Creek Restoration Action Strategy –
Upper Riley Creek Sediment Source Assessment

Chanhassen, MN

Prepared for
Riley Purgatory Bluff Creek Watershed District

April 2017

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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.

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1.0 Introduction and Objectives

The 2015 Creek Restoration Action Strategy Assessment (CRAS) (Reference (1)) prioritized stream segments within the Riley Purgatory Bluff Creek Watershed District (District) for stabilization. Upper Riley Creek was identified within this assessment as a degraded stream segment however the scope of CRAS did not include the evaluation of stream degradation causes or the identification of viable restoration alternatives. This report serves as a continuation of the 2015 CRAS efforts, with additional input from the draft Lake Susan TMDL (Reference (2)). The studies objectives were as follows:

- Coordinate with RPBCWD Staff on assessments of stream conditions and potential watershed improvements;
- Identify the nature and cause of erosion in Upper Riley Creek, as identified by the 2015 CRAS, through a combination of field and desktop-based methods;
- Examine the contributing watershed for additional sediment sources;
- Estimate erosion rates and potential for cost per pound of phosphorus reduction that could be achieved through a stabilization project;
- Develop preliminary feasibility-level design concepts and opinions of probable cost to assist with future planning and restoration efforts.

1.1 Background and Past Studies

Upper Riley Creek includes those portions of Riley Creek between Lake Ann and Lake Susan in the city of Chanhassen, Minnesota. Upper Riley Creek is approximately 9,000 feet long and has documented erosion through much of the reach. The watershed tributary to this reach is about 1,994 acres with roughly 35% of the area covered by impervious surfaces. The erosion has detrimental effects on water quality and stream habitat in the creek and downstream Lake Susan. The District has been aware of erosion issues in this reach for several years and most of this reach was assessed by RPBCWD staff in October 2013. The reaches were not re-assessed as part of the CRAS in 2015; however the inspection photos and notes were used to develop scores as part of the CRAS.

The following summarizes key points from past studies for the Upper Riley Watershed:

- Stormwater treatment in the subwatershed does not meet current standards
  - Stormwater ponds appear to be undersized or non-existent for many parcels with a large impervious area (Reference (3))
  - Stormwater abstraction is not a part of stormwater features in the subwatershed; however the soil types make it difficult to use infiltration practices (Reference (4)).
- Creek erosion has been identified as a key contributor to sediment loading to Lake Susan (Reference (2))

Significant creek erosion has been identified within this subwatershed and half of the identified sub-reaches have been classified as a high priority for stabilization. The following sections further document past studies relevant to this reach of Riley Creek.

1.2 Susan, Ann, and Lucy Subwatershed: Stormwater Retrofit Assessment

In 2011, Carver County Soil and Water Conservation District prepared a stormwater retrofit assessment intended to identify potential watershed improvements to reduce TSS and TP loading to Lake Susan and other waterbodies (Reference (4)). The study suggests improvements to 18 total ponds contributing to Lake Susan. Improvements include adding 1 to 3 feet of storage above the normal water level. The increase in storage above the normal water level would lead to reductions in runoff rates reaching Riley Creek, however rate reduction was not quantified in this study

The Carver County assessment did not address streambank erosion as a contributor to TP or TSS loading to Lake Susan.

1.3 Lake Susan Use Attainability Assessment (UAA) Updated

A study conducted by Wenck in 2013 indicated the contributing watershed would continue to develop and add impervious surface associated with industrial and residential development (Reference (3)). BMPs were proposed in the 2013 Wenck report with the goal of reducing TP loading through increased dead storage in ponds and installation of iron enhanced sand filters. For locations where the dead storage surface area is increased live storage is assumed to also increase resulting in reduced runoff rates to Riley Creek.

The UAA update also did not addressed streambank erosion as a contributor to TP or TSS loading to Lake Susan.

1.4 Lake Susan TMDL

A draft TMDL is being developed in fall of 2016 that encompass the Riley Creek and Purgatory Creek Watersheds (Reference (2)). The TMDL indicates that Lake Susan is significantly impacted by Total Phosphorus (TP) loading and Total Suspended Solids (TSS) loading from streambank erosion on Riley Creek. To meet TP loading requirements of the TMDL, the streambank erosion needs to be reduced in concert with additional watershed and internal BMPs.

1.5 Creek Restoration Action Strategy (CRAS)

The 2015 CRAS Report evaluated the Upper Riley Creek sub-reaches 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. The second tier of categories include those that provide supporting benefit to stream restoration, including watershed benefits, public education, partnership opportunities, and project cost per pound of phosphorus.

The CRAS report identified the Upper Riley Creek reach as moderately unstable to unstable with most of the reach having a medium threat to infrastructure. The Tier I evaluation summary indicates that upstream of Park Road the reach is a moderate priority for restoration with some benefit from stream restoration. However, downstream of Park Drive the reach is classified as a high priority for restoration that could notably reduce infrastructure risk and improve stream health. It should also be noted that the scores developed for the 2015 CRAS report for Upper Riley Creek were based on photos and assessments completed by former RPBCWD staff in 2013, so the scores were solely dependent on staff notes and available photos. The lack of a more recent on-site assessment, coupled with the TMDL results and known sediment loading to Lake Susan, Upper Riley Creek and its watershed were targeted for a more up-to-date assessment to more accurately place these reaches within the CRAS rankings and identify remedial measures.

Tables 1.1, 1.2, and 1.3 provide a summary of the Tier I scores, a summary of the Tier II scores, and a summary of the total score, respectively, as identified for the Upper Riley Creek reaches in the CRAS report. Higher Tier I CRAS scores indicate a greater need for stream improvements and create initial ratings for “severe,” “high,” “moderate,” and “low” to indicate a priority level for stream projects. Higher Tier II CRAS scores indicate additional benefits to assist with prioritization within an identified level. Figure 1-1 summarizes the Tier I scores by subreach.

Table 1.1 CRAS (2015) Tier I Scores for Upper Riley Creek

Reach	Description	Infrastructure	Erosion/ Channel Stability	Ecological Benefits	Water Quality Summary	Tier I Score	Tier I Priority
R5	Lake Ann to Hwy 5	5	5	5	1	16	Moderate
R4A	Hwy 5 to Park Drive	3	5	5	3	16	Moderate
R4B	Park Drive to Park Road	1	5	5	3	14	Moderate
R4C	Park Road to Railroad Bridge	5	7	5	3	20	High
R4D	Railroad Bridge to Powers Blvd	5	7	5	3	20	High
R4E	Powers Blvd to Lake Susan	5	7	5	3	20	High

Table 1.2 CRAS (2015) Tier II Scores for Upper Riley Creek

Reach	Description	Public Education	Watershed Benefits	Partnership Opportunities	Cost	Tier II Score
R5	Lake Ann to Hwy 5	5	7	3	3	18
R4A	Hwy 5 to Park Drive	1	7	1	7	16
R4B	Park Drive to Park Road	1	7	1	5	14
R4C	Park Road to Railroad Bridge	1	7	1	7	16
R4D	Railroad Bridge to Powers Blvd	1	5	1	3	10
R4E	Powers Blvd to Lake Susan	7	5	1	3	16

Table 1.3 Summary of CRAS (2015) Rating and Tier I and II Scores for Upper Riley Creek

Reach	Description	Tier I Score	Tier I Rating	Tier II Score	Total Score
R5	Lake Ann to Hwy 5	16	Moderate	18	34
R4A	Hwy 5 to Park Drive	16	Moderate	16	32
R4B	Park Drive to Park Road	14	Moderate	14	28
R4C	Park Road to Railroad Bridge	20	High	16	36
R4D	Railroad Bridge to Powers Blvd	20	High	10	30
R4E	Powers Blvd to Lake Susan	20	High	16	36

Barr Footer: ArcGIS 10.3, 2015-07-10 11:52 File: I:\Client\RPBC_WD\Work_Orders\2014_Creek_Restoration_Action_Strategy_CRAS\Maps\Reports\20150602_CRAS\Final\Riley Creek Tier 1 Score.mxd User: mbs2

