cost for this reach is $162,000, including construction costs, engineering, and design. Costs for permitting and construction management are not included. The anticipated range for costs is between $145,800 and $226,800.

Based on the estimated pollutant reduction and the opinion of probably cost, the cost per pound of TP and TSS load reductions are $1,033 and $0.65 per year, respectively.

5.3.2 Concept B – Moderate alternative: protect infrastructure and raise bed to reduce entrenchment and bank sediment inputs

A significant portion of Reach B5C is incised with a relatively narrow floodplain. In addition to the work outlined in Concept A, this alternative would utilize a series of rock riffles, cross vanes, or wood structures to raise the bed and reconnect the channel to the available floodplain. It would also effectively reduce bank heights and BEHI scores in the reach upstream of the grade control structure. This approach has been utilized on similar projects and would minimize the extent of grading and disturbance of banks by limiting construction activity to either end of the stream reach, thus limiting the trees needing to be cut down. Concept B structures are shown in Figure 5-8.

The pollutant reduction by stabilizing this reach, including the side ravine between the main channel and the wetland to the south, is estimated to be 16.8 tons of sediment per year or 33,500 pounds of TSS per year and approximately 21 pounds of TP per year.

The engineer's opinion of probable cost for this reach is $213,300, including construction costs and engineering design. The anticipated range for costs is between $192,000 and $298,600.

Based on the estimated pollutant reduction and the opinion of probably cost, the cost per pound of TP and TSS load reductions are $712 and $0.45 per year respectively.

Figure 5-8 Concept B: Moderate Concept Restoration of Reach B5C

5.3.3 Concept C – High alternative: infrastructure, grade control and bank protection

This option builds upon the previous two concepts and would additionally include:

- infrastructure protection & gully control practices from Option A,
- the grade-control structure from Option B and
- streambank erosion control practices on banks that are above the floodplain and unvegetated.

Locations of these structures are shown in Figure 5-9.

The actively eroding banks will continue to erode until the creek cuts away enough material to create a connected floodplain. The pollutant reduction by stabilizing this reach, including the side ravine between the main channel and the wetland to the south, is estimated to be 30 tons of sediment per year, which is equivalent to approximately 61,200 pounds of TSS per year and approximately 38 pounds of TP per year.

The engineer's opinion of probable cost for this reach is $365,700, including construction costs, engineering, and design. Costs for permitting and construction management are not included. The anticipated range for costs is between $329,100 and $512,000.

Based on the estimated pollutant reduction and the opinion of probable cost, the cost per pound of TP and TSS load reductions are $681 and $0.43 per year, respectively.

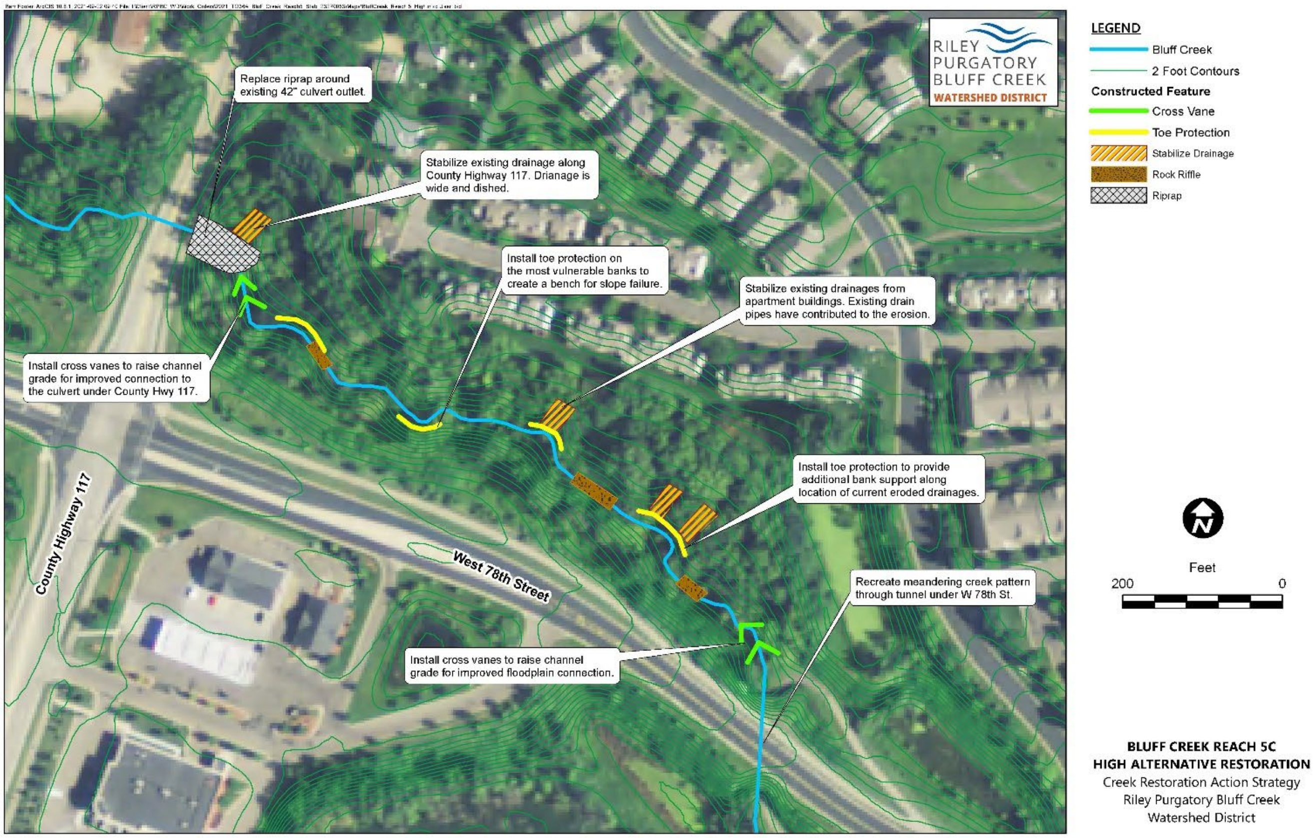

Figure 5-9 Concept C: High Concept Restoration of Reach B5C

5.4 Assessment of Reach B5C Restoration Options using Stream Quantification Tool (SQT) framework

The U.S. Army Corps of Engineers *Function-Based Stream Assessment Methodology* (MNSQT SC, 2020) (Reference (19)) was used to assess the stream function criteria and selecting the option with most potential ecological uplift. The methodology focuses on the hierarchical relationships of stream functional categories to determine the overall function condition of a stream reach (project area). The stream functional categories consist of five critical functions: Hydrology, Hydraulics, Geomorphology, Physiochemistry, and Biology, all of which have associated broad level statements. A more detailed form of function-based parameters was assessed and qualitatively measured, which describes and supports the functional statements within each functional category. These evaluations are defined by performance standard categories: **Functioning**, **Functioning-At-Risk**, and **Not Functioning**. The performance standards are defined by the *Function-Based Rapid Stream Assessment Methodology* (Reference (19) for each of the function-based parameters.

Because this is a relatively new tool and the level of effort can be extensive at the planning level, the qualitative assessment focused on Reach B5C as a trial. While the assessment was qualitative, it is supported by quantitative measurements from field surveys and other analyses done on site by RPBCWD and Barr Engineering. Overall, the assessment identifies the existing condition of the project area and helps quantify the improvement or degradation that each restoration alternative may have on the river's function pertaining to hydrology, hydraulics, and geomorphology.

