TECHNICAL MEMORANDUM

To: Lower Minnesota River Watershed District

From: Inter-Fluve, Inc.

Date: May 18, 2021 **Project:** Area 3 Lower Minnesota River

Re: Area 3 Findings and Alternative Review Memorandum

The Lower Minnesota River Watershed District (LMRWD) retained Inter-Fluve, Inc. (Inter-Fluve) to assess the eroding bluffs at "Area 3" along the Lower Minnesota River and to conceptualize and evaluate alternative treatments to stabilize the bluff toe. This technical memorandum includes a summary of the project background and project goals; an analysis of existing conditions based on existing data review, onsite investigation, and hydraulic modeling; a summary of findings and project considerations; a review of past recommendations and alternatives considered; proposed alternatives and recommendations; and suggested next steps and schedule. This assessment is in agreement with prior assessments in that the bluff failure is being driven by a combination of factors including channel migration, increased magnitude of flows, lack of vegetative cover, other anthropogenic influences (e.g., stormwater, ponds, development runoff), and soil saturation due to groundwater seeps. The immediate recommended course of action is to complete the bathymetric survey (instead of after 90% design as currently scoped) in order to inform the scope and scale of an appropriate bluff toe stabilization measure. This report includes description of three alternatives that are intended to represent potential recommendations that could result from the findings of the bathymetric survey. It should be noted that the bathymetric survey findings will inform the final recommended alternatives. The alternatives presented in this report are: 1) A large scale rock bluff toe stabilization 2) A localized rock bluff toe and bioengineered bluff toe stabilization and 3) No-action and monitor.

BACKGROUND AND PROJECT GOALS

Area 3 is a site along the left bank of the Lower Minnesota River in Eden Prairie, approximately 19.6 river miles upstream of the Minnesota's River confluence with the Mississippi River (Figure 1). The site is adjacent to a former roadway that is now used as a walking path. Vertically, the project area is divided into three sections each characterized by a difference in slope (Figure 2). The lowermost section, the bluff toe, has an approximate 4H:1V slope, and is variably inundated by the Minnesota River. The middle portion of the slope is an eroding bluff characterized by steep (approx. 0.5H:1V on average) sandy slopes, void of vegetation. Several groundwater seeps emerge from the face of the bluff throughout its lower half. The upper portion of the slope (termed upper slope) is characterized by much milder slopes (approx. 4H:1V on average), with grassy vegetation, few trees, and some gullying erosion. The upper limit of the upper slope abuts a residential development with maintained lawns and minimal buffer between the lawns and the slope.

Figure 1: Project location map as provided by LMRWD in addendum No. 1 of the project RFP

The reach of the Minnesota River has seen significant land use changes over the last century. In the early 1900s[1], the adjacent area was largely agricultural. The Allied Waste Landfill was

[1] Note that approximate dates in this paragraph were assessed based on historical aerial imagery as provided in the 2008 SRF report (SRF 2008).

constructed just northwest of the Area 3 slope in the 1970s. In the 1980s, the area north and northeast of Area 3 was subdivided, and residential development began. The area directly above the Area 3 slope was not developed until the late 1990s. Several ponds, assumed to be stormwater treatment ponds, were constructed in the upslope areas above the bluff, as part of this development.

Several past studies and preliminary design efforts have assessed Area 3. Those studies are summarized in the next section. As a result of the previous efforts, Inter-Fluve was retained to develop alternative solutions for treatments along the bluff toe to minimize the effect of fluvial processes on bluff erosion. We understand that other project teams are continuing to evaluate the geotechnical slope stability and issues associated with gullying on the upper slope. It should be noted that Inter-Fluve reviewed the upper slope immediately adjacent to the bluff area and did not identify gullying associated with the bluff feature. It is understood that gullying is associated with overland drainages in the upper slope from the residential properties. These upslope erosion locations have not been evaluated by Inter-Fluve staff.

The primary goal of this project is to limit fluvial influence on the bluff toe and adjacent areas through implementation of a riverbank stabilization project. It is understood that based on previous analyses there are likely additional geotechnical solutions that would be required for bluff and upper slope stabilization that are being reviewed and addressed by others. A secondary goal of the project is to limit input of sediment from Area 3 into the Minnesota River in efforts to address the river's Total Maximum Daily Load (TMDL) for sediment. Protection of a non-functional City stormwater pond located downstream of the eroding bluff was identified as a desire by the City in order to comply with their MS4 permit. It is understood that Inter-Fluve's current scope is to provide alternative approaches to mitigate fluvial bluff toe erosion. This can be achieved through the alternative designs proposed within this memo. However, due to larger scale river process, future bluff failure risk will not be eliminated by stabilizing the bluff toe. Consequently, Inter-Fluve's analysis and recommendations extend beyond solutions at the bluff toe to address longer-term river process impacts at the Area 3 site.

Figure 2: Drone image with schematic lines showing site descriptor terminology used in this report.

EXISTING CONDITIONS SUMMARY

This section summarizes past data collection, assessment, and design efforts; describes the results of our onsite findings through geomorphic assessment and drone survey; and details our existing conditions modeling efforts and findings.

Geomorphic Context

When Glacial Lake Agassiz (the remnants of which include Lake Winnipeg, Lake Manitoba, Lake of the Woods, and Red Lake) overtopped, floods carved the modern Minnesota River valley. The modern Minnesota River meanders within the bounds of the valley carved during the glacial floods. Historically, the land surrounding the Minnesota River was dominated by natural tall-grass prairies and wetlands, but was largely converted to row crop agriculture over the past 150 years. As previously noted, there has also been significant residential development in the last 40 years, especially in the downstream portions of the Minnesota River watershed, near the Twin Cities. The land use change has resulted in increased rainfall runoff which, coupled with increasing magnitude of precipitation due to climate change, increased sediment supply to the river and increased flow in the river. These changes have resulted in significant changes to the Minnesota River system and accelerated downstream sedimentation in Lake Pepin (Tetra Tech 2020). Currently, the dominant source of sediment to the Minnesota River stems from accelerated erosion of river banks and bluffs due to increased discharge (Belmont et al. 2011). Increased discharge has resulted in morphological change within the Minnesota River. Since 1938, the Minnesota River between Mankato and Saint Paul has widened by 52%, shortened by 7%, and caused aggradation of the floodplain surface (Lenhart et al. 2013). The ultimate result of these morphologic changes is an increase in bankfull shear stress and stream power. The resulting condition inhibits growth of woody riparian vegetation on low lying sand bars, limits the accessibility of the River to its floodplain, and reduces the amount of sediment storage available in the floodplain.