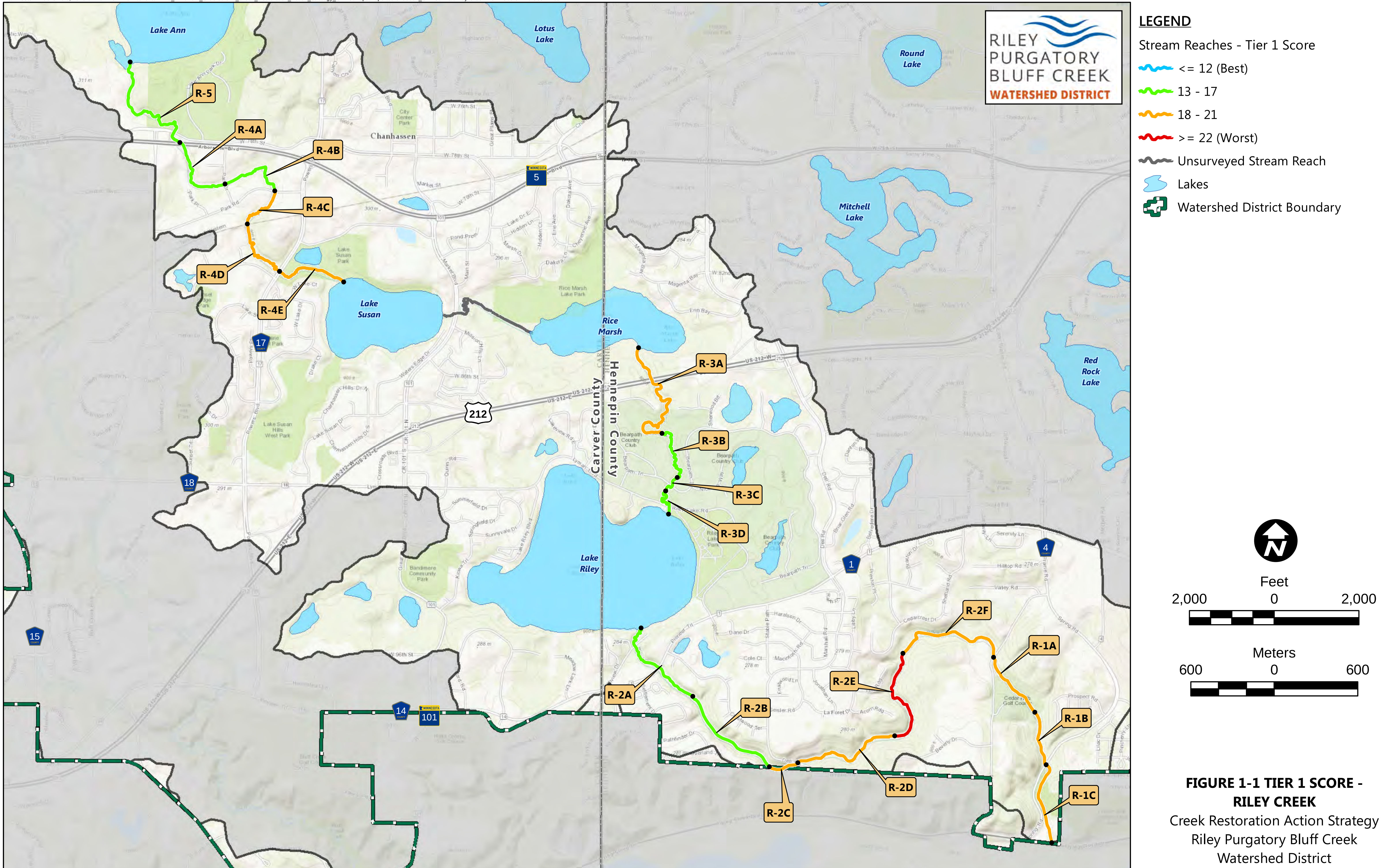


FIGURE 1-1 TIER 1 SCORE - RILEY CREEK

Creek Restoration Action Strategy
Riley Purgatory Bluff Creek
Watershed District

2.0 Sediment Source Assessment

Sediment delivery from the watershed to a stream is a natural process that occurs in all watersheds (Figure 2-1); however changes to the watershed change the dynamics of sediment delivery to and through the stream system. The basic sediment delivery to a stream can be broken down into three categories: surface erosion processes, hydrologic processes, and channel processes (Reference (5)). Each of these processes is summarized in this section.

2.1 Surface Erosion

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 within this reach, the nature of the erosion is consistent with channel processes (Section 2.3) rather than mass wasting of a slope. The subwatershed does not have any known areas that could otherwise be labeled as mass wasting, and a review of aerial photography did not uncover any other unusual sediment sources.

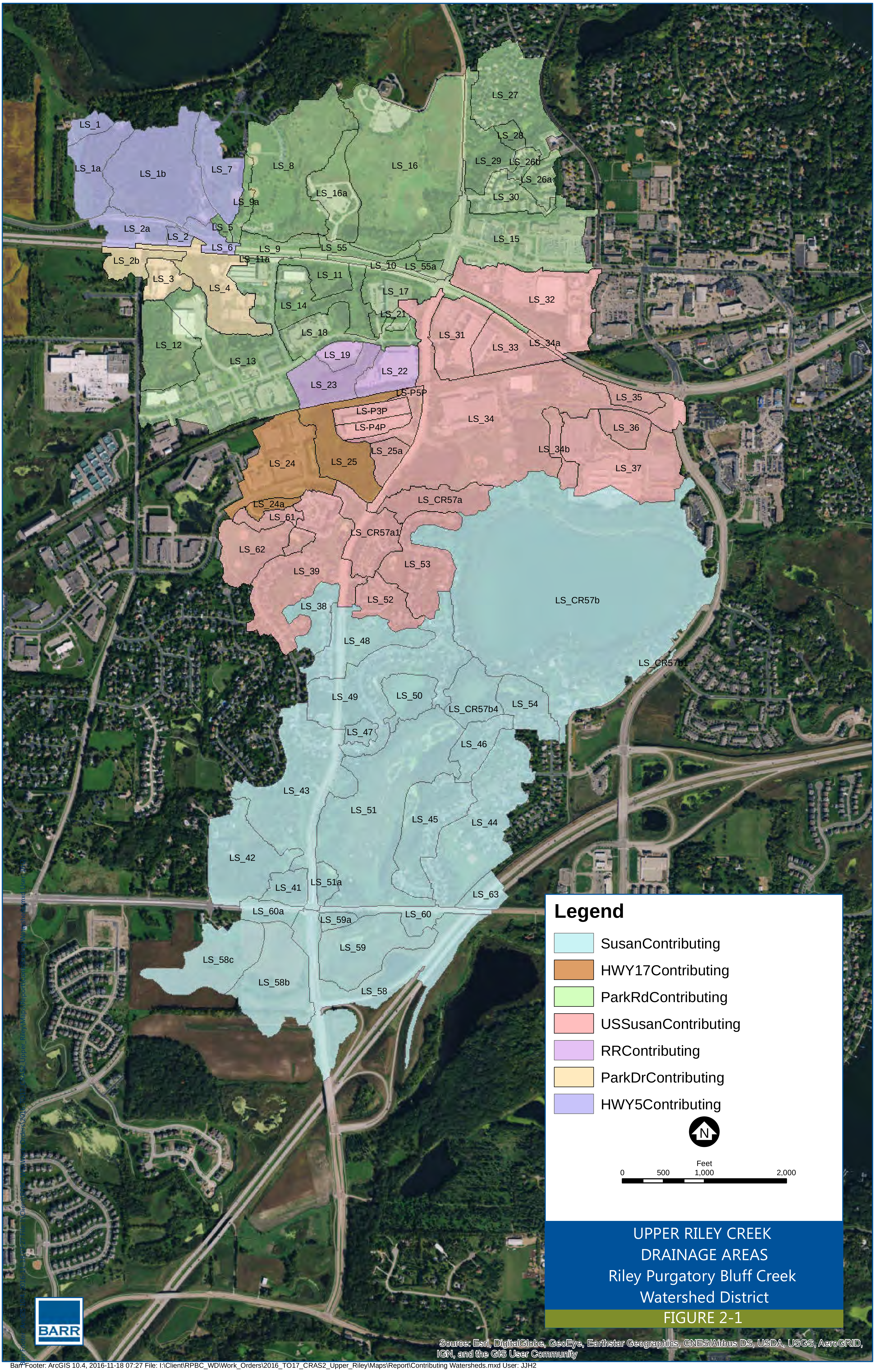
Surface erosion on natural surfaces is dependent on the watershed slope and the vegetation. Areas of a watershed that are unvegetated or poorly vegetated (e.g. fallow fields, development sites) will erode more and contribute more sediment than a portion that is well vegetated. The Upper Riley Creek watershed is relatively flat and well vegetated, so there appears to be minimal natural erosion from hillslopes.

The contributing watershed can play both a direct and indirect role in sediment delivery 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). Indirect influences of sediment delivery involve hydrologic processes and are covered in Section 2.3.

2.1.1 Historical Assessment

Historical change in the watershed land use and vegetation characteristics can lead to changes in surface erosion. Historical imagery from 1937 through 2016 was reviewed in order to identify changes in the land use patterns for the areas contributing to Upper Riley Creek. The specific imagery is included in Appendix A.

Between the early 1900's and 1950's, the contributing watershed to Upper Riley Creek was primarily agricultural. The area immediately south of Lake Ann (Lake Ann Park) was, and is currently, largely forested, so land use within the Lake Ann Park area has not changed significantly in the past century. In areas near and south of Highway 5, much of the area immediately adjacent to the creek was agricultural. The overall alignment of the stream is similar to existing conditions with a portion appearing to be straightened.


LS_1
LS_1a
LS_1b
LS_7
LS_9a
LS_5
LS_2a
LS_2
LS_6
LS_2b
LS_3
LS_4
LS_8
LS_16
LS_16a
LS_9
LS_11a
LS_55
LS_10
LS_55a
LS_11
LS_17
LS_14
LS_21
LS_18
LS_12
LS_13
LS_19
LS_22
LS_23
LS_27
LS_28
LS_29
LS_26b
LS_26a
LS_30
LS_15
LS_32
LS_31
LS_33
LS_34a
LS-P5P
LS-P3P
LS-P4P
LS_34
LS_35
LS_36
LS_34b
LS_37
LS_25a
LS_24
LS_25
LS_24a
LS_CR57a
LS_61
LS_CR57a1
LS_62
LS_39
LS_53
LS_52
LS_38
LS_CR57b
LS_48
LS_CR57b1
LS_49
LS_50
LS_CR57b4
LS_54
LS_47
LS_46
LS_43
LS_51
LS_45
LS_44
LS_42
LS_41
LS_51a
LS_63
LS_60a
LS_59a
LS_60
LS_59
LS_58c
LS_58b
LS_58
Legend
SusanContributing
HWY17Contributing
ParkRdContributing
USSusanContributing
RRContributing
ParkDrContributing
HWY5Contributing
N
Feet
0 500 1,000 2,000
UPPER RILEY CREEK
DRAINAGE AREAS
Riley Purgatory Bluff Creek
Watershed District
FIGURE 2-1
BARR
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

In the 1960's and 1970's, homes were constructed on nearby larger lakes; however, the Upper Riley Creek watershed was still predominantly agricultural. The city of Chanhassen grew slightly in this time and some industrial facilities adjacent to the city of Chanhassen were constructed. By 1979, a few developments appeared within the watershed, but agriculture remained the dominant land use.