The *Function-Based Rapid Stream Assessment* methodology used in the Stream Quantification Tool (SQT) for Minnesota was used as a guide. An desktop, qualitative assessment of the five stream functional categories was conducted rather than a full SQT due to budget constraints at the planning level. The hydrology functional category was evaluated primarily via desktop review. The hydraulics and geomorphology were evaluated via desktop review and from our field visit in summer 2021. The physiochemistry and biology of the channel were not directly measured in 2021, but data on existing stream conditions and field observations provided enough information to qualitatively assess these factors.

To facilitate a side-by-side review of the decision parameters, a comparison matrix table was developed and is included as Table 5-7. To minimize subjectivity, comparison of the parameter criteria valuation was limited to positive (+ or ++), negative (-), or neutral (0). The positive, negative, and neutral values assigned to the alternatives represent the adverse impacts, positive benefits, or no change that would characterize each alternative compared to existing conditions, anticipated conditions through the life of the project, and the practicability of implementation of the alternative.

Table 5-7 Stream Quantification Tool (SQT) assessment of functional change from Reach B5C Stream Restoration Activities

	Hydrology	Hydraulics	Geo-morphology	Physico-chemistry	Biology
Existing Condition	Functioning	Function-at-risk	Function-at-risk	Function-at-risk	Function-at-risk
Concept A	Neutral	+	+	+	neutral
Concept B	Neutral	++	++	+	+
Concept C	Neutral	++	++	++	+

5.4.1 Function-Based Rapid Stream Assessment:

The following is a summary of the function-based rapid assessment of the existing condition and the restoration concepts for Reach B5C.

- **Existing Conditions** – The option to take no action (i.e., current site conditions) was evaluated and included to establish a baseline for comparison of each Concept.
    - **Hydrology –** The existing hydrologic regime is intermittent flow with occasional flashy rises during stormwater events. The median flow predicted by Streamstats is 0.05 cfs. It is **functioning-at-risk** since the stream supports some ecological functions but has been degraded and functioning at less than 100% of its potential.
    - **Hydraulics –** During high flows undercutting of banks is scouring below the culvert is occurring at the upstream end of the reach. The stream is **functioning-at-risk to not functioning at some locations.**
    - **Geomorphology –** There is some moderate channel incision occurring. The stream has very low sinuosity, reducing the natural variation in riffles and pools. The stream bed has limited coarse material and is much of it is embedded with fine sediment. We classified it as **functioning-at-risk.**

- **Physicochemistry –** The stream likely has warm temperatures and low dissolved oxygen (DO) during low flow conditions during the summer to early fall. Stream monitoring data, Streamstats output and field observations confirm that the stream has little or no flow with discontinuous pools most of the time. It was classified as **Functioning at risk.**
- **Biology –** The reach has limited biological value for fish, although some small stream fish are present in the reach. There is invertebrate habitat on the stream bed and some wood pieces providing structure for macroinvertebrates. It was classified as **Nonfunctional** to **functioning-at-risk.**

- **Concept A – Low intervention: protect infrastructure and land**
  - **Hydrology –** The hydrology of the creek is not altered by the proposed actions described for Concept A, therefore the result is neutral).
  - **Hydraulics –** The hydraulics at the upstream culvert outlet would be addressed by grading and rip-rap. There would be slight improvement (+).
  - **Geomorphology –** There is little or no change to the river itself in this Concept, although erosion in the gullies entering Bluff Creek would be mitigated with erosion control practices. (+).
  - **Physicochemistry –** No change to the creek itself, though reduced sediment input from gullies would benefit in-stream water quality (+).
  - **Biology –** There would be slight improvements for fish and invertebrates through reduced sediment loading(neutral).
- **Concept B - Moderate intervention: protect infrastructure and raise bed to reduce entrenchment and bank sediment input**s
  - **Hydrology –** The hydrology of the creek is not impacted by this d by the proposed actions described for Concept B. (The result is neutral).

- **Hydraulics –** This option improves the hydraulics by protecting the culvert outlet and protecting the bed against erosion via the installation of rock riffles. (++).
- **Geomorphology –** Reduces entrenchment and slightly increases floodplain connectivity (++). Reduce lateral erosion by reducing the avg. BEHI score and the length of the bank eroding. Bed form diversity would be improved by placement of the riffles and less sediment loading that contributes to embeddedness of coarse materials.
- **Physicochemistry –** Reduced sediment input from gullies and riffles would benefit in-stream water quality, since the creek is impaired for phosphorus (+).
- **Biology –** Riffles provide spawning habitat for fish such as bluegill and coarse substrate for aquatic invertebrates to attach upon (+).

- **Concept C - High intervention: infrastructure, grade control and bank protection**
  - **Hydrology –** The hydrology of this concept is not altered by the proposed actions. (neutral). Upstream watershed practices that store water would be required for that.
  - **Hydraulics –** This option improves the hydraulics by protecting the culvert outlet and protecting the bed against erosion via the installation of rock riffles. (++).
  - **Geomorphology –** Reduces entrenchment and slightly increases floodplain connectivity (++).
  - **Physicochemistry –** Further reduced sediment input from gullies and riffles would benefit in-stream water quality, since the creek is impaired for phosphorus (++)**.**
  - **Biology –** Riffles provide spawning habitat for fish such as bluegill and coarse substrate for aquatic invertebrates to attach upon (+).

5.5 Summary of Project Impacts and Benefits

Table 5-4 summarizes the estimated annual pollutant removals and Engineer's opinion of probable cost for each conceptual design considered. Because RPBCWD prefers to take a holistic, ecological approach to restoration projects, a second evaluation matrix with additional qualitative considerations has been provided. Table 5-8 provides a summary of each conceptual design based on the following criteria:

- **Annual Pounds of TP Removed** – *quantitative* – 0 for the lowest reduction in annual TP and 1.0 for highest reduction in annual TP.
- **Cost per Pound of TP Removed** – *quantitative* – 0 for the highest cost per pound of TP removed and 1.0 for lowest cost for the lowest cost per pound of TP removed.
- **Annual Pounds of TSS Removed** – *quantitative* – 0 for the lowest reduction in annual TSS and 1.0 for highest reduction in annual TP.
- **Cost per Pound of TSS Removed** – *quantitative* – 0 for the highest cost per pound of TSS removed and 1.0 for lowest cost for the lowest cost per pound of TP removed.
- **Opinion of Probable Cost** – *quantitative* – 0 for the highest capital cost and 1.0 for the lowest capital cost.
- **Upland/Tree Impact** – *quantitative* – 0 for the largest upland impact and 1.0 for the lowest upland impact.
- **Ecologically Enhanced Area** – *quantitative* – 0 for the smallest ecologically enhanced area and 1.0 for the largest area of ecological enhanement.
- **Habitat Creation** – *qualitative* – assigned a value of 0 if no BMP provides no additional habitat, 0.5 if BMP provides some habitat, and 1.0 if BMP provides habitat for the entire footprint area.
- **Educational Opportunity** – *qualitative* – assigned a value of 0 if the BMP cannot be seen by the general public, 0.5 if some aspects of the BMP are visible, and 1.0 if the BMP is fully visible and can be used for educational demonstrations.

The individual scores for each parameter were summed into a total score, with the largest score being the recommended options. Based on the results, the wetland restoration in reach B5a and the full restoration of the creek in reach B5C score the highest.