Summary of Past Assessment and Design Work

Several past efforts to assess and develop conceptual level designs to address the bluff erosion at Area 3 have occurred over the last two decades.

In 2008, SRF Consulting Group, Inc. (SRF) completed an erosion stability study for the area that included a historical photo analysis[2], topographic survey, soil and slope stability analysis, and flood elevation analysis (SRF, 2008). As a result of this analysis, it was determined that several factors were contributing the instability of the bluff including: "low internal soil strength properties; removal of vegetation; frequent river flooding; soil saturation due to flooding and the presence of springs; high velocities along the outside bend of the river during flood stage; and presence of steep slopes." (SRF, 2008.) In addition, the report found that "more than likely, it is a combination of localized erosive velocities as the river flows around the bend and the permanent soil saturation that occurs near the springs that has accelerated bluff erosion, which would otherwise occur more slowly from flooding saturation/desaturation, low in-situ soil shear strength, steep slopes, and the removal of vegetation." (SRF, 2008.) This report suggested two alternatives: 1) regrading of the slope of the toe to achieve a 3H:1V slope and stabilizing it with riprap up to the 100-year flood elevation, and 2) implementing a 2H:1V riprap slope at the toe, with a 1H:1V reinforced soil slope above. The report recommended pursuing the second alternative, but only after further investigatory work by a geotechnical engineer, additional survey, hydraulic assessment, and landscape architectural review.

In 2010, Wenck Associates, Inc. (Wenck) in association with Stanley Consultants Inc. (Stanley) completed an assessment report on Area 3 entitled *Minnesota River Bank and Bluff Stabilization* (Wenck, 2010.) This assessment expanded the length of the bank from the SRF assessment, and included additional data collection, hydraulic modeling, and geotechnical testing and analysis. A georeferenced air photo analysis showed bank locations in 1937, 1969, and 2008 (Figure 2). The study also completed a hydrologic analysis and found that Minnesota River flow rates are increasing. The analysis found that a 1993 flood caused significant erosion on the bluff, which was likely "exacerbated by concentrated surface runoff from the bluff and seepage flows that weaken the support at the toe of the slope." (Wenck, 2010.) The study recommended addressing

[2] It is our understanding that this analysis did not include georeferencing of the various aerial photographs.

the issue through bank stabilization work and considered three alternatives: 1) a riprap blanket, 2) bendway weirs, and 3) rock vanes (Wenck, 2010). A do nothing alternative was not considered as it was identified that natural progression of the meander bend would result in downstream movement, compromising the City's stormwater pond. Ultimately, the rock vane alternative was recommended in consideration of the lowest anticipated construction cost. Inclinometers were also installed to monitor the bluff slope as part of this effort.

Since 2010, LMRWD, Wenck, Stanley, Braun Intertec, and Barr Engineering have been involved in additional geotechnical monitoring work, which we understand is ongoing and will lead to slope stabilization design recommendations in order to protect the bluff and upper slope, and ultimately the properties at the top of the bluff.

In 2013, a bank toe stabilization effort using rock and bioengineering was implemented around the perimeter of the City stormwater pond to protect the pond. However, a Wenck report indicated that vegetation did not grow due to high water conditions, resulting in failure of the bioengineering techniques (Wenck, 2017.)

In 2016, Wenck installed several bank pins to monitor bank movement and assess the risk to the City stormwater pond. This effort determined that over time "the City stormwater pond will be overrun by the Minnesota River considering the direction of the river meander." This report suggested two approaches "1) armor the bank with a revetment possibly in combination with bend way weirs or 2) establish a vegetated bank that even though the bank erodes the erosion is at an acceptable rate." (Wenck, 2017).

Inter-Fluve agrees with the compounding processes driving bluff failure identified by SRF and Wenck, which include increased soil pore-pressure caused by groundwater seeps and river flooding frequency, lack of vegetation on the bluff face, and erosive hydraulic forces at the bluff toe. The solutions proposed by the previous studies are investigated within this memo.

<u>Site Assessment</u>

Inter-Fluve conducted an onsite geomorphic site assessment on April 2, 2021 in the late afternoon. At the time of the visit, the water surface elevation was at approximately 703.9 feet NAVD88 and the discharge was approximately 10,650 cubic feet per second (cfs) at the USGS gage station 05330000 Minnesota River near Jordan, MN (USGS NWIS Web Interface). The Minnesota River channel in the project reach is currently between 250 and 350 feet wide. Upstream and downstream of the project site, the both channel banks are actively eroding. At Area 3, the left bank (bluff toe) is erosional, and the right bank is depositional. The floodplain below the valley walls is characterized by a floodplain forest, with some development, agricultural land, and several floodplain lakes. Where the City's non-functional stormwater pond is located downstream of the Area 3 bluff, there is a floodplain bench dominated by reed canary grass and willow shrubs. A stormwater outlet empties into an incised ditch that carved through this floodplain (Figure 3). It appears that this floodplain bench is the former location of the City stormwater pond that has been filled in and is no longer serving any water quality benefit Based on review of historic air photos and past reports, it is clear that several phases of construction and repair have been done to restore or rebuild the pond. We understand that in 2013 a rock toe and bioengineering stabilization project was implemented to fortify the river bank along the length of the pond, however, due to high water, vegetation never established. Inter-Fluve observed the failed treatment in the field and also identified a structure that appeared to be a constructed log structure on the bank adjacent to the pond location (Figure 4).