Much of the development in the Upper Riley Creek watershed occurred in the 1980's and 1990's. Between 1979 and 1991, approximately 75% of the current development occurred. Between 1991 and 2002 a belt of industrial development with significant impervious area was developed in the central portion of the watershed, resulting in developed conditions similar that present day. The only changes since 2002 have included occasional in-fill projects on undeveloped parcels.

2.1.2 Total Suspended Solids (TSS)

Total Suspended Solids originating from the watersheds reaching Lake Susan were quantified by a P8 model, originally developed by Wenck Associates, Inc. for RPBCWD and modified by Barr Engineering Co. for the TMDL analysis (Reference (2)). The TSS loading values should be considered order of magnitude values for the purpose of this analysis. The P8 model indicates a total of 138,600 lbs of sediment leave the watersheds contributing to Lake Susan each year while 83,000 lbs reach Lake Susan from the contributing watersheds each year (excluding loading from the streambank erosion). The existing detention basins and natural wetlands are removing approximately 67% of the sediment originating in the watershed. Two watersheds are documented in Figure 2-2 as providing less than 20% removal of TSS from runoff. These two watersheds are providing minimal TSS reduction and contribute approximately 6,650 lbs/yr of TSS to Riley Creek (8% of the incoming loading with 1% of the contributing drainage area).

2.2 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:

- Rapid 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 the stream will result in degradation of the stream bed and banks with transport of the eroded sediment downstream.

Legend
Minimal TSS Reduction (<20%)
Minimal Volume Reduction (<20%)
N
Feet
0 400 800 1,600
UPPER RILEY CREEK
WATERSHEDS WITH
MINIMAL TREATMENT
Riley Purgatory Bluff Creek
Watershed District
FIGURE 2-2
LS_2a
LS_2
LS_2b
LS_3
LS_10
LS_11
LS_18
LS_19
LS_22
LS_24
LS_31
LS_32
LS_33
LS_34b
LS_37
LS_CR57a1
LS_54
BARR
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

2.2.1 Flood Frequency and Magnitude Primer

Prior to the introduction of agriculture and grazing practices, Upper Riley Creek was likely in dynamic equilibrium with its watershed and was 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. 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 again.

The most significant change associated with urbanization within the creek corridor is an increase in runoff from the watershed. With urbanization, the rate and volume of runoff generally increases, as shown in Figure 2.3 assuming mitigating measures are not implemented.

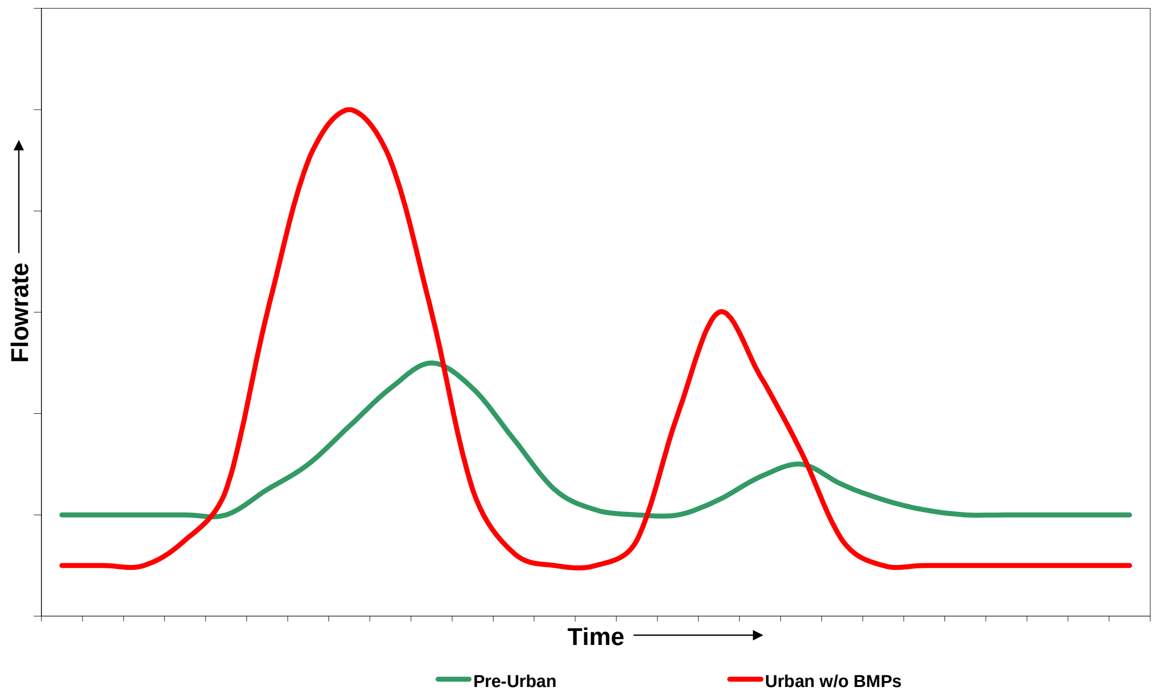


Figure 2.3 Change in Streamflow Due to Urbanization (Center for Watershed Protection, 2003)

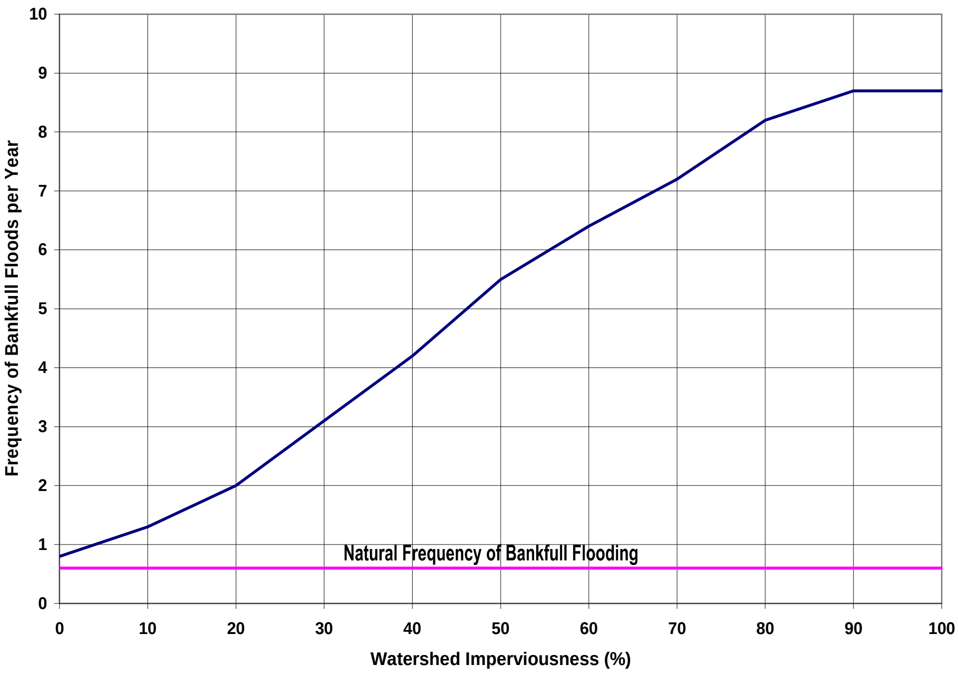


Figure 2.4 Conceptual Frequency of Bankfull Flooding as a Function of Imperviousness (Center for Watershed Protection, 2003)

The shape, pattern, and profile of the creek channel are closely 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 consistently convey the bankfull discharge without significant erosion. With urbanization, an increase in watershed imperviousness typically leads to an increase in the frequency of bankfull discharge as illustrated in Figure 2.4. 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.

Detention ponds are often constructed to slow the rate of storm water flow to the creek, and thus attempt to maintain a more natural peak rate of flow to the creek and limit the impact to the magnitude of bankfull flows. 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.

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 will be less in watersheds with a lot of natural storage in lakes and wetlands, compared to those with little natural storage, because the channel will already be adjusted to a longer hydrograph.

2.2.2 Upper Riley Creek Runoff Volume and Rate

Upper Riley Creek receives runoff from three distinct land use areas; undeveloped parkland, industrial, and residential. The industrial areas include the largest amount of impervious surface with most areas receiving treatment by retention/detention ponds. Table 2.1 summarizes the land use area and percentages contributing to Lake Susan (Reference (2)).

The largest percentage of contributing area is defined as undeveloped with other large percentages including open water, park, single family homes (residential), and industrial. The areas defined as residential and industrial have the potential to greatly increase runoff rates and volumes as compared to pre-development conditions due to increased imperviousness, leading to in-stream erosion.

Table 2.1 Contributing area to Lake Susan defined by 2016 land use

Land use	Area, ac	Land use Percentage
Agricultural/Farmstead	60	4%
Airport	0	0%
Retail and Other Commercial	52	4%
Golf course	0	0%
Major Highway	75	5%
Office	13	1%
Industrial and Utility	172	12%
Mixed Use	5.4	0%
Institutional	22	2%
Single Family Detached	260	18%
Multifamily	14	1%
Single Family Attached	41	3%
Seasonal/Vacation	0	0%
Park, Recreational, or Preserve	247	17%
Undeveloped	313	21%
Open Water	209	14%

The RPBCWD developed a detailed PCSWMM hydrologic and hydraulic model of Riley Creek in 2016. This model includes existing watersheds and land use to determine the rate and volume of runoff conveyed in Riley Creek. The PCSWMM model was used to analyze the impacts industrial and residential development in the watershed may have on the peak discharge and volume of water in this section of Riley Creek. The watershed imperviousness factor in the model was reduced to 0% as compared to the existing watershed imperviousness of 35%. The maximum infiltration rate was increased in order to approximate potential pre-development conditions. Figure 2-5 and Figure 2-6 summarize the existing and pre-development conditions 2-yr cumulative runoff volume and percent increase in runoff volume (as compared to the immediate upstream segment) at several locations along the project reach.