Table 5-8 Evaluation Matrix Summary of Bluff Creek Reach 5 Conceptual Design Options

Evaluation Parameter	B5A – Concept A	B5B – Concept A	B5B – Concept B	B5C – Concept A	B5C – Concept B	B5C – Concept C
Annual TP Load Removed	0.82	0.7	0.7	0.29	0.56	1
Cost/lb TP Removed	0.54	0	0.21	0.13	0.4	0.42
Annual TSS Load Removed	0.14	0.7	0.7	0.29	0.56	1
Cost/lb TSS Removed	0	0.64	0.71	0.68	0.78	0.79
Opinion of Probable Cost	0.46	0	0.21	0.63	0.52	0.17
Upland/Tree Impact	0.38	0	0	0.51	0.4	0.21
Ecologically Enhanced Area	1	0.06	0.06	0.01	0.04	0.07
Habitat Creation	1	1	1	0	0.5	1
Educational Opportunity	1	0	0	0	0.5	0.5
Total Score	**5.33**	**3.09**	**3.59**	**2.55**	**4.25**	**5.17**

5.6 Management Activities

To ensure the success of the proposed restoration activities, the following inspection and maintenance activities are recommended for the stream reach.

5.6.1 Inspections

If a project is implemented, annual inspection of the Project during the growing season each year will be needed. All inspections will include the tasks listed below, along with any other visual observation necessary. In addition, stream bank erosion issues often develop following high flow events; therefore the inspection tasks listed below should also be performed following storm events exceeding a 10-year return period for storm events with durations of 12 hours or greater, as defined by Atlas 14 and as recorded at the National Weather Service station in Chanhassen.

- Inspect the condition of each of the stream bank protection locations throughout the Project Area. Criteria to note include but are not limited to the following:
    - For areas with riprap protection, should note:
        - The general condition of the riprap.
        - Observed displacement of riprap material.

- For areas with rock vanes and cross vanes for bank protection, should note:
    - Displacement of boulders used to construct the vanes.
    - Potential undermining of the vanes due to scour immediately downstream of the vanes.
    - Flow patterns that appear to be eroding around the vane.
    - Any bank erosion within approximately 10 feet of the vane.
- For areas with root wads for bank protection, should note:
    - The general condition of the root wads (moved, rotted, etc.).
    - Any bank erosion within approximately 10 feet of the root wad.
- For areas with re-established vegetation, should note:
    - The general condition of seeded areas and vegetative plantings.
    - The survival rates of vegetative plantings.
    - The percent cover by grasses and forbs in seeded areas.

- Document significant bank erosion locations, as defined as areas with raw, unvegetated banks greater than approximately 2 feet tall and with bank angles steeper than approximately 45 degrees.
- Note any observed changes in the stream flow pattern or direction throughout the Project, and note other locations where bank protection may be required;
- Examine storm sewer outlets for undermining, blockage and scour at the outlet and erosion;
- Record location of accumulated debris, downed trees and branches that may adversely redirect the stream flow into the stream banks;
- Take photographs to document the inspection findings in the preceding inspection tasks.

Over the life of the project, the inspection form may be periodically revised to improve inspection effectiveness, including but not limited to the implementation of a mobile data collection app.

5.6.2 Maintenance

Routine maintenance activities may include removal of fallen trees that may impede the flow of water, revegetating exposed soils, replacement of boulders for cross vanes, repair of displaced riprap and maintenance of buffer areas as identified through the inspection report. Maintenance will consist of activities to ensure that the flow of water is not impeded. All maintenance activities will comply with RPBCWD's standard buffer maintenance requirements as summarized below:

- Buffer vegetation must not be cultivated, cropped, pastured, mowed, fertilized, subject to the placement of mulch or yard waste, or otherwise disturbed, except for periodic cutting or burning that promotes the health of the buffer, actions to address disease or invasive species, mowing for purposes of public safety, temporary disturbance for placement or repair of buried utilities, or other actions to maintain or improve buffer quality and performance, each as approved by RPBCWD in advance in writing or when implemented pursuant to a written maintenance plan approved by RPBCWD.
- Diseased, noxious, invasive or otherwise hazardous trees or vegetation may be selectively removed from buffer areas and trees may be selectively removed or pruned to maintain health.
- Pesticides and herbicides may be used in accordance with Minnesota Department of Agriculture rules and guidelines.
- No fill, debris or other material will be placed within a buffer.
- No structure or impervious cover (hard surface) may be created within a buffer area.

Routine Maintenance of the Project is defined as activities that will not require equipment that would adversely impact the Project area, as follows:

- Removing fallen trees that are causing bank erosion;
- Vegetation maintenance, such as vegetation replacement that does not require the use of heavy equipment within the Project area;
- Replacement of cross vane boulders and repair of displaced riprap.

Routine Maintenance does not include reconstruction of failed toe and bank stabilization design elements requiring heavy equipment.

6.0 Additional Assessments and Permitting

6.1 Additional Assessments Needed

Additional assessments will be needed early in final design process to complete project planning and permitting prior to construction. Brief descriptions of these assessments are included below.

- *Phase I Environmental Assessment* – This assessment would be needed to determine the likelihood of contamination within the project area. This is key for project planning because discovery of contamination requires swift action to contain the contamination and can be expensive. Barr recommends completing a Phase I environmental site assessment consistent with ASTM E1527 – 13 during the early design stages of project development to better assess the risk that past environmental releases could impact the project cost and execution.

- *Phase I Cultural and Historical Assessment* – This assessment is needed for USACE permitting to determine the likelihood of cultural and historical artifacts being present within the project area. An archeological assessment of the Area of Potential Impact (APE) is required for permitting, and Barr recommends completion of this assessment early in the project design phase to determine if there is a reasonable probability of encountering in-tact archeological artifacts or features within the project site. The results of this assessment will determine if additional archeological work is necessary prior to construction.

- *Wetland delineation* – This assessment is necessary to determine the project impacts and complete permitting. The type of impacts may require additional mitigation. In addition, an assessment following the Minnesota Routine Assessment Method (MnRAM) will aid in determining the existing ecological function and value and the potential increase in values post restoration.

6.2 Permitting Considerations

Several permits and approvals would be required prior to construction of the proposed stabilization project, as described in the following sections. To facilitate the permit review process, the USACE and MnDNR would be invited on a project site visit in order to discuss preliminary stabilization concept plans and answer initial project questions.

6.2.1 Wetlands impacts

A wetland delineation has not been completed for this study. Field observations indicate that only the channel is likely to be considered to be a wetland and be directly impacted in Reach B5C; however the floodplain adjacent to Reach B5C might have some wetland area. As such, all construction access and work areas would need to be reviewed by the Local Government Unit (LGU) administering the Wetland Conservation Act (WCA) and the USACE. If wetland restoration activities are undertaken upstream of Galpin Boulevard, wetland delineation would be needed and an assessment of the potential change in wetland area from the restoration activities.

6.2.2 USACE Letter of Permission

Impacts to waters of the U.S., such as Bluff Creek, must be permitted by the USACE. It is expected that Reach B5B-B5C would impact less than 3 acres and would be authorized under a Letter of Permission (LOP-05-MN). Review of the Letter of Permission request by USACE for similar projects has taken up to six months. As such, the authorization request and wetland delineation report should be submitted at least 6 months prior to the start of construction and may be submitted prior to finalization of construction documents. Because the proposed activities involve stabilizing existing streambanks and creating better floodplain connectivity, this type of work is generally considered self-mitigating and/or an enhancement to the aquatic system. As such, USACE-required mitigation is not expected.