Figure 3: Photo taken of incised channel carved through former stormwater pond.

Figure 4: Drone image showing exposed log crib structure and failed bank stabilization.

The eroding section of the Area 3 bluff is estimated to be approximately 700 feet long and 60 feet high, with evidence of erosion concentrated in three scallops spaced along the bluff top. The shape of these scallops coincides with the location of groundwater seeps along the bottom half of the eroded bluff (Figure 5). The bluff erosion has impacted approximately 500 feet of the former road/trail surface. The bluff is composed of exposed fine sand with sparse gravels concentrated in the upper ~10 feet of the bluff face. Alluvial material, likely sourced from the eroding bluff with minor flood deposits, is present at the base of the eroding bluff. Only minimal vegetation was observed on the bluff face. Several cliff swallow nests were observed in the upper portion of the eroded bluff. Upslope of the eroding bluff, the slope is largely prairie grasses interspersed with cedar trees.

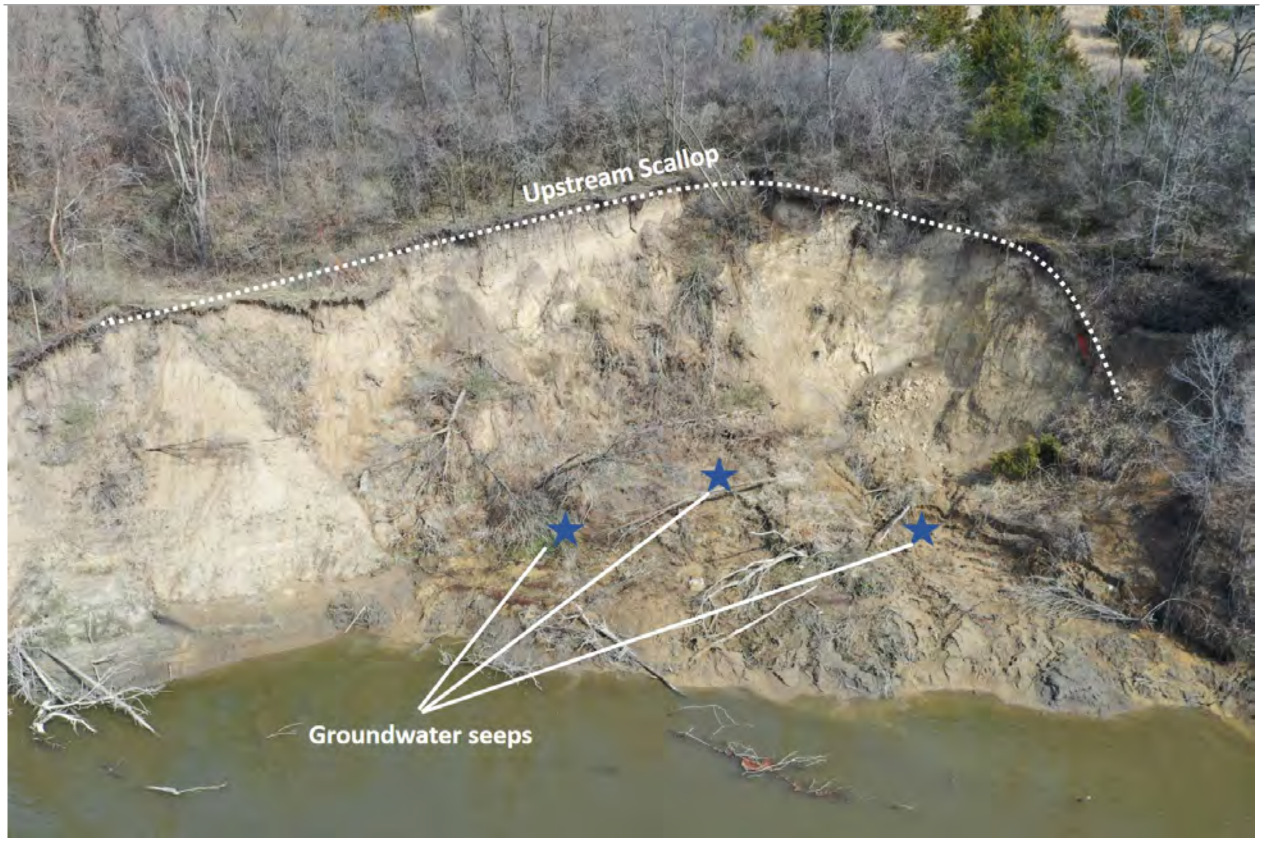

Figure 5: Drone image of bluff segment showing scallop shape and approximate location of groundwater seeps.

Drone Survey

A drone survey was conducted on April 6th, 2021. The project site is located in class D airspace and the drone flight was authorized through the Federal Aviation Administration Low Altitude Authorization and Notification Capability (FAA LAANC) system, and was limited to below 50 feet above ground level (AGL). The survey was conducted in compliance with FAA regulations. Both top-down and oblique photos were collected. Photos were processed using Pix4D software to create a seamless surface and aerial photo mosaic.

A topographic surface was created using photogrammetry to determine the 3D location of points identified in overlapping images. Spurious points, typically representing vegetation, were removed and the remaining points used to create the resultant bare earth surface. Because this technique cannot determine the ground surface through vegetation, the photogrammetry surface was vertically adjusted and matched with the most recent lidar to create a seamless surface of the project site. At the time of the survey the Minnesota River discharge was approximately 8,320 cfs at the USGS gage station 05330000 Minnesota River near Jordan, MN (USGS NWIS Web Interface).