Compared to existing conditions, the theoretical pre-development condition has approximately 52% less runoff volume as shown in Figure 2-5. In addition, the true pre-development condition likely experienced less runoff volume and lower runoff rates than those approximated because of natural depressions and conveyances rather than the existing storm sewers. The segment immediately upstream of Lake Susan shows large increases in flow in Figure 2-6. The reach downstream of Park Road was also the creek section identified as having significant erosion. When the percent increase in drainage area is plotted there is a clear trend that corroborates the volume increase at Park Road and upstream of Lake Susan (Figure 2-7).

The PCSWMM model was also revised to approximate pre-development runoff peaks by assuming a fully pervious condition; however it still includes conveyance structures that are present today but were not present before development because pre-development flow patterns would have to be assumed. Since those conveyance structures were maintained for this analysis, the results defined as "Pre-development" should be considered proxies for actual pre-development modeling results and therefore the peaks should be analyzed for trends, not necessarily for their absolute value.

Figure 2-9 and Figure 2-10 provide the PCSWMM existing and pre-development 2-year and 10-year peak discharges. For the downstream section of the reach (HWY17), the 2-year peak discharge has increased by 125% as compared to pre-development conditions. The increase in the HWY17 reach is only 14% for the 10-year peak discharge. The 2-year event appears to have been impacted the most by watershed development and is critical when assessing stream erosion impacts.

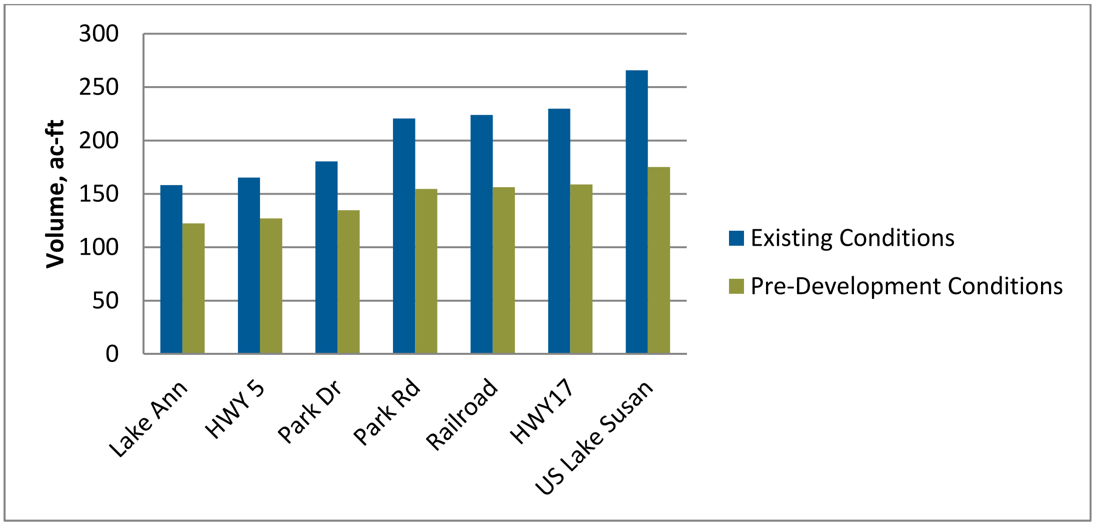


Figure 2-5 Cumulative runoff volume from the 2-year design storm from Lake Ann to upstream of Lake Susan

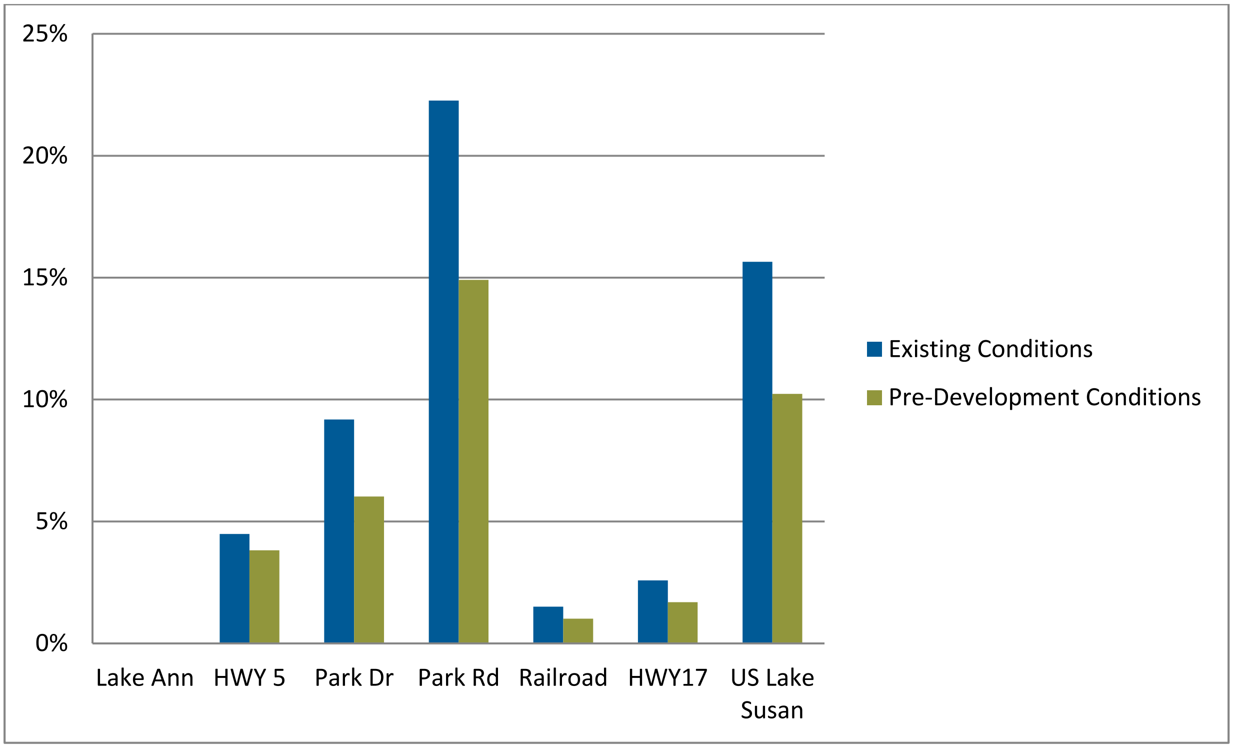


Figure 2-6 **Percent increase in runoff volume from the 2-year design storm from Lake Ann to upstream of Lake Susan**

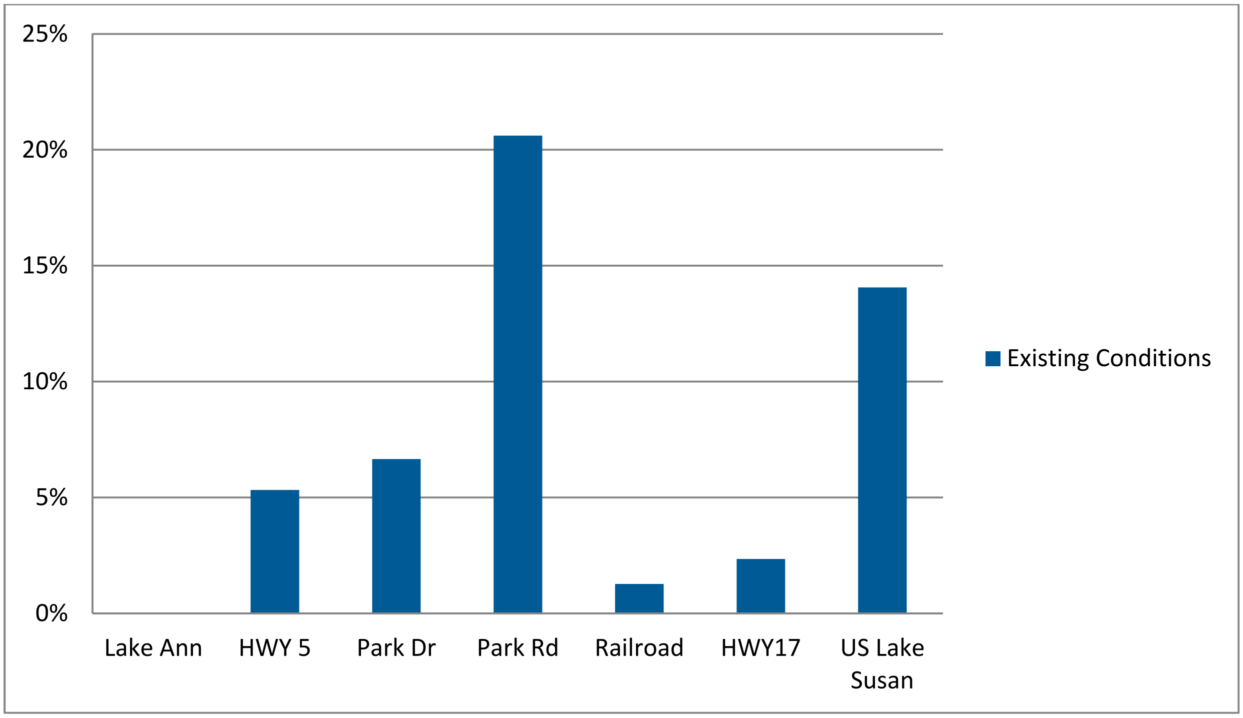


Figure 2-7 **Percent increase in contributing drainage area along Riley Creek**


Legend
7.4-inch rainfall event *Atlas 14 100-Year Event*
STORM SEWER AND INUNDATION EXTENTS
Riley Purgatory Bluff Creek Watershed District
FIGURE 2-8
N
Feet
0
500
1,000
BARR
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