6.2.3 MnDNR Work in Public Waters Permit

Since Bluff Creek is considered a public water by the MnDNR, a Work in Public Waters Permit from the agency would be required for all stabilization activities on Bluff Creek. Work in Public Waters Permits are reviewed by the MnDNR Area Hydrologist and are typically issued in two to four months. The permit application may be submitted prior to finalization of construction documents. Because the proposed activities involve stabilizing existing streambanks and creating better floodplain connectivity, this type of work is generally considered self-mitigating and/or an enhancement to the aquatic system. As such, MnDNR-required mitigation is not expected.

6.2.4 MPCA Construction Stormwater General Permit

Construction of the proposed concepts should not require a National Pollutant Discharge Elimination System/State Disposal System Construction Stormwater (CSW)

General Permit issued by the MPCA, which would require preparation of a stormwater pollution prevention plan (SWPPP). Determination of the need for permitting would be determined once final grading plans are developed.

Based on the field investigation, there is debris along Reach B5B that may have resulted in contamination in the soil; therefore, additional permits for disposing of contaminated soil may be needed. Contaminated materials would need to be handled and managed appropriately. The response to discovery of contamination typically includes entering the MPCA's voluntary program. In accordance with MPCA guidance, a construction contingency plan could be prepared for these projects. This would include specifying initial procedures for handling potentially impacted materials, collecting analytical samples, and working with the MPCA to determine a method for managing impacted materials.

6.2.5 Environmental Assessment Worksheet

The Minnesota administrative rules (MN Rules 4410.4300, Subpart 27) require the preparation of an Environmental Assessment Worksheet (EAW) for any project that would "change or diminish the course, current, or cross-section of one acre or more of any public water or public waters wetland." Depending on the preferred alternative and associated construction footprint of each project, an EAW may be required. At this time, it is expected that an EAW may be required for remeandering Reach B5B (Concept A). The remaining options considered for these reaches are not anticipated to require an EAW. However, if restoration of the wetland upstream of Galpin Boulevard is pursued additional environmental evaluations may be required.

6.2.6 City of Chanhassen Earthwork Permit

The City of Chanhassen requires an earthwork permit for grading activities. Check with the City for grading permit requirements.

6.2.7 RPBCWD Permit

The RPBCWD has developed district-wide rules for floodplain management and drainage alterations, erosion and sediment control, wetland and creek buffers, dredging and sediment removal, shoreline and streambank stabilization, waterbody crossings and structures, appropriation of public surface waters, and stormwater management. The RPBCWD requires a District Permit for construction on either of reaches to ensure the project is developed in compliance with District rules.

7.0 Agreements

Table 7-1 summarizes anticipated agreements required prior to construction of the Upper Riley Creek Restoration Project.

Table 7-1 Summary of Anticipated Agreements

Description	Notes	Period	Lead Organization
Cooperative agreement between RPBCWD and City of Chanhassen	Cooperative agreement between RPBCWD and City of Chanhassen for activities related to construction and maintenance of the restoration project. The agreement would establish procedures for performing specific tasks, and define responsibilities of each organization.	2023	RPBCWD and City of Chanhassen

8.0 Recommendations

This study assessed erosion issues on Reach B5 on Bluff Creek and evaluated options for stabilizing the reach. The assessments and evaluation considered erosion reduction benefits, impacts to aquatic habitat, ecological functional change through the SQT, the ability to use natural materials, such as wood, in restoration, and cost-effectiveness.

Based on the results of the district's recent monitoring efforts, as summarized in Table 4-3 and Table 4-4, Reach B5B and B5C do not achieve the MPCA water quality standards. In addition, the CRAS identified B5B and B5C as potential restoration areas.

8.1 Reach B5A

While the in-stream actions don't change the hydrologic inputs of the stream, practices in the upstream reaches could reduce the hydrograph peaks flowing into Bluff Creek. Restoration of the wetland hydrology in Reach B5A would help reduce peak flows and erosion in stream reaches B5B and B5C resulting in a project that is more resilient to the changing climate. Installation of water retention structure at the wetland outlet would detain stormwater in the upstream wetland while minimizing the potential for increasing flood risk to adjacent properties. Restoration of the wetland hydrology would also enhance pollutant removals and carbon sequestration based on P8 modeling and the recently published WRET tool respectively. Therefore, a project on Reach 5 of Bluff Creek should include provisions for the assessment and potential enhancement of the wetland surrounding the headwaters of Bluff Creek.

8.2 Reach B5B

Restoration of Reach B5B is not recommended until a Phase I Environmental Assessment can be completed to determine the need and potential cost for remediating pollution (if present) within the project area.

Once the Phase I Environmental Assessment is completed, Concept A would be the preferred solution on this reach. The opinion of probable cost for Concept A is higher than Concept B, however it has additional value by creating additional, more natural habitat than Concept B.

8.3 Reach B5C

The three concepts evaluated for this reach would accomplish varying levels of pollutant load reduction and project ecological benefits. While all options are viable alternatives, Concept C provides the most cost-effective reduction of sediment and phosphorus load and provides the greatest ecological benefit.

Restoration of Reach B5C is recommended at this time with Concept C. Compared to Reach B5B, this reach has a higher sediment loading and a restoration project will be more cost-effective in terms of per pound of TP and TSS reduced. There is also less uncertainty in the potential costs for stabilizing this reach because it is presumed that no environmental clean-up within the project area will be necessary.

As discussed in the SQT assessment, the projects would reduce streambank sediment loading, reduce or prevent further entrenchment and improve in-stream conditions for aquatic life. In-stream conditions would be enhanced by reducing sediment inputs and providing coarse substrate via the riffle for fish spawning and invertebrate colonization.

Permitting for this reach will also be easier compared to Reach B5B due to the minimal impact to wetlands adjacent to the creek and lack of a potential need for an EAW.

8.4 Recommended Strategies for Ecological Enhancement and Management

Based on the 10-year plan prioritization and this assessment, it is recommended that the District develop a project to pursue the following:

- Restoration of the wetland hydrology upstream of Galpin Avenue (see Figure 5-2)
- Restoration of the stream corridor and eroded gullies in Reach B5C (see Figure 5-9).

These restoration measures could be grouped into a single Project or phased using an adaptive management approach by beginning the restoration efforts in the reach by restoring the wetland hydrology.

The Project will enhance the ecology of Bluff Creek by restoring the hydrology to the partially drained wetland at the creek headwaters, providing greater stream depth variability, more channel bed substructure types, and varied channel velocities. The proposed Project will remove accumulated debris from within the channel, reduce erosion and improve water quality while also improving natural stream habitat for aquatic organisms. Providing better floodplain connectivity for Bluff Creek also enhances surrounding riparian habitat and improves the ecological function through the corridor. By establishing a stable stream corridor, the Project will also help address the Minnesota Pollution Control Agency's (MPCA's) identified turbidity impairment in Bluff Creek. Several adjacent trails provide opportunities for interpretive signage and future programming to educate the public on the importance of diverse stream corridors. As summarized in Table 8-2, the combined restoration of the wetland hydrology and Reach B5C stream corridor is estimated to be 34 tons of sediment per year, which is equivalent to approximately 68,455 pounds of TSS per year and approximately 69 pounds of TP per year. The engineer's opinion of probable cost is $606,100 for this reach with a range between $545,500 and $848,600. If this project this pursued, it is recommended that RPBCWD budget $650,000 to allow for design flexibility and present construction industry volatility.

In addition to the expected water quality improvement expect from restoring the stream, the Project will provide other benefits as summarized in Table 8-2.