1-D Modeling Summary

A 1-D HEC-RAS model was provided by the LMRWD to use as a basis for hydraulic analysis. The model was created in 2004 with input from the USGS and USACE as part of the "Flood-Plain Areas of the Lower Minnesota River" report which was used in the development of the 2016 FEMA FIS Study for Hennepin County. The model was updated by adding six sections where bathymetry data was collected in 2020, updating bluff topography with drone topography collected in 2021, and updating floodplain topography with LiDAR collected in 2009. Existing section 52 was adjusted to cut through a bathymetric cross-section and was also updated with bathymetry, drone topo, and LiDAR.

The model results were used to investigate hydraulic conditions to assess the current bluff toe erosion and inform potential bluff toe stabilization measures. The hydraulic properties of the cross-sections are reported below in Table 1, the average channel velocity and shear stresses calculated in HEC-RAS were multiplied to estimate maximum values using a method by Sclafani (2011). The maximum shear stress is a localized value that theoretically occurs near the apex of the bend, on the outer bank, and at the maximum channel depth (thalweg). This analysis indicates that the largest material the channel has the ability to transport along the thalweg is fine to coarse gravels at a variety of flows from low-flows to flood-flows. At Area 3, the river almost always has the competency to transport the sand along the outer bank (bluff toe) of the river which comprises the bluff toe. However, the rate at which the river is able to transport this material is not easily estimated with hydraulic models. A direct and accurate way to estimate the rate of sediment transport and the rate of channel migration is by collecting annual bathymetric and topographic surveys of the area of interest.

The maximum scour depth was calculated to estimate potential rock volume required for bluff toe stabilization using the Maynord (1996) equation. The Maynord equation is an empirical equation that applies relationships of radius of curvature, top width, and average channel depth to estimate scour potential. The max scour depth was calculated to be 6.6 ft deeper than the current maximum channel depth, using a recommended factor of safety of 1.19. Scour analysis calculations will be refined with new bathymetric survey data. A launchable rock toe is anticipated to be the best way to protect against this potential scour.

Table 1: Hydraulic Analysis Results RAS Section 52

Flow Event	Flow (cfs)	Max Flow Depth (ft)	Max Bend Velocity (ft/s)	Max Bend Shear (lb/sq-ft)	Sediment Transported by Max Shear
500-yr	148,000	57.2	3.2	0.32	Coarse Gravel (16mm)
100-yr	103,000	51.9	2.9	0.29	Coarse Gravel (16mm)
100-yr Fldwy	103,000	52.1	2.9	0.26	Coarse Gravel (16mm)
50-yr	85,300	49.5	2.7	0.26	Coarse Gravel (16mm)
10-yr	48,500	42.8	2.4	0.20	Medium to Coarse Gravel (8-16mm)
2-yr	17,000	37.6	1.4	0.06	Fine Gravel (4mm)
15,000cfs	15,000	32.2	2.1	0.17	Medium to Coarse Gravel (8-16mm)
10,000cfs	10,000	28.8	1.8	0.14	Medium Gravel (8mm)
8,000cfs	8,000	27.0	1.7	0.11	Medium Gravel (8mm)

SUMMARY OF FINDINGS AND DISCUSSION

Based on the existing conditions, Inter-Fluve has made several observations that describe erosion processes at Area 3. We agree with past reports that there are local drivers (soil properties, groundwater seeps, fluvial processes, vegetation management, upslope land use) and regional (increased flows, increased flood frequency) and compounding factors that are leading to the bluff erosion at Area 3. In order to assess what potential approach might provide a long-term, cost-effective solution for the site, many factors must be considered. Land use changes and climate change are causing loss of native vegetation, increased precipitation and landscape irrigation contributing to soil saturation and groundwater seeps, widening of the Minnesota River, and increased flows, all of which are contributing to the bluff erosion at this site. We believe that increased soil saturation has resulted in weakened soil structure, increased soil pore water pressure and increased groundwater seepage at the bluff face. Flood flows then erode this more easily entrained material at the bluff toe resulting in increased potential for mass wasting.

The following list summarizes Inter-Fluve's observations that corroborate the above statements.

- A review of recent aerial photographs from GoogleEarth[3] reveals that the two meander bends upstream of Area 3 are shifting down-valley, which is an expected geomorphic trend and aligns with aerial photo analysis. This trend suggests that the trajectory of the Area 3 meander bend is also down valley. However, the presence and location of the stormwater pond stabilization work[4] is delaying down valley migration, resulting in persistent northward erosion at Area 3. This trend is illustrated below on Figure 6.