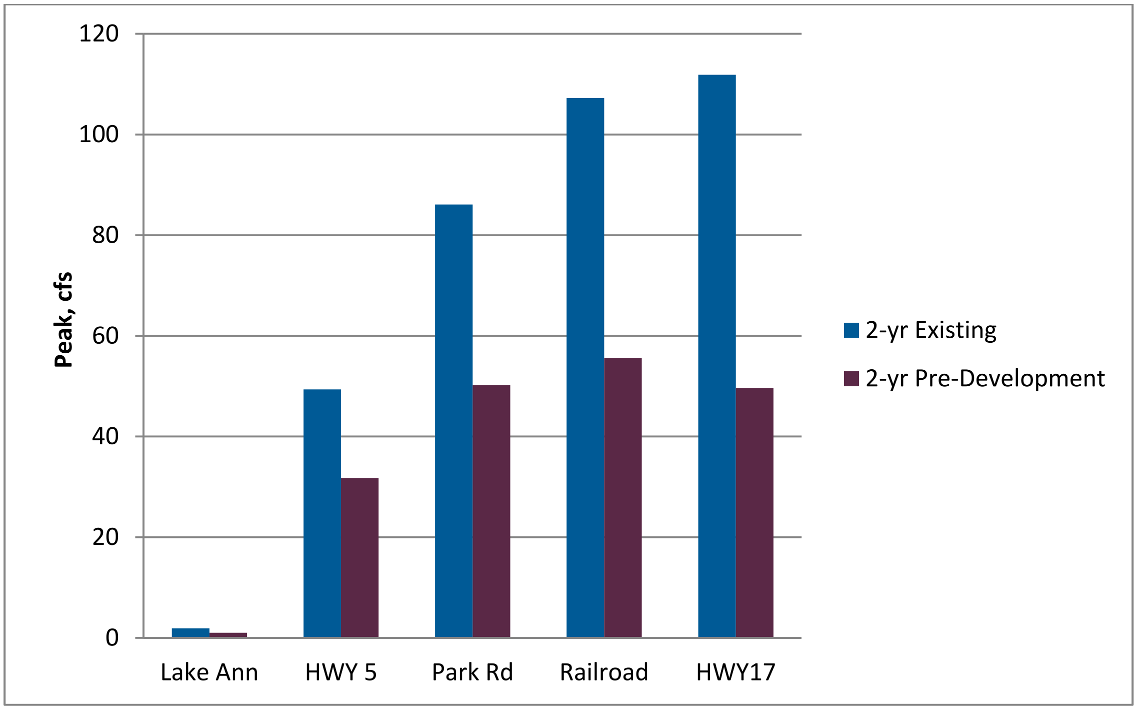


Figure 2-9 **Peak 2-year discharge in Riley Creek for existing and pre-development conditions**

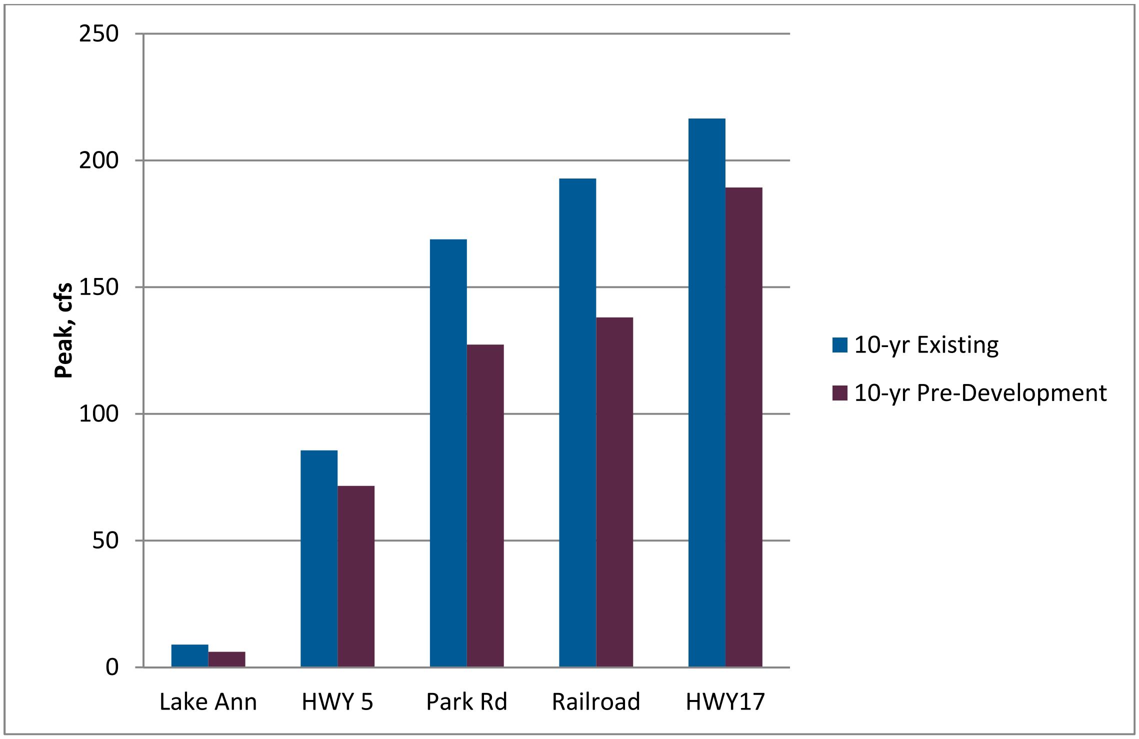


Figure 2-10 **Peak 10-year discharge in Riley Creek for existing and pre-development conditions**

2.2.3 Watershed Detention Storage

A P8 model, originally developed by Wenck Associates, Inc for RPBCWD and modified for the TMDL analysis (Reference (2)) was used for this study to highlight areas of minimal detention. Watersheds that reduced the runoff peak by less than 20% are highlighted on Figure 2-2. Many of these watersheds discharge runoff directly to Riley Creek with no detention or include ponds with minimal detention.

2.2.4 Climate Adaptation

Climate adaptation was the focus of a recent study by RPBCWD for the identification of future infrastructure impacts (Reference (6)). Table 2.2 summarizes the key 100-year precipitation event rainfall depths associated with the vulnerability analysis.

Table 2.2 Vulnerability analysis rainfall depth summary

Precipitation Event Condition	100-yr, 24-hour Precipitation depth, in
Atlas 14	7.4
TP-40	6.0
Future Moderate	10.2
Future Optimistic	5.5
Future Pessimistic	17.6

The Atlas 14 rainfall depth is the current regulatory 100-yr precipitation depth based on rainfall data up to 2012 in some circumstances. The TP-40 rainfall depth was determined based on data up to 1961 and was the regulatory 100-yr precipitation depth before the Atlas 14 update was issued (Reference (7)).

Future site conditions could be subject to further rainfall increases. A recent publication identified in Reference (6) determined mid-century (year 2050) 100-yr precipitation depths for Moderate, Optimistic, and Pessimistic climate conditions. Inundation mapping for the 90% percent confidence interval (similar depths to the future optimistic and future moderate precipitation depths) is shown on Figure 2-8. The future moderate scenario would result in an approximate 38% increase in the precipitation, subsequent increases in peak discharge and volume in the Riley Creek, and additional channel erosion.

2.3 Channel Processes

Erosion and mass wasting due to channel processes involves the direct loss of soil from the streambanks and bed. Erosion and migration of the channel banks and bed are natural processes of all stream systems, however changes to the stream hydrology can result in increases in the stream erosion and migration rates. Increases in streambank erosion can cause damage to nearby infrastructure as well as result in downstream sedimentation and pollution of lakes or other waterbodies. This section evaluates the in-stream stability/erosion rates of Upper Riley Creek primary through field data collection.

2.3.1 Sediment Transport Primer

Sediment transport is an important function of the creek. It forms the shape of the channel, including the pools and riffles which are very 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.

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 results in greater erosion potential.

2.3.2 Upper Riley Creek Erosion Potential and Modified Pfankuch Channel Stability Ratings

Site visits and high-level geomorphological assessments were completed by District and Barr staff on October 18, November 21, and November 28, 2016. Upper Riley Creek was divided into six segments based on physical characteristics or logical breaks (i.e. a major roadway crossing) and bank erosion hazard index (BEHI), near bank stress, and modified Pfankuch channel stability rating worksheets were completed for each segment (Reference (5)). A formal survey of the Upper Riley Creek segment was not completed.

The Pfankuch method assigns channel stability rating based on a series of qualitative questions to predict creek stability. The method evaluates 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 (5)). The scores completed by District and Barr staff were similar but the relatively minor differences resulted in different ratings for two reaches, as summarized in Table 2.3. In general, the condition of the creek degrades from Lake Ann to Lake Susan. The reviewers concurred that the channel is in worse condition downstream of Park Road, which is the location where the contribution watershed increases significantly. Write-ups of the assessment completed by District staff are included in Appendix B.

Table 2.3 Modified Pfankuch Channel Stability Rating

Reach	Description	Pfankuch Rating	CRAS Score
R5	Lake Ann to Hwy 5	Good	3
R4A	Hwy 5 to Park Drive	Good / Fair	3 / 5
R4B	Park Drive to Park Road	Good	3
R4C	Park Road to Railroad Bridge	Fair	5
R4D	Railroad Bridge to Powers Blvd	Fair	5 / 7
R4E	Powers Blvd to Lake Susan	Fair / Poor	5 / 7

2.3.3 BEHI Scores

The Bank Erosion Hazard Index (BEHI) was developed by Dave Rosgen and adopted by the U.S. Environmental Protection Agency (EPA) as a method for assessing streambank erosion condition and potential using variables that are known to affect bank erosion rates. The BEHI method assigns points (low scores being low susceptibility and higher scores being high susceptibility) to several aspects of streambank condition and considers bank height, bankfull height, bank angle, root depth, root density, and vegetated surface protection (Reference (5)). Scores are then correlated to a streambank risk rating ranging from very low risk to extreme risk and are used to help estimate erosion rates. A summary of the BEHI rating is provided in Table 2.4.