Table 8-1 Recommended Implementation Strategy Summary of Cost Estimates and Pollutant Loading Reduction

Reach	Concept	Alternative Description	Ecological Enhancement Area (ac)	Project Opinion of Probable Cost (1)	Annualized Cost (2)	TP Loading		TSS Loading	
						Load Reduction (lb/yr)(3)	Cost/lb Reduced (4)	Load Reduction (lb/yr) (3)	Cost/lb Reduced(4)
B5A	A	Restore Wetland Hydrology	7.9	$240,400 ($216,400-$336,600)	$16,828	31	$543	8,255	$2.04
B5C	C	Stabilize Gullies, Install grade control, Restore Bank	0.6	$365,700 ($329,100-$512,000)	$25,599	38	$681	60,200	$0.43
		Total	8.5	$606,100 ($545,500-$848,600)	$42,427	69	$1,224	68,455	$2.47

(1) A Class 4/5 screening-level opinion of probable cost. The cost opinion is based on project-related information available to Barr at this time and includes a conceptual-level design of the project. Includes 30% project contingency, 30% for planning, engineering, and design, and 10% for construction administration. Lower bound assumed at -10% and upper bound assumed at +50%.

(2) Assumed to be 2% of the total project cost for annual maintenance plus the initial project cost distributed evenly over a 20 year project lifespan.

(3) Reductions reflect the estimated load decrease from the proposed project element and exclude any ancillary benefits that reduced flows would have on further reducing erosion, scour, and pollutant transport from downstream reaches.

(4) Annualized cost divided by estimated annual pollution load reduction.

Table 8-2 Potential Project Benefit Summary

<table>
<tr><th>Benefits</th><th>Qualitative Discussion</th><th>Metric</th></tr>
<tr><td>Habitat
(acres)</td><td>Create in-channel habitat for fish and macroinvertebrates providing pools, riffle and refuge area for aquatic life. Improve riparian habitat conditions through invasive species removal and better connection of riparian corridor to stream channel.</td><td>Up to 0.3 acres of in-channel habitat improvements;
Up to 7.9 acres of wetland habitat improvements</td></tr>
<tr><td>Pollutants
(e.g., TP, TSS, etc; lbs)</td><td>Restore wetland hydrology. Restore stable streambanks and improve riparian buffer to reduce movement of eroded soil and nutrients to Bluff Creek.</td><td>Reduce TSS by 68,455 lbs/yr;
Reduce TP by 69 lbs/yr</td></tr>
<tr><td>Abstraction
(cubic ft)</td><td>Re-connecting Bluff Creek channel to floodplain allows for greater infiltration due to sandy soils found in the floodplain. Vegetation found within the floodplain also improves infiltration.</td><td>Metric cannot be measured in the context of this Project.</td></tr>
<tr><td>Streambank Restored
(feet)</td><td>Restore stable streambanks and improve riparian buffer is significant driver of the other benefits presented in this table.</td><td>1,000 feet of channel length</td></tr>
<tr><td>Groundwater Conserved
(gal)</td><td colspan="2">Benefit is not applicable.</td></tr>
<tr><td>Community Reach</td><td colspan="2">A portion of the project is located on public property accessible by public trail system public hearing will be held prior to RPBCWD Board ordering project; will hold adjacent landowner meetings prior to construction; informational pamphlets explaining project will be placed along the trail during construction; plans for future interpretive signage</td></tr>
<tr><td>Flow Reduction
(fps, cfs, psf, etc.)</td><td>Restore the headwaters wetland hydrology and re-connect Bluff Creek channel to floodplain, allowing high flows to extend into floodplain, reducing velocity of flows through the area.</td><td><table><tr><th rowspan="2">Storm Event</th><th colspan="2">Reductions</th></tr><tr><th>Flow (cfs)</th><th>B5C Velocity (fps)</th></tr><tr><td>1</td><td>28.0</td><td>1.9</td></tr><tr><td>2</td><td>41.3</td><td>2.0</td></tr><tr><td>10</td><td>43.1</td><td>0.9</td></tr><tr><td>100</td><td>-3.0</td><td>0.0</td></tr></table>+ indicates a reduction
- indicated an increase</td></tr>
<tr><td>Flood Storage
(ac. ft)</td><td>Improve connectivity of creek to floodplain, providing for project resiliency and reducing flow velocities</td><td></td></tr>
<tr><td>Wetland Management Class</td><td colspan="2">Restoring the hydrology to the headwaters wetland has the potential to improve the wetland management classification</td></tr>
</table>

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Appendix A Historical Imagery

The area surrounding Reach B5C of Bluff Creek underwent considerable change since the 1991 aerial photo shown below. There was development around the creek and a new road installed south of the creek. These changes would have reduced connectivity with the landscape, increased runoff leading to increased sediment and nutrient loading and degradation of the stream's water quality and ecological integrity.

1991

2002

2020

Appendix B Cost Estimate Summary for Concept Options

This section presents the general methodology used to develop an engineer's opinion of probable cost (OPC) of the evaluated alternatives. The OPC estimates have been developed for each alternative evaluated. OPC estimates are considered Class 4 feasibility-level estimates as defined by the American Association of Cost Engineers International (AACI International). The Class 4 level OPC estimates typically have an acceptable range of between -10% to -30% on the low range and +20% to +50% on the high range. Based on the development of concepts and initial vetting of the concepts, a range for the OPC estimate between -10% and +50% of the estimated construction budget was used for budgeting. The cost estimates for each stabilization measure, including the quantities and unit costs, are included in Appendix B. These costs were combined with respective pollutant load reduction (sediment and TP) estimates to estimate the efficiency of each alternative in terms of dollars per pound of pollutant removed.

- The OPC's incorporate a 30% construction contingency.
- Costs associated with design, permitting, and legal services is assumed to be 20% of the estimated construction costs (excluding contingency).
- Costs associated with construction management are assumed to be 10% of the estimated construction costs (excluding contingency).
- Development of the necessary permits and associated documentation is assumed to cost $10,000.
- Construction easements may be necessary to construct the project; however, the cost is expected to be negligible.
- Additional work may be required to determine if cultural and/or historical resources are present at any project site.

The annualized pollutant-reduction cost for an alternative is the annual load reduction divided by the annualized cost.

Reach	Alternative	Project Cost Estimate(1)	Annualized Maintenance Cost(2)
B5A	A	$240,400 ($216,400-$336,600)	$4,808 ($4,328-$6,732)
B5B	A	$442,700 ($398,400-$619,800)	$8,854 ($7,968-$12,396)
B5B	B	$348,900 ($314,000-$488,500)	$6,978 ($6,280-$09,770)
B5C	A	$162,000 ($145,800-$226,800)	$3,240 ($2,916-$4,536)
B5C	B	$213,300 ($192,000-$298,600)	$4,266 ($3,840-$5,972)
B5C	C	$365,700 ($329,100-$512,000)	$7,314 ($6,582-$10,240)
* Costs may not sum due to rounding.			

(1) A Class 4/5 screening-level opinion of probable cost, as defined by the American Association of Cost Engineers International (AACI International), has been prepared for these alternatives. The opinion of probable construction cost provided in this table is based on Barr's experience and qualifications and represents our best judgment as experienced and qualified professionals familiar with the project. The cost opinion is based on project-related information available to Barr at this time and includes a conceptual-level design of the project. Includes 30% project contingency, 30% for planning, engineering, and design, and 10% for construction administration. Lower bound assumed at -10% and upper bound assumed at +50%.