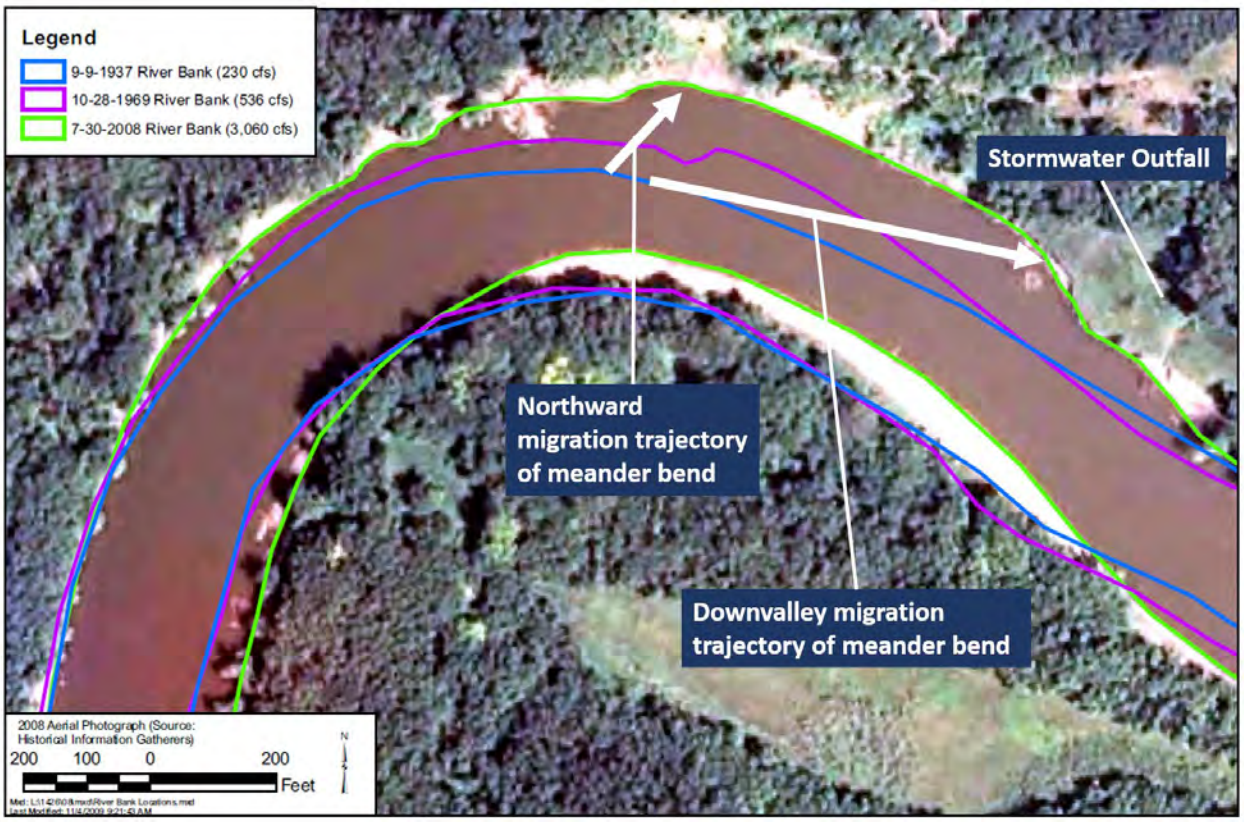

Figure 6: Historical Aerial photograph analysis showing bank lines from 1937, 1969, and 2008 (modified from Wenck, 2010)

- Inter-Fluve's onsite observations of bilateral bank erosion and historical air photo analysis indicate that the river segment upstream of the Area 3 bluff is widening. In the Area 3 segment, the inside bend is experiencing deposition, and the outside bend is eroding (or moving north in the direction of the bluff.) The aerial photo analysis (see Figure 5) shows the historic trends of meander bend migration for the project area. The

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[3] Note that these photos are not precisely georeferenced, but the intent of this photo review was to confirm the general trajectory of the river system. A landmark was referenced in both compared images to check for reasonable accuracy of the image locations.

[4] Based on the historic aerial photographs, the City stormwater pond appears to be inundated and filled or breached, then restored several times throughout the photo series.

bank locations of the upstream half of the outside of the meander bend experienced more gradual movement, whereas the downstream half is experienced more rapid movement in a shape that is not parallel to the previous river bank location. This suggests that while the meander bend is moving toward the outside bend, there may be other factors influencing the bluff movement (e.g., increased soil saturation from river flooding frequency and groundwater seeps and irrigation/anthropogenic activity, etc.) We can roughly estimate bluff retreat at the top of the middle bluff, but migration rates at the bluff toe can't be computed because each photo occurs at a different river stage and flow rate- and we lack repeated bathymetric data. Repeat bathymetric and topographic survey would provide the data necessary to determine migration rates.

- The shape of the scallops in the upper bluff aligns with the locations of the groundwater seeps expressed in the lower bluff and near the midpoint of the bluff.[5] This suggests that the seeps may be playing a role in the bluff erosion.
- Based on the historical air photos included in Appendix A of SRF's 2008 report, bluff scour first appears in the 1979 photo which coincides with the appearance of the upslope landfill and associated pond. Another significant change can be observed in the 1991 photo, which shows the City stormwater pond in the floodplain downstream of the Area 3 slope. In that photo, it appears that the photo was taken during a comparatively low water condition, yet the toe of the Area 3 bluff is inundated. Within the set, the 1997 photo is the first photo that shows loss of a segment of the former farm road/walking trail. The 2000 photo shows the development of additional stormwater ponds associated with the upslope development. This suggests that anthropogenic activity (City stormwater pond construction, landscape irrigation, upslope pond creation, other development, etc.) is likely playing a role in the bluff erosion.
- The results of the 2020 bathymetric data suggest that the subsurface channel bank slope in front of the Area 3 bluff is fairly flat which suggests that the mass wasting is pushing material out at the toe, and that the river (at least at the time of survey) was not evacuating that material downstream. Bluff erosion is often cyclical. Initial bluff erosion was likely driven primarily by erosion at the toe, but subsequent failures have deposited significant material at the bluff toe, and at the present time, increased pore pressure due to flooding and groundwater seepage, and lack of vegetation contribute to continued erosion of the bluff.

[5] The bluff extends from the bottom of the river to the top of the feature; therefore "toe" of the bluff is 15 feet under water and the "midpoint" is just above the existing water surface elevation.

The anticipated trajectory of this meander bend is to continue to erode both north and downstream. Because the City stormwater pond area and associated rock toe limit the River's ability to migrate downstream, it may be advantageous to consider solutions that remove this restriction to river bank movement, especially considering the fact that the stormwater treatment benefit is not present and long-term viability of the pond is unlikely. Our observations, along with those of previous studies suggest that increased pore pressure from groundwater seeps may have a significant impact on the bluff erosion which would require a geotechnical solution to address.

We suggest that additional bathymetric survey be completed now to accurately assess subsurface slopes and processes. Detailed bathymetry is needed to verify erosion patterns at the toe and to properly size stabilization measures. The following sections review past recommendations and our proposed next steps and alternatives given our findings.

ALTERNATIVES CONSIDERED

Considerations taken into account while assessing feasible alternatives include scale and capacity to address the hydraulic forces at the site, scour depth, longevity (both in the face of climate change and river trajectory), potential cost, and perceived permitting feasibility.

The list below provides review of past recommendations and potential alternatives based on the considerations listed above.