Table 2.4 Summary of Average BEHI Ratings

Reach	Description	BEHI Rating
R5	Lake Ann to Hwy 5	Low
R4A	Hwy 5 to Park Drive	Moderate
R4B	Park Drive to Park Road	Low/Moderate
R4C	Park Road to Railroad Bridge	Moderate
R4D	Railroad Bridge to Powers Blvd	Moderate/High
R4E	Powers Blvd to Lake Susan	High

In general, the Upper Riley Creek reach is susceptible to streambank erosion, likely due to tall streambanks in combination with lower root densities and lower vegetated surface protection.

2.3.4 Near Bank Stress Ratings

Near bank stress (NBS) quantifies the amount of stress affecting a streambank using one of seven different calculation methods, and the use of this method requires an in-depth analysis with survey data to fully determine the severity of the near bank stress (Reference (5)). The survey needed to complete a full NBS analysis was not completed for this phase of assessment. NBS ratings can change rapidly along a stream and the localized NBS near an actively eroding bank can significantly impact both actual and predicted erosion rates. Ratings on most banks are very low or low so a low average rating was assumed for all reaches in order to estimate erosion. For perspective, the range of erosion rates for a stream with a NBS rating of low is approximately 0.035 ft/yr, 0.15 ft/yr, and 0.25 ft/yr, for “low,” “moderate,” and “high” BEHI ratings, respectively (Reference (5)).

2.3.5 Bank Erosion Rates

Based on the BEHI and NBS Ratings, the erosion rates and volumes for each reach were estimated and summarized in Table 2.5.

Table 2.5 Estimated annual erosion volume for each subreach

Reach	Description	Estimated Bank Erosion Rate[1] (feet per year)	Estimated Average Bank Height (ft)	Reach Length (ft)	Estimated Annual Erosion Volume (tons/yr)
R5	Lake Ann to Hwy 5	0.035	2	3300	15
R4A	Hwy 5 to Park Drive	0.15	3	1770	41
R4B	Park Drive to Park Road	0.09	4	1820	34
R4C	Park Road to Railroad Bridge	0.15	3	1200	28
R4D	Railroad Bridge to Powers Blvd	0.20	3	1780	55
R4E	Powers Blvd to Lake Susan	0.25	3	1960	76
			Total	11,830	250

1 – from Reference (5)

2.4 Miscellaneous Considerations

2.4.1 Habitat Assessment

RPBCWD Staff assessed the habitat conditions based on the Minnesota Stream Habitat Assessment protocol developed by the MPCA, and the ratings ranged from “good” 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. Table 2.6 provides a summary of the MSHA ratings by reach.

Table 2.6 MSHA habitat ratings for each subreach

Reach	Description	MSHA Rating
R5	Lake Ann to Hwy 5	Good
R4A	Hwy 5 to Park Drive	Fair
R4B	Park Drive to Park Road	Fair
R4C	Park Road to Railroad Bridge	Fair
R4D	Railroad Bridge to Powers Blvd	Fair
R4E	Powers Blvd to Lake Susan	Fair

2.4.2 Revised CRAS Scores

Based on the assessments completed in 2016, the following tables provide a summary of updated CRAS scores for Upper Riley Creek.

Table 2.7 Updated Tier I CRAS Scores based on 2016 assessments

Reach	Description	Infra-structure	Erosion/ Channel Stability	Ecological Benefits	Water Quality Summary	Tier I Score	Tier I priority
R5	Lake Ann to Hwy 5	1	3	3	1	12	Low
R4A	Hwy 5 to Park Dr.	5	5	5	3	18	High
R4B	Park Dr. to Park Rd.	3	3	5	3	14	Low
R4C	Park Rd. to Railroad Br.	5	5	5	3	18	High
R4D	Railroad Br. to Powers Blvd.	3	7	5	3	18	High
R4E	Powers Blvd. to Lake Susan	3	7	5	3	18	High

2.5 Analysis Summary

2.5.1 Surface Erosion

Surface erosion for the watersheds contributing to Upper Riley Creek and Lake Susan was evaluated both qualitatively and quantitatively. Review of the watershed indicates the presence of streambank erosion within this reach, however the nature of the erosion is consistent with channel processes caused by anthropogenic activity. The subwatershed lacks known areas that could be labeled as mass wasting. A review of aerial photography did not uncover any other unusual sediment sources. The watershed is relatively flat and is well vegetated, so natural erosion from hillslopes is not expected to be significant.

Many developments within this subwatershed appear to lack BMPs that meet minimum current requirements as many ponds were identified as being undersized. Undersized ponds are unlikely to effectively reduce peak flows or sufficiently remove sediment in stormwater runoff. Two watersheds with minimal total suspended solids removal are highlighted in Figure 2-2.

2.5.2 Hydrologic Processes

The evaluation of hydrologic processes reviewed available data associated with existing hydrologic and hydraulic models, watershed land use, climate studies, and the TMDL study with the intent of identifying contributing causes of streambank erosion in Riley Creek and sediment deposition in Lake Susan. The watershed analysis determined the following key items:

- The upstream third of the watershed remains largely pervious with some single family homes while the center of the watershed is industrial with significant impervious area. The downstream third of the watershed is a mix of industrial and single family homes. The watershed is anticipated to continue to develop and add impervious surface in the future.
- The additional impervious area associated primarily with the central industrial area has resulted in increases in the 2-year design storm runoff volume and peak discharge of approximately 52% and 126% for the reach immediately upstream of Lake Susan, respectively.
- Large increases in runoff volume occur at Park Road and immediately upstream of Lake Susan. The increases in runoff volume can be attributed to the installation of storm sewer conveyance systems through the pre-development watershed divides and to the large amount of impervious surfaces without sufficient stormwater detention.
- Future increases in precipitation will result in increased runoff volumes and peak discharges over the next 50 years which should be considered in future regulations and designs (Reference (7)).
- Streambank erosion can largely be attributed to the increase in impervious area in the watershed and to the revisions of drainage divides/conveyance features causing increased runoff volumes and rates.
- Watersheds with little or no runoff detention and subsequent low TSS removal were identified in this analysis. These watersheds could be locations for improvements to existing BMPs or construction of new BMPs with the goal of reducing the runoff peaks reaching Riley Creek.

2.5.3 Channel Processes

Site visits and high-level geomorphological assessments were completed as part of this assessment. Based on visual observation and basic measurements, the Upper Riley Creek reach is susceptible to streambank erosion due to tall streambanks in combination with lower root densities and lower vegetated surface protection.

3.0 Remedial Concepts

3.1 Watershed Improvements

A design goal based on approximated pre-development conditions was developed because the stream is assumed stable during pre-development conditions. The pre-development conditions model assumed all land, except lakes and wetlands, is pervious. As described earlier, the existing conveyance structures (storm sewers and drainageways) remained in the models to avoid an overabundance of assumptions regarding pre-development conveyances. The results presented in Table 3.1 indicate the largest reduction in runoff peak needs to occur for the smaller, more frequent 2-year design storm. In addition, the true pre-development condition likely experienced lower rates than those approximated in Table 3.1 because of natural depressions and conveyances rather than the existing storm sewers.

Table 3.1 Existing and pre-developed conditions estimated peak design discharges

Development Condition	2-year Design Flow (cfs)	10-year Design Flow (cfs)
Existing Conditions	112	217
Pre-development Conditions[1]	50	190

[1]For this scenario, Pre-development condition assumes the watershed is fully pervious, however existing conveyance structures remained when estimating the flows

Any project in the Upper Riley Creek subwatershed that increases abstraction and/or reduces peak runoff rates would contribute to the goal of improving stream health and providing benefits for the entire watershed. Therefore, cost-share opportunities to improve stormwater management on individual parcels should be pursued.

This study examined the potential for larger scale projects that include more than one parcel and would contribute towards meeting the design peak discharge values as shown in Table 3.1, and three such projects are described in the following sections and shown in Figure 3-1. Table 3.2 outlines the proposed alternatives and the associated costs.

All costs described in this section are Class 5 screening-level opinion of probable costs, as defined by the American Association of Cost Engineers International (AACI International). The opinion of probable construction cost provided 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 25% project contingency, 20% for planning, engineering, and design, and 7% for construction administration. Lower bound estimates assumed at -25% and upper bound estimates assumed at +40%.

Table 3.2 **Potential Upper Riley Creek Watershed Projects**

Improvement	Watershed	Pond	Modification Description	Construction Cost Estimate(1)	TP Loading		TSS Loading	
					Load Reduction (lb/yr)	Cost/lb Reduced(2)	Load Reduction (lb/yr)	Cost/lb Reduced(2)
CH-1a	LS-19	3.95p	Fix berm	$ 86,000	9	$ 660	9,600	$ 0.63
CH-2a	LS-13	3.62	Install diversion to wetland	$ 77,000				
CH-2b	LS-12	3.62	Expand wetland	$ 767,000	5	$ 14,660	741	$ 98.52
CH-2c	LS-3	3.61	New storm or channel into wetland	$ 134,000				
CH-3a	LS-11	3.78	Expand pond, repair outlet, divert upstream ponds into this pond	$ 711,000				
CH-3b	LS-16	3.14	Create new outlet structure and raise normal water level	$ 113,000	93	$ 3,020	58,757	$ 1.16
CH-3c	LS-29	3.13	Create new outlet structure and raise normal water level	$ 82,000				
Reach R5			Stream restoration	$ 848,000	17	$ 3,420	30,000	$ 1.97
Reach R4A			Stream restoration	$ 456,000	48	$ 673	82,700	$ 0.39
Reach R4B			Stream restoration	$ 469,000	39	$ 840	68,100	$ 0.48
Reach R4C			Stream restoration	$ 310,000	32	$ 680	56,200	$ 0.39
Reach R4D			Stream restoration	$ 457,000	64	$ 500	110,600	$ 0.29
Reeach R4E			Stream restoration	$ 502,000	87	$ 400	152,000	$ 0.23

(1) A Class 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 25% project contingency, 30% for planning, engineering, design, and legal, and 7% for construction administration. Lower bound assumed at -25% and upper bound assumed at +40%.