(2) Assumed to be 2% of the total project cost

Detailed breakdowns of the cost are shown below using the general categories of mobilization, site prep, design and restoration. There is a total estimated construction cost, a contingency construction cost of 30% of the total and a 30% engineering & design. F & I stands for "furnish and install" in the following tables.

BARR

PREPARED BY: BARR ENGINEERING CO.

Preliminary Design Level

ENGINEER'S OPINION OF PROBABLE COST 3/13/2022

PROJECT: Bluff Creek - B5A- Restore Wetland Hydrology

LOCATION: Chanhassen, Minnesota

PROJECT #: 23270053 - TO36A

ESTIMATED COSTS					
Item No:	Item Description	Unit	Estimated Quantity	Unit Cost	Total Cost
Mobilization					
1	Mobilization and Demobilization	LS	1	$ 10,800	$ 10,800.00
2	Water Control	LS	1	$ 3,200	$ 3,200.00
3	Traffic Control	LS	1	$ 2,100	$ 2,100.00
4	Temporary Easement for Access	LS	1	$ 5,500	$ 5,500.00
Site Preparation					
5	Temporary Erosion and Sediment Control	LS	1	$ 3,700	$ 3,700.00
7	F&I Rock Construction Entrance	EA	1	$ 1,430	$ 1,430.00
8	F&I Sediment Logs	LF	600	$ 5.50	$ 3,300.00
10	Clearing and Grubbing	ACRE	0.5	$ 4,400	$ 2,200.00
Civil Design					
11	Boulder Cross Vane	Each	1	$ 2,750	$ 2,750.00
12	Field Stone Riprap MnDOT Class III	TON	5	$ 91.30	$ 456.50
13	Control Structure	SF	800	$ 60.00	$ 48,000.00
14	Grading	SY	2420	$ 4.40	$ 10,648.00
Restoration					
18	F&I Import Topsoil	CY	200	$ 41.80	$ 8,360.00
19	F&I Native Seed	ACRE	0.5	$ 3,520	$ 1,760.00
20	F&I Mulch	SY	2400	$ 0.86	$ 2,059.20
21	F&I Erosion Control Blanket	SY	1200	$ 2.75	$ 3,300.00
23	Restore Access Paths and Haul Roads	LF	600	$ 5.50	$ 3,300.00
24	Vegetation Establishment (3 years)	EA	3	$ 1,650	$ 4,950.00
	Construction Cost Subtotal				$117,800
	Construction Cost Contingency		30%		$35,300
	Engineering Design		30%		$45,900
	Construction Administration		15%		$23,000
	Permitting		10%		$15,300
	Legal Assistance		2%		$3,100
	TOTAL PROJECT COST (Mid Range Estimate)				**$240,400**
	Low Range Estimate (-10%)				$216,400
	High Range Estimate (+40%)				$336,600

Notes:

1 Design Work Completed to Approximately 10% Design Level.

2 Quantities Based on Design Work Completed.

3 Unit Prices Based on Information Available at This Time.

4 This preliminary cost estimate (Class 4, 10% design completion per ASTM E 2516-11(2019) is based on preliminary-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design. The estimated accuracy range for the Total Project Cost as the project is defined is -10% to +40%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

BARR

PREPARED BY: BARR ENGINEERING CO.

Preliminary Design Level

ENGINEER'S OPINION OF PROBABLE COST 3/13/2022

PROJECT: Bluff Creek - B5B Option A - Remeander Creek

LOCATION: Chanhassen, Minnesota

PROJECT #: 23270053 - TO36A

ESTIMATED COSTS					
Item No:	Item Description	Unit	Estimated Quantity	Unit Cost	Total Cost
Mobilization					
1	Mobilization and Demobilization	LS	1	$ 12,100	$ 12,100.00
2	Water Control	LS	1	$ 3,600	$ 3,600.00
3	Traffic Control	LS	1	$ 2,300	$ 2,300.00
4	Temporary Easement for Access	LS	1	$ 5,500	$ 5,500.00
Site Preparation					
5	Temporary Erosion and Sediment Control	LS	1	$ 3,700	$ 3,700.00
6	Tree Removals	EA	20	$ 330	$ 6,600.00
7	F&I Rock Construction Entrance	EA	2	$ 1,430	$ 2,860.00
8	F&I Sediment Logs	LF	1970	$ 5.50	$ 10,835.00
10	Clearing and Grubbing	ACRE	0.8	$ 4,400	$ 3,520.00
Civil Design					
11	Boulder Cross Vane	Each	8	$ 2,750	$ 22,000.00
12	Field Stone Riprap MnDOT Class III	TON	20	$ 91.30	$ 1,826.00
13	Granular Filter MNDOT Spec 3601	TON	20	$ 38.50	$ 770.00
14	Grading	SY	1291	$ 4.40	$ 5,678.93
15	Excavate New Channel	CY	2200	$ 16.50	$ 36,300.00
16	Environmental Investigation and Clean-up	LS	1	$ 55,000.00	$ 55,000.00
Restoration					
18	F&I Import Topsoil	CY	300	$ 41.80	$ 12,540.00
19	F&I Native Seed	ACRE	0.8	$ 3,520	$ 2,816.00
20	F&I Mulch	SY	3900	$ 0.86	$ 3,346.20
21	F&I Erosion Control Blanket	SY	1950	$ 2.75	$ 5,362.50
22	Live Stakes	EA	220	$ 9.90	$ 2,178.00
23	Restore Access Paths and Haul Roads	LF	985	$ 5.50	$ 5,417.50
24	Vegetation Establishment (3 years)	EA	3	$ 6,600	$ 19,800.00
	Construction Cost Subtotal				$224,100
	Construction Cost Contingency		30%		$67,200
	Engineering Design		30%		$87,400
	Construction Administration		10%		$29,100
	Permitting		10%		$29,100
	Legal Assistance		2%		$5,800
	TOTAL PROJECT COST (Mid Range Estimate)				**$442,700**
	Low Range Estimate (-10%)				$398,400
	High Range Estimate (+40%)				$619,800

Notes:

[1] Design Work Completed to Approximately 10% Design Level.

[2] Quantities Based on Design Work Completed.

[3] Unit Prices Based on Information Available at This Time.

[4] This preliminary cost estimate (Class 4, 10% design completion per ASTM E 2516-11(2019) is based on preliminary-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design. The estimated accuracy range for the Total Project Cost as the project is defined is -10% to +40%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

BARR

PREPARED BY: BARR ENGINEERING CO.