1. SRF Alt. 1--Regrading and rock toe at 3H:1V up to 100-year elevation: A rock toe is likely a viable solution for bluff toe stabilization. The slope, scale, and lateral and vertical extents need to be designed to consider long term impacts. If toe stabilization is determined to be warranted based on bathymetric findings and stakeholder preference, a preliminary concept layout for a rock toe has been developed and is described in the following section. The final design, scale, and extent of such a treatment will be a function of the findings of the bathymetric survey. The potential cost of this alternative will be a function of design longevity, and upon further design refinement we will provide analysis to inform the LMRWD in making a decision on the balance between these factors.
2. SRF Alt. 2--2H:1V riprap slope at the toe, and 1H:1V reinforced soil slope above: The benefit of a reinforced soil slope, is that it can be implemented at steep slopes. Based on our understanding of the drivers and project goals, stabilization at a steep slope would not be necessary or warranted to stabilize the toe of the bluff. Depending on what treatments are proposed upslope and how the seeps are managed, a reinforced soil slope section may be warranted from a geotechnical slope stability perspective, but not from a toe stabilization perspective.
3. Wenck Alt. 1--Riprap blanket: A riprap blanket is a similar treatment to a rock toe and is likely a viable solution for bluff toe stabilization for the reasons listed in Item 1.

4. Wenck Alt. 2--Bendway weirs: Based on the scale of the system and the depth of the pool at Area 3, bendway weirs would likely not be a viable solution. Due to the scale and orientation of the site, the weirs would likely be difficult or infeasible to construct, would encroach on the shipping channel potentially posing permitting challenges, and may create more instability than currently exists upstream and downstream of the treatment area. The cost associated with this alternative was not considered because of the listed concerns.
5. Wenck Alt. 3--Rock vanes: Rock vanes are very similar to bendway weirs and pose the same concerns as listed in Item 4.
6. Large Wood Crib or Large Wood Log Jam: Due to the depth of the channel and the site geometry, the length of log piles necessary to support a large wood structure in this location would not be feasible. It is likely that 40-to-50-foot-long long piles would be needed for this application, which cannot be sourced locally, and reaches beyond the feasible application of such a treatment. Depending on the selected alternative or set of alternatives, it is possible that some large wood rootwads or logs could be added to the bank to provide habitat. It is preferable to use large wood in rivers with natural analogs. Because the river width is many times wider than the length of a large wood piece, log jams in the Minnesota River tend to be marginal and localized, and do not extend down to the channel thalweg. The costs, longevity, and permitting of this treatment were not considered because it wasn't feasible from a constructability standpoint.
7. Vegetative Bioengineering Solution: It is possible that a vegetative solution could be implemented at the toe of slope, depending on the findings of the bathymetric survey. It would likely need to be paired with some stone treatment, the scale of which also depends on the findings of the bathymetric survey. We understand that the 2013 treatment adjacent to the City stormwater pond failed due to lack of vegetation establishment during high water conditions. If such a solution is pursued, vegetative treatments would likely be recommended at a higher elevation along the toe of the bluff than the 2013 installation.

PROPOSED ALTERNATIVES AND RECOMMENDATIONS

Below are two recommendations that should be pursued in conjunction with the design of a bluff toe stabilization. Additionally, the increased pore pressure caused by the frequency of river flooding and groundwater seeps will likely result in continued mass wasting of the bluff into the river.

1. Pursue decommissioning of the City Stormwater Pond. We understand that that the stormwater pond is a part of the City's current MS4 compliance; however, the pond has had continued functional issues, and is currently not retaining any water or providing any water quality benefits. The river is anticipated to move in the direction of the stormwater pond, so stormwater treatment in this location is not a viable long-term solution. Removing the bank and structures in this location and allowing the river

meander bend to move on its natural trajectory is seen as one of the highest priorities for addressing the long-term bluff erosion at Area 3. Our observations indicate that the pond location is inhibiting downstream meander bend migration which is causing increased erosive forces along the bluff toe. Treatment here should include removal of bank armoring and legacy stormwater pond infrastructure which would allow for the natural movement of the river bend downstream. Based on our analysis, the pond removal is critical to the long-term stability of the bluff and is strongly recommended.

   a. Option - Consider removing deposited material from the inside bend opposite Area 3. This should only be implemented in conjunction with decommissioning of the City stormwater pond, as material is anticipated to continue to deposit on that point bar without removal of the pond. Removal of this material may help accelerate the natural downstream movement of the meander bend, and thus relieve pressure from Area 3. Additionally, there is a stand of trees on the upstream end of the inside bend that appears to be holding the bend in place on the upstream side. Removal of this stand of trees may also help accelerate the natural progression of the river meander bend in a downstream direction.

2. Continue geotechnical investigations on the upper slope and include assessment and design for addressing groundwater seeps. Investigate how the stormwater ponds and landscape irrigation at the top of the slope may be impacting the seeps (e.g., Are the stormwater ponds lined or have they sealed? Are they functioning as designed?) Design and implement a measure to express seeps at the bottom of the bluff to prevent continued soil wasting from seep erosion allowing vegetation to establish and stabilize the bluff toe.

Recommended Next Step: **Conduct bathymetric survey**

In order to better understand the shape of the subsurface bluff toe slope, the recent slope failure driver, and hydraulic transport mechanisms at Area 3, we recommend conducting the bathymetric survey earlier in the proposed schedule. This will allow us to better determine the extent of the material sloughing off the bluff, and whether it appears to be mobilizing and evacuating downstream, or not. This will give insight to whether a toe stabilization should be pursued in conjunction with the other recommendations, and, if toe stabilization is warranted, what the extent, scale, and scope of the toe treatment should be.