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

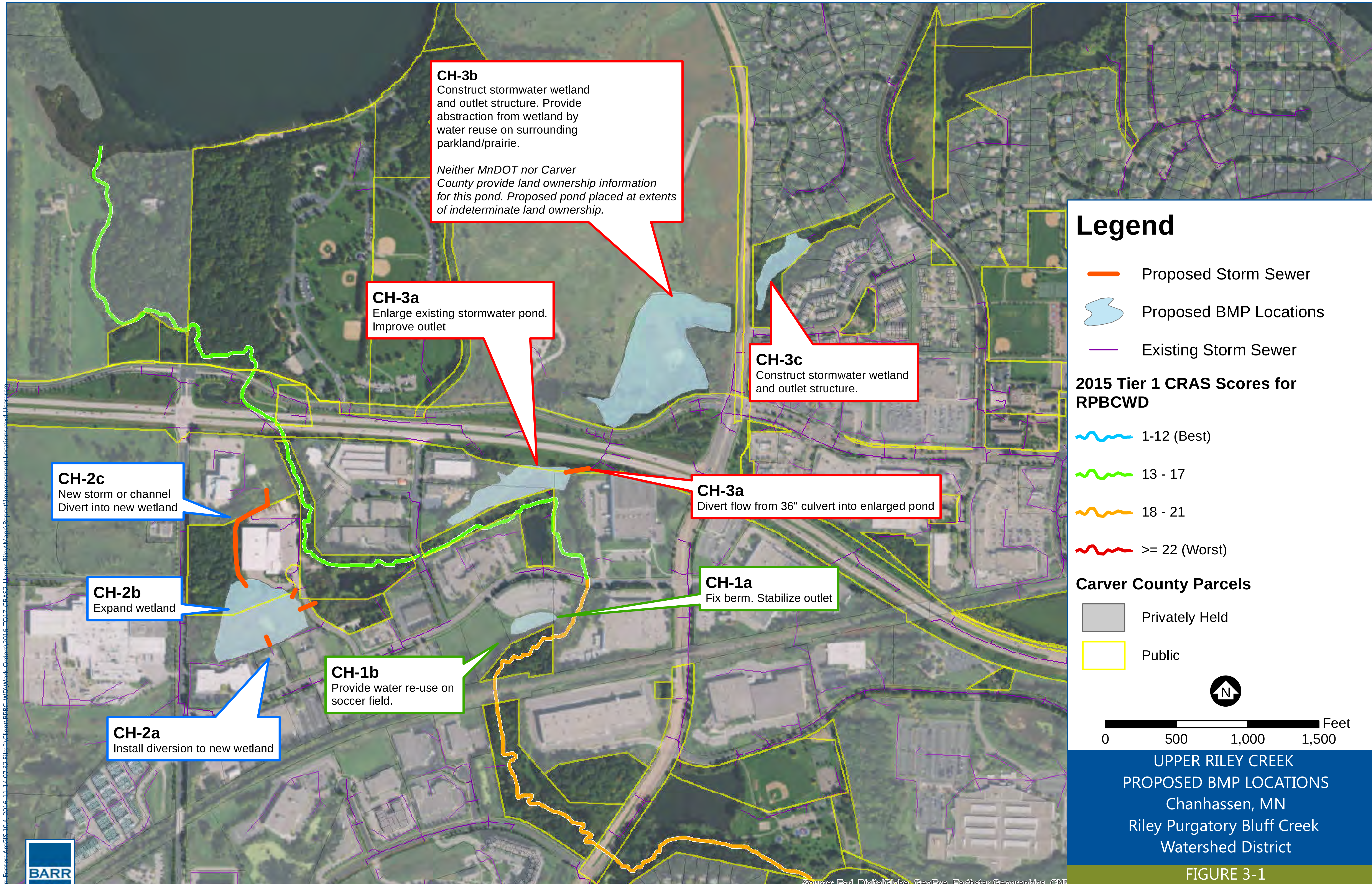
Hydraulic and water quality modeling was completed in support of the proposed alternatives. The modeling was representative of high level design with minimal project definition for each proposed BMP. Further optimization of the BMP configuration, including storage volumes and outlet design could produce improved sediment capture efficiency and runoff rate reduction. For instance, optimizing the proposed storage outlet design for the 2-year design event could improve sediment capture and rate reduction for this frequent event; however the rate reductions for large events, such as the 10-year or 100-year events may not be as significant.

As shown in Section 2.2, implementation of all large scale projects described below would not fully achieve the goal of reducing the peak flows to the estimated pre-development rates. Since the preliminary designs for each potential project were not optimized, the contribution from each individual project toward rate reduction was not quantified. Nonetheless, reduction in peak flow rates along Upper Riley Creek would benefit all downstream waterbodies.

3.1.1 CH-1a and CH-1b (Reach R4C)

An existing stormwater pond treats parking lot runoff on property owned by IWCO on the west side of the channel, downstream of Park Road. Sediment runoff from the parking lot washes into the stormwater pond where it settles. The berm and swale which separates the stormwater pond from Upper Riley Creek has eroded, providing minimal treatment. Project CH-1a includes stabilizing the eroding swale and rebuilding the berm. The project is expected to cost approximately $86,000. Annualized costs for pollutant removal associated with project CH-1A range from $0.63 per pound TSS/year to $660 per pound TP/year. The reductions of TP and TSS listed above are associated with the additional treatment of runoff from the IWCO parking lot and do not include the reduced erosion in Upper Riley Creek that results from reducing volumes and peak flow rates. Quantification of the reduced erosion in Upper Riley Creek would prove additional project benefits.

CH-1b involves using the improved pond for irrigation of the adjacent sports field, further reducing volumes and flow rates as well as reducing TP and TSS entering Upper Riley Creek. The cost estimates presented here do not include the costs of a water re-use system.


CH-3b
Construct stormwater wetland and outlet structure. Provide abstraction from wetland by water reuse on surrounding parkland/prairie.
Neither MnDOT nor Carver County provide land ownership information for this pond. Proposed pond placed at extents of indeterminate land ownership.
CH-3a
Enlarge existing stormwater pond. Improve outlet
CH-3c
Construct stormwater wetland and outlet structure.
CH-3a
Divert flow from 36" culvert into enlarged pond
CH-2c
New storm or channel
Divert into new wetland
CH-2b
Expand wetland
CH-1a
Fix berm. Stabilize outlet
CH-1b
Provide water re-use on soccer field.
CH-2a
Install diversion to new wetland
Legend
Proposed Storm Sewer
Proposed BMP Locations
Existing Storm Sewer
2015 Tier 1 CRAS Scores for RPBCWD
1-12 (Best)
13 - 17
18 - 21
>= 22 (Worst)
Carver County Parcels
Privately Held
Public
N
Feet
0
500
1,000
1,500
UPPER RILEY CREEK
PROPOSED BMP LOCATIONS
Chanhassen, MN
Riley Purgatory Bluff Creek
Watershed District
FIGURE 3-1
BARR
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNE

3.1.2 CH-2a, CH-2b, and CH-2c (Reach R4A)

The existing wetland located adjacent to Chanhassen Public Works only collects water from its immediate drainage area and does not include an outlet to any downstream waterbodies. Several improvements of this wetland are feasible that could reduce pollutant loading and storm runoff rates from the surrounding watersheds. The combination of the three improvements could result in wetland impacts, which would need further review and analysis. BMPs CH-2a, CH-2b and CH-2c were analyzed as a single BMP combination to streamline the assessment and because the performance of these three BMPs are interconnected.

3.1.2.1 CH-2a

Existing storm sewer that manages runoff from impervious areas north of Park Road discharges into the wetland complex downstream of Park Place. Additional treatment benefits would be available if this storm sewer was routed into the existing wetland immediately south of the Chanhassen Public works (CH-2a). This wetland would provide pretreatment of the stormwater before conveyance into the next downstream wetland. Rerouting the storm sewer is expected to cost approximately $77,000.

3.1.2.2 CH-2b

Expansion of the existing wetland located south of Chanhassen Public Works (CH-2b) could allow for additional pollutant loading reduction and rate control if either alternatives CH-2a and/or CH-2c were implemented. The wetland expansion would provide additional flood detention storage and increase surface area. Expansion of the existing wetland is expected to cost approximately $767,000.

3.1.2.3 CH-2c

Runoff from Paisley Park currently passes through a small stormwater pond before its discharge into Upper Riley Creek. Minimal detention and pollutant treatment is provided by this stormwater pond. Installing new storm sewer or a swale around the Chanhassen Public Works with an outlet in the existing wetland immediately south of Chanhassen Public Works would provide additional treatment and reduce pollutant loading and runoff rates. The new storm sewer or swale is expected to cost approximately $134,000.