Preliminary Design Level

ENGINEER'S OPINION OF PROBABLE COST 3/13/2022

PROJECT: Bluff Creek - B5B Option B - Restore In-Place

LOCATION: Chanhassen, Minnesota

PROJECT #: 23270053 - TO36A

ESTIMATED COSTS					
Item No:	Item Description	Unit	Estimated Quantity	Unit Cost	Total Cost
Mobilization					
1	Mobilization and Demobilization	LS	1	$ 16,600	$ 16,600.00
2	Water Control	LS	1	$ 4,900	$ 4,900.00
3	Traffic Control	LS	1	$ 3,200	$ 3,200.00
4	Temporary Easement for Access	LS	1	$ 5,500	$ 5,500.00
Site Preparation					
5	Temporary Erosion and Sediment Control	LS	1	$ 3,300	$ 3,300.00
6	Tree Removals	EA	20	$ 330	$ 6,600.00
7	F&I Rock Construction Entrance	EA	2	$ 1,430	$ 2,860.00
8	F&I Sediment Logs	LF	1970	$ 5.50	$ 10,835.00
10	Clearing and Grubbing	ACRE	0.8	$ 4,400	$ 3,520.00
Civil Design					
11	Boulder Cross Vane	Each	5	$ 2,750	$ 13,750.00
12	Field Stone Riprap MnDOT Class III	TON	15	$ 91.30	$ 1,369.50
13	Granular Filter MNDOT Spec 3601	TON	15	$ 38.50	$ 577.50
14	Grading	SY	700	$ 4.40	$ 3,080.00
16	Environmental Investigation and Clean-up	LS	1	$ 55,000.00	$ 55,000.00
Restoration					
18	F&I Import Topsoil	CY	300	$ 41.80	$ 12,540.00
19	F&I Native Seed	ACRE	0.8	$ 3,520	$ 2,816.00
20	F&I Mulch	SY	3900	$ 0.86	$ 3,346.20
21	F&I Erosion Control Blanket	SY	1950	$ 2.75	$ 5,362.50
22	Live Stakes	EA	220	$ 9.90	$ 2,178.00
23	Restore Access Paths and Haul Roads	LF	985	$ 5.50	$ 5,417.50
24	Vegetation Establishment (3 years)	EA	3	$ 6,600	$ 19,800.00
	Construction Cost Subtotal				$182,600
	Construction Cost Contingency		30%		$54,800
	Engineering Design		30%		$71,200
	Construction Administration		10%		$23,700
	Permitting		5%		$11,900
	Legal Assistance		2%		$4,700
	TOTAL PROJECT COST (Mid Range Estimate)				**$348,900**
	Low Range Estimate (-10%)				$314,000
	High Range Estimate (+40%)				$488,500

Notes:

[1] Design Work Completed to Approximately 10% Design Level.

[2] Quantities Based on Design Work Completed.

[3] Unit Prices Based on Information Available at This Time.

[4] This preliminary cost estimate (Class 4, 10% design completion per ASTM E 2516-11(2019) is based on preliminary-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design. The estimated accuracy range for the Total Project Cost as the project is defined is -10% to +40%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

PREPARED BY: BARR ENGINEERING CO.

BARR

Preliminary Design Level

ENGINEER'S OPINION OF PROBABLE COST 12/20/2021

PROJECT: Bluff Creek - B5C Option A - Stabilize Gullies and Riprap Culvert Outlet

LOCATION: Chanhassen, Minnesota

PROJECT #: 23270053 - TO36A

ESTIMATED COSTS					
Item No:	Item Description	Unit	Estimated Quantity	Unit Cost	Total Cost
Mobilization					
1	Mobilization and Demobilization	LS	1	$7,800	$ 7,800.00
2	Water Control	LS	1	$5,500	$ 5,500.00
3	Traffic Control	LS	1	$2,750	$ 2,750.00
4	Temporary Easement for Access	LS	1	$5,500	$ 5,500.00
Site Preparation					
5	Temporary Erosion and Sediment Control	LS	1	$ 1,200	$ 1,200.00
6	Tree Removals	EA	10	$ 330	$ 3,300.00
7	F&I Rock Construction Entrance	EA	1	$ 1,430	$ 1,430.00
8	F&I Sediment Logs	LF	200	$ 5.50	$ 1,100.00
10	Clearing and Grubbing	ACRE	0.28	$ 4,400	$ 1,232.00
Civil Design					
12	Field Stone Riprap MnDOT Class III	TON	332	$ 91.30	$ 30,311.60
14	Grading	SY	1355	$ 4.40	$ 5,962.88
17	F&I Import General Fill	CY	149	$ 38.50	$ 5,735.07
Restoration					
18	F&I Import Topsoil	CY	74	$ 41.80	$ 3,093.20
19	F&I Native Seed	ACRE	0.39	$ 3,520	$ 1,372.80
20	F&I Mulch	SY	466	$ 0.86	$ 399.83
21	F&I Erosion Control Blanket	SY	400	$ 2.75	$ 1,100.00
22	Live Stakes	EA	100	$ 9.90	$ 990.00
23	Restore Access Paths and Haul Roads	LF	200	$ 5.50	$ 1,100.00
24	Vegetation Establishment (3 years)	EA	3	$ 1,650	$ 4,950.00
	Construction Cost Subtotal				$84,800
	Construction Cost Contingency		30%		$25,400
	Engineering Design		30%		$33,100
	Construction Administration		10%		$11,000
	Permitting		5%		$5,500
	Legal Assistance		2%		$2,200
	TOTAL PROJECT COST (Mid Range Estimate)				**$162,000**
	Low Range Estimate (-10%)				$145,800
	High Range Estimate (+40%)				$226,800

Notes:

[1] Design Work Completed to Approximately 10% Design Level.

[2] Quantities Based on Design Work Completed.

[3] Unit Prices Based on Information Available at This Time.

[4] This preliminary cost estimate (Class 4, 10% design completion per ASTM E 2516-11(2019) is based on preliminary-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design. The estimated accuracy range for the Total Project Cost as the project is defined is -10% to +40%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

BARR

PREPARED BY: BARR ENGINEERING CO.

Preliminary Design Level

ENGINEER'S OPINION OF PROBABLE COST 12/20/2021

PROJECT: Bluff Creek - B5C Option B - Stabilize Gullies, Install grade control

LOCATION: Chanhassen, Minnesota

PROJECT #: 23270053 - TO36A

ESTIMATED COSTS					
Item No:	Item Description	Unit	Estimated Quantity	Unit Cost	Total Cost
Mobilization					
1	Mobilization and Demobilization	LS	1	$ 11,000	$ 11,000.00
2	Water Control	LS	1	$ 5,500	$ 5,500.00
3	Traffic Control	LS	1	$ 2,750	$ 2,750.00
4	Temporary Easement for Access	LS	1	$ 5,500	$ 5,500.00
Site Preparation					
5	Temporary Erosion and Sediment Control	LS	1	$ 1,900	$ 1,900.00
6	Tree Removals	EA	15	$ 330	$ 4,950.00
7	F&I Rock Construction Entrance	EA	1	$ 1,430	$ 1,430.00
8	F&I Sediment Logs	LF	200	$ 5.50	$ 1,100.00
10	Clearing and Grubbing	ACRE	0.37	$ 4,400	$ 1,628.00
Civil Design					
12	Field Stone Riprap MnDOT Class III	TON	495	$ 91.30	$ 45,193.50
13	Granular Filter MNDOT Spec 3601	TON	62	$ 38.50	$ 2,387.00
14	Grading	SY	1791	$ 4.40	$ 7,879.52
17	F&I Import General Fill	CY	149	$ 38.50	$ 5,735.07
Restoration					
18	F&I Import Topsoil	CY	74	$ 41.80	$ 3,093.20
19	F&I Native Seed	ACRE	0.48	$ 3,520	$ 1,689.60
20	F&I Mulch	SY	457	$ 0.86	$ 392.11
21	F&I Erosion Control Blanket	SY	2300	$ 2.75	$ 6,325.00
22	Live Stakes	EA	100	$ 9.90	$ 990.00
23	Restore Access Paths and Haul Roads	LF	200	$ 5.50	$ 1,100.00
24	Vegetation Establishment (3 years)	EA	3	$ 3,300	$ 9,900.00
	Construction Cost Subtotal				$109,400
	30% Construction Cost Contingency		30%		$32,800
	Engineering Design (30%)		30%		$42,700
	Construction Administration		10%		$18,500
	Permitting		5%		$7,100
	Legal Assistance		2%		$2,800
	TOTAL PROJECT COST (Mid Range Estimate)				**$213,300**
	Low Range Estimate (-10%)				$192,000
	High Range Estimate (+40%)				$298,600

Notes:

[1] Design Work Completed to Approximately 10% Design Level.