The data collected from the upcoming bathymetric survey will be used to refine the alternative designs, as well as provide the information necessary to select a preferred alternative. Currently the bathymetry is limited to widely spaced cross-sections which necessitates interpolation of the surface between the sections. Without an accurate understanding of slopes and channel depths, most elements of design would be based on assumptions with a large amount of uncertainty. Feasible alternative approaches to stabilize the toe may range from no action and monitoring (assuming the City stormwater pond is decommissioned and the seeps are addressed) to large scale toe stabilization with a launchable rock toe. An intermediate recommendation may include a localized toe treatment with rock and bioengineering. For planning purposes three potential conceptual alternatives with planimetric layouts have been developed for comparison. These include: 1) Large scale rock toe stabilization, 2) localized rock and bioengineering toe stabilization, 3) no action and monitoring. It should be noted that these are conceptual layouts only and it is anticipated that the results of the bathymetric survey will provide insight into the need for and feasibility of each alternative addressing the bluff erosion at site.

Conceptual Alternative 1: Large Scale Rock Toe Stabilization

Conceptual Alternative 1 shown in Figure 1, Appendix 1 proposes a large-scale rock toe stabilization along the failing bluff toe. The rock toe would be designed to mitigate fluvial bluff toe erosion at high flow events, and launch into the channel to armor the bank in the event of further channel scour. Based on moment stability analysis (Julien, 2010) MNDOT Class II riprap was determined to be a conservative riprap size for this design. The downstream extension of the treatment is proposed to mitigate the risk of future bluff erosion due to channel migration through this reach. It is recommended that this alternative is constructed along with the decommissioning of the city stormwater pond. A budgetary opinion of construction cost is included in Table 2. This opinion of cost is deemed an Association for the Advancement of Cost Engineering (AACE) class 4 cost estimate based on the current phase of design.

Permitting requirements for Conceptual Alternative 1 and Concept Alternative 2 will be similar; however, the larger footprint associated with the construction of Alternative 1 may trigger more extensive wetland mitigation requirements. It is likely that a wetland delineation may be required for permitting this project.

Table 2: Conceptual Alternative 1 Budgetary Opinion of Construction Cost

Minnesota River Area 3
Conceptual Alternative 1
Budgetary Opinion of Construction Cost
April 2021

Item #	Item	Unit	Quantity	Unit Cost	Sub total
1	MOBILIZATION AND DEMOBILIZATION	LUMP	1	$ 107,000	$ 107,000
2	SITE ACCESS AND STAGING	LUMP	1	$ 51,000	$ 51,000
3	EROSION AND SEDIMENT CONTROL	LUMP	1	$ 30,000	$ 30,000
4	CLEARING	ACRE	2.0	$ 10,000	$ 20,000
5	RIPRAP CLASS II	CY	8,000	$ 90	$ 720,000
6	GRANULAR FILTER	CY	1,300	$ 60	$ 78,000
7	EARTHWORK CUT	CY	1,000	$ 15	$ 15,000
8	HAUL AND OFFSITE DISPOSAL OF CLEAN FILL	CY	1,000	$ 22	$ 22,000
9	SURFACE FABRIC	SY	6,025	$ 12	$ 72,295
10	REVEGETATION	ACRE	1	$ 50,000	$ 50,000
11	AS-BUILT SURVEY	LUMP	1	$ 10,000	$ 10,000

Subtotal		**$ 1,175,295**
Contingency	30%	$ 352,588
TOTAL		**$ 1,527,883**

<u>Conceptual Alternative 2: Localized Rock and Bioengineering Toe Stabilization</u>
Conceptual Alternative 2 shown in Figure 2, Appendix 1 proposes a localized rock and bioengineering toe stabilization along the failing bluff toe. The rock at the toe of the bluff would be designed to mitigate fluvial bluff toe erosion at high flow events. The bioengineered treatment would be upslope of the rock toe and provide soil stability and a reduction in erosive fluvial forces at the toe of the bluff through vegetation establishment. Based on moment stability analysis (Julien, 2010) MNDOT Class II riprap was determined to be a conservative riprap size for this design. It is recommended that this alternative is constructed along with the decommissioning of the city stormwater pond. A budgetary opinion of construction cost is included in Table 4. This opinion of cost is deemed a AACE class 4 cost estimate based on the current phase of design.

Permitting requirements for Conceptual Alternative 1 and Concept Alternative 2 will be similar; however, the smaller footprint associated with the construction of Alternative 2 may require less extensive wetland mitigation requirements.

Table 3: Conceptual Alternative 2 Budgetary Opinion of Construction Cost

Minnesota River Area 3
Conceptual Alternative 2
Budgetary Opinion of Construction Cost
April 2021

Item #	Item	Unit	Quantity	Unit Cost	Sub total
1	MOBILIZATION AND DEMOBILIZATION	LUMP	1	$ 55,000	$ 55,000
2	SITE ACCESS AND STAGING	LUMP	1	$ 28,000	$ 28,000
3	EROSION AND SEDIMENT CONTROL	LUMP	1	$ 16,000	$ 16,000
4	CLEARING	ACRE	1	$ 10,000	$ 10,000
5	RIPRAP CLASS II	CY	3,400	$ 90	$ 306,000
6	GRANULAR FILTER	CY	570	$ 60	$ 34,200
7	EARTHWORK CUT	CY	500	$ 15	$ 7,500
8	HAUL AND OFFSITE DISPOSAL OF CLEAN FILL	CY	500	$ 22	$ 11,000
9	FES LIFTS	FACE FEET	2,100	$ 40	$ 84,000
10	SURFACE FABRIC	SY	3,500	$ 12	$ 42,000
11	REVEGETATION	ACRE	0.6	$ 50,000	$ 30,000
12	AS-BUILT SURVEY	LUMP	1	$ 10,000	$ 10,000

Subtotal		**$ 633,700**
Contingency	30%	$ 190,110
TOTAL		**$ 823,810**

Conceptual Alternative 3: No Action and Monitoring

With the removal of the city stormwater pond, it is possible that the direction of migration of the meander bend may deviate from the current northward progression and begin migrating down valley to the east. In this scenario, the fluvial component of the bluff toe failure may be dampened to a degree which requires no action at the bluff toe. In order to address the ongoing success or failure of this option, annual monitoring of the project area is proposed. This would include drone collected topography of the bluff face, RTK GPS topographic survey of both left and right banks and floodplains, and detailed bathymetric survey. This data collection should occur annually during low flow, leaf off conditions in the fall before snow accumulation and ice buildup. The tenure of monitoring would depend on findings as it relates to bank movements, and adjacent projects (e.g., stormwater pond removal, upper bluff stabilization work, etc.)

SUGGESTED SCHEDULE

Given the findings and recommendations presented within this memorandum, we suggest the following amended project schedule for this project to allow for collection of bathymetric survey data sooner than originally anticipated.

Task	Date/Due by Date
Alternatives Review Meeting	May 6
Bathymetric Survey	Week of May 17
Meeting to Discuss Survey Results	Week of May 24
Preliminary 60% Design*	July 16
Final 90% Design*	August 27
100% Design Tasks*	Scheduled upon notification of construction funding

*If warranted based on selected alternative/approach

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APPENDIX 1 – CONCEPTUAL ALTERNATIVE FIGURES

NO.	BY	DATE	REVISION DESCRIPTION

DRAWN	DESIGNED	CHECKED
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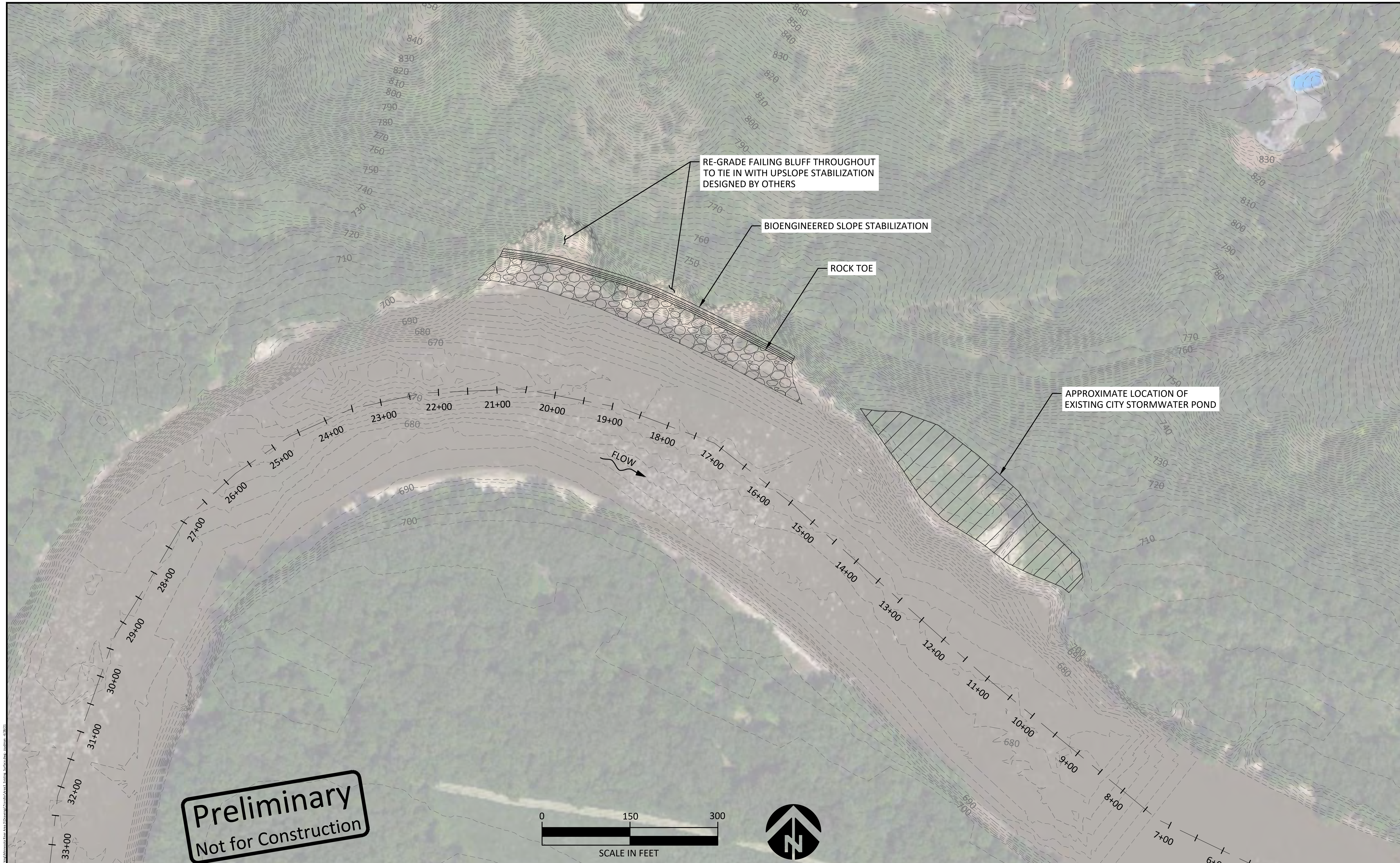
APPROVED	DATE	PROJECT
----	4/28/2021	

LOWER MINNESOTA RIVER WATERSHED DISTRICT
MINNESOTA RIVER AREA 3
CONCEPTUAL DESIGN

inter-fluve
1539 Grand Avenue, 2nd Floor
Saint Paul, MN 55105
651.243.9700
www.interfluve.com

CONCEPT ALTERNATIVE 1

SHEET
1 OF 2



NO.	BY	DATE	REVISION DESCRIPTION

---- DRAWN	---- DESIGNED	---- CHECKED
---- APPROVED	4/28/2021 DATE	PROJECT

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CONCEPT ALTERNATIVE 2

SHEET
2 OF 2

APPENDIX 2 – SELECT DRONE IMAGES