[2] Quantities Based on Design Work Completed.

[3] Unit Prices Based on Information Available at This Time.

[4] This preliminary cost estimate (Class 4, 10% design completion per ASTM E 2516-11(2019) is based on preliminary-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design. The estimated accuracy range for the Total Project Cost as the project is defined is -10% to +40%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

PREPARED BY: BARR ENGINEERING CO.

Preliminary Design Level

ENGINEER'S OPINION OF PROBABLE COST 12/20/2021

PROJECT: Bluff Creek - B5C Option C - Stabilize Gullies, Install grade control, Bank Stabilization

LOCATION: Chanhassen, Minnesota

PROJECT #: 23270053 - TO36A

ESTIMATED COSTS					
Item No:	Item Description	Unit	Estimated Quantity	Unit Cost	Total Cost
Mobilization					
1	Mobilization and Demobilization	LS	1	$ 19,000	$ 19,000.00
2	Water Control	LS	1	$ 5,500	$ 5,500.00
3	Traffic Control	LS	1	$ 2,750	$ 2,750.00
4	Temporary Easement for Access	LS	1	$ 5,500	$ 5,500.00
Site Preparation					
5	Temporary Erosion and Sediment Control	LS	1	$ 2,300	$ 2,300.00
6	Tree Removals	EA	20	$ 330	$ 6,600.00
7	F&I Rock Construction Entrance	EA	2	$ 1,430	$ 2,860.00
8	F&I Sediment Logs	LF	400	$ 5.50	$ 2,200.00
10	Clearing and Grubbing	ACRE	0.48	$ 4,400	$ 2,112.00
Civil Design					
11	Boulder Cross Vane	Each	4	$ 2,750	$ 11,000.00
12	Field Stone Riprap MnDOT Class III	TON	581	$ 91.30	$ 53,045.30
13	Granular Filter MNDOT Spec 3601	TON	140	$ 38.50	$ 5,390.00
14	Grading	SY	2323	$ 4.40	$ 10,222.08
17	F&I Import General Fill	CY	769	$ 38.50	$ 29,619.33
Restoration					
18	F&I Import Topsoil	CY	385	$ 41.80	$ 16,093.00
19	F&I Native Seed	ACRE	0.63	$ 3,520	$ 2,217.60
20	F&I Mulch	SY	768	$ 0.86	$ 658.94
21	F&I Erosion Control Blanket	SY	3000	$ 2.75	$ 8,250.00
22	Live Stakes	EA	220	$ 9.90	$ 2,178.00
23	Restore Access Paths and Haul Roads	LF	200	$ 5.50	$ 1,100.00
24	Vegetation Establishment (3 years)	EA	3	$ 6,600	$ 19,800.00
	Construction Cost Subtotal				$187,500
	Construction Cost Contingency		30%		$56,300
	Engineering Design		30%		$73,100
	Construction Administration		10%		$31,700
	Permitting		5%		$12,200
	Legal Assistance		2%		$4,900
	TOTAL PROJECT COST (Mid Range Estimate)				**$365,700**
	Low Range Estimate (-10%)				$329,100
	High Range Estimate (+40%)				$512,000

Notes:

[1] Design Work Completed to Approximately 10% Design Level.

[2] Quantities Based on Design Work Completed.

[3] Unit Prices Based on Information Available at This Time.

[4] This preliminary cost estimate (Class 4, 10% design completion per ASTM E 2516-11(2019) is based on preliminary-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design. The estimated accuracy range for the Total Project Cost as the project is defined is -10% to +40%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

Appendix C Soil Test Results from Streambanks

ANALYTICAL DATA REPORT

Soil Job No.	**191 2020-21**	**Research Analytical Laboratory**
Report to:	**Chris Lenhart**	**University of Minnesota**
Date Received:	**6/28/2021**	**1902 Dudley Avenue**
Date Reported:	**7/6/2021, 7/13/2021**	**St. Paul, MN 55108**
Study Name:	**Bluff Creek**	**ral@umn.edu**
Sample Type:	**Soil**	**612-625-3101**

Sample Number	Sample ID	Bray P (mg/kg soil)	Olsen P (mg/kg soil)	NH_4OAc-K (mg/kg soil)	LOI OM (%)	Water pH
1	A: Topsoil - eroding bank	41 / 44	24 / 25	295 / 302	6.0 / 5.9	7.5 / 7.5
2	A: mid bank	31	21	118	1.6	7.9
3	A: lower bank	< 1	10	134	1.0	8.0
4	B: upper bank	29	22	258	4.1	7.2
5	B: mid bank	29	19	146	2.5	7.7
6	B: lower bank	< 1	12	97	1.2	8.0

Soil Job No.	**191 2020-21**	**ANALYTICAL DATA REPORT - ICP**	**Research Analytical Laboratory**
Report to:	**Chris Lenhart**	**Sample Prep Method: Microwave Digestion with HNO_3 (EPA 3051)**	**University of Minnesota**
Date Received:	**6/28/2021**		**1902 Dudley Avenue**
Date Reported:	**7/13/2021**		**St. Paul, MN 55108**
Study Name:	**Bluff Creek**		**ral@umn.edu**
Sample Type:	**Soil**	** LOD - Limit of Detection (batchwise instrument detection limit)*	**612-625-3101**

***LOD is expressed in units of mg/L solution, independent of dilution factors used to calculate sample concentrations*

Results falling below the Method Detection Limit (MDL) are flagged with grey fill

Laboratory ID	Sample ID	Al (mg/kg)	B (mg/kg)	Ca (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	K (mg/kg)	Mg (mg/kg)	Mn (mg/kg)	Na (mg/kg)	Ni (mg/kg)	P (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
	LOD (mg/L)***	*<0.017*	*<0.007*	*<0.117*	*<0.001*	*<0.001*	*<0.007*	*<0.004*	*<0.094*	*<0.029*	*<0.007*	*<0.010*	*<0.003*	*<0.033*	*<0.002*	*<0.010*
1	A: Topsoil - eroding bank	7529.9	*2.411*	8339.5	0.407	15.281	10.297	14420.3	1636.37	2961.6	745.09	49.81	16.754	633.21	21.864	50.014
1 dup	A: Topsoil - eroding bank d	7773.8	*2.402*	8778.3	0.361	15.318	10.390	14191.3	1690.12	3062.0	747.91	48.88	17.585	616.56	22.189	49.941
3	A: lower bank	4827.5	*<0.007 ***	56285	0.336	12.492	11.083	13701.0	1138.75	16997.0	767.74	183.41	28.189	459.26	9.757	43.036

	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	Zn
Method Detection limit (MDL) (mg/L)	*0.024*	*0.034*	*0.172*	*0.001*	*0.001*	*0.005*	*0.039*	*0.3*	*0.084*	*0.008*	*0.032*	*0.008*	*0.023*	*0.005*	*0.028*
*MDL * average spl dilution factor (~mg/kg)*	*7.65*	*10.73*	*54.92*	*0.21*	*0.36*	*1.68*	*12.42*	*97.1*	*26.96*	*2.65*	*10.08*	*2.50*	*7.45*	*1.70*	*8.87*

Method Detection Limit is defined as the average analytical blank result plus 3 standard deviations