3.1.2.4 CH-2a, CH-2b, and CH-2c Annualized Pollutant Removal Costs

Annualized costs for pollutant removal associated with full implementation of CH-2a, CH-2b, and CH-2c range from $98.52 per pound TSS to $14,660 per pound TP. The reductions of TP and TSS are summarized in Table 3.2 and are associated with the additional treatment of runoff from the redirected drainage routes and the expansion of the wetland. These values do not include the reduced erosion in Upper Riley Creek that results from reducing peak flow rates. Quantification of the reduced erosion in Upper Riley Creek would prove additional project benefits.

3.1.3 CH-3a, CH-3b, and CH-3c

Runoff originating in the residential watersheds east of Powers Boulevard drains through a series of low lying wetlands before discharging into Upper Riley Creek downstream of Highway 5. Conveyance of the discharge from the 36 inch pipe under Highway 5 is resulting in significant erosion upstream of the confluence with Upper Riley Creek. The following alternatives are designed to reduce the runoff rates in order to reduce the potential for continued erosion of this channel, in addition to providing removal of pollutants originating in the contributing watersheds through sedimentation.

3.1.3.1 CH-3a

This project would involve rerouting the pipe underneath Highway 5 into the existing pond on the north side of Upper Riley Creek instead of directly draining into the creek. The pond on the north side of the creek will be excavated by increasing its permanent pool volume by 2.3 acre-ft and the flood pool by 6 acre-ft. This project would also prevent the continuing erosion of a channel connecting the pipe under Highway 5 to Upper Riley Creek. The project is expected to cost approximately $711,000.

3.1.3.2 CH-3b

This project would add an outlet structure in the ravine west of Powers Blvd, upstream of Highway 5, thereby creating a wet pond. The additional storage and permanent pool would improve pollutant removal while reducing runoff rates. The project is expected to cost approximately $113,000.

The pond could be used for irrigation of the Eckankar Temple Complex, further reducing volumes and flow rates as well as reducing TP and TSS entering Upper Riley Creek. The cost estimates presented here do not include the costs of a water re-use system.

3.1.3.3 CH-3c

This project would modify the existing outlet structures in the ravine east of Powers Boulevard, thereby creating a wet pond. The additional storage and permanent pool would improve pollutant removal while reducing runoff rates. The project is expected to cost approximately $82,000.

3.1.3.4 CH-3a, CH-3b, and CH-3c Annualized Pollutant Removal Costs

Annualized costs for pollutant removal associated with full implementation of CH-3a, CH-3b, and CH-3c range from $1.16 per pound TSS to $1,780 per pound TP. The reductions of TP and TSS listed in Table 3.2 associated with the additional treatment of runoff from upstream control structure improvements and the re-routing of stormwater into the expanded pond downstream of Highway 5. These values do not include the reduced erosion in Upper Riley Creek that results from reducing volumes and/or peak flow rates. Quantification of the reduced erosion in Upper Riley Creek would prove additional project benefits.

Because these three projects would be constructed in series, there are diminishing returns for sediment removal with each additional pond brought online. The sediment reductions presented in Table 3.2 assume the ponds are constructed in order from CH-3a to CH-3b to CH-3c. The results indicate that adding pond CH-3c after pond CH-3b would not significantly increase sediment reduction from the contributing watershed; however it should be noted that adding the additional storage would contribute to extended detention and reduced peak flow rates.

The additional contributing watershed between projects CH-3b and CH3c has only a small percentage of impervious area and it does not contribute significantly more sediment loading from the watershed. Therefore, implementing either CH-3b or CH-3c will have similar water quality benefits. Therefore, if only one of CH-3b or CH-3c were implemented, the annualized cost (combined with project CH-3a) for pollutant removal would be approximately $1.04 per pound TSS to $656 per pound TP

3.1.4 Watershed Projects Summary

The watershed projects summarized in previous sections will improve TSS removal within the watersheds and reduce peak runoff rates reaching Upper Riley Creek. Table 3.3 summarizes the peak discharge associated with the installation of all BMPs previously identified.

Table 3.3 Existing, Pre-developed conditions estimated peak design discharges

Development Condition	2-year Design Flow (cfs)	10-year Design Flow (cfs)
Watershed BMP Implementation	76	198

While successful in reducing the peak discharges for the 2-year and 10-year design storms, if all proposed BMPs were fully implemented, it will still fall short of meeting the approximated pre-development conditions (Table 3.3). Therefore, additional in-channel improvements will be necessary to stabilize the channel and minimize streambank erosion. Further refinements of the design, specifically focusing on smaller events, could produce improved rate reductions.

3.1.5 In-Channel Improvements

When evaluating in-channel improvements, several different approaches may be selected to best meet overall project goals in areas targeted for stabilization. As a result, there are a large number of potential solutions to provide stabilization benefits for the Upper Riley Creek reach.

Stream stabilization techniques generally fall into two categories: bioengineering (also known as soft armoring) and hard armoring. Bioengineering employs biological and ecological concepts to control erosion using vegetation or a combination of vegetation and construction materials, such as logs and boulders. Techniques that do not use vegetation, but are intended to achieve stabilization of natural flow patterns and create in-stream habitat (i.e. boulder or log vanes) are general included under the umbrella of bioengineering. Hard armoring techniques include the use of engineered materials, such as stone (riprap or boulders), gabions, and concrete to stabilize slopes and minimize erosion.

Bioengineering maintains more of a streams natural function while providing better habitat and a more natural appearance than hard armoring. Once vegetation becomes well-established, this approach can also be self-maintaining. Due to biodegradation of construction materials and variable vegetation establishment success, it is typically assumed that bioengineering installations have a shorter life span and may need more frequent (if less expensive) maintenance, particularly as the vegetation is becoming established. Hard armoring and bioengineering techniques present different challenges, costs, and benefits for stream stabilization design. However, regulatory agencies, including the Unites States Army Corps of Engineers and Minnesota Department of Natural Resources, have expressed a preference for stream stabilization using bioengineering over hard armoring where possible. In addition, District Rules (Rule F) state a preference for natural materials and bioengineering over hard armoring.

Examples of in-channel stabilization techniques that may be suitable to address streambank erosion in this reach of Upper Riley Creek include, but are not limited to: boulder or log vanes, constructed riffles, active floodplain/vegetated bench, vegetated buffer, vegetated reinforces slope stabilization, root wads, toe wood, scarp toe stabilization, and/or scarp stabilization. Riprap or other hard armoring may be considered in areas that experience extreme stresses that contribute erosion.

Specific stabilization measures should be selected and designed based on expected velocities and shear stresses within the channel for all sites and reaches. Published threshold values for stabilization measures can aid in the selection of stabilization criteria. Examples of published threshold criteria are presented in Table 3.4.

Table 3.4 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 (9)

b – Sotir and Fischenich (2003)

c – for use in constructed riffles and grade control

d – for use in rock vanes

As shown in Table 3.4, native soil (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). Hydraulic model results for Upper Riley Creek indicate peak velocities and shear stresses during the 2-year event are approximately 2.6 fps and 1.1 lbs/ft^2, respectively. During the 10-year event peak velocities and shear stresses are approximately 3.5 fps and 1.4 lbs/ft^2. These results indicate velocity and shear stress could regularly exceed the threshold values and that stabilization is needed.

Table 3.2 summarizes the estimated cost and pollution reduction for stabilizing each of the six subreaches included in this study and the following paragraphs summarize the stabilization considerations for each subreach.

3.1.5.1 Reach R5

Reach R5 between Lake Ann and Highway 5 is reasonably stable and is a low priority for stabilization, according to the updated CRAS score in Table 2.7, although there is a long term infrastructure risk associated with this reach due to a culvert in poor condition. The estimated cost to stabilize this reach is approximately $848,000. A project on this reach is expected to reduce TSS loading by approximately 30,000 pounds per year and TP loading by approximately 17 pounds per year. Annualized pollutant reduction costs associated with stabilizing this reach is estimated to be $1.97 per pound TSS to $3,420 per pound TP.

3.1.5.2 Reach R4A

Reach R4A between Highway 5 and Park Drive is moderately unstable and is a high priority for stabilization, according to the updated CRAS score in Table 2.7. The location of this reach immediately adjacent to the city of Chanhassen Public Works building and parking lot creates a medium term risk of erosion encroaching on the Public Works site. The estimated cost to stabilize this reach is approximately $456,000. A project on this reach is expected to reduce TSS loading by approximately 82,700 pounds per year and TP loading by approximately 48 pounds per year. Annualized pollutant reduction costs associated with stabilizing this reach is estimated to be $0.39 per pound TSS to $673 per pound TP.

3.1.5.3 Reach R4B

Reach R4B between Park Drive and Park Road is reasonably stable and is a low priority for stabilization, according to the updated CRAS score in Table 2.7. This reach was straightened in the past and is redeveloping a meander pattern, but there is no risk to infrastructure. The estimated cost to stabilize this reach is approximately $469,000. A project on this reach is expected to reduce TSS loading by approximately 68,100 pounds per year and TP loading by approximately 39 pounds per year. Annualized pollutant reduction costs associated with stabilizing this reach is estimated to be $0.48 per pound TSS to $840 per pound TP.

3.1.5.4 Reach R4C

Reach R4C between Park Road and the Railroad Bridge is moderately unstable and is a high priority for stabilization, according to the updated CRAS score in Table 2.7. Increased flows within this reach compared to upstream reaches contribute to the bank erosion present. The estimated cost to stabilize this reach is approximately $310,000. A project on this reach is expected to reduce TSS loading by approximately 56,200 pounds per year and TP loading by approximately 32 pounds per year. Annualized pollutant reduction costs associated with stabilizing this reach is estimated to be $0.39 per pound TSS to $680 per pound TP.

3.1.5.5 Reach R4D

Reach R4D between the Railroad Bridge and Powers Boulevard is moderately unstable and is a high priority for stabilization, according to the updated CRAS score in Table 2.7. The estimated cost to stabilize this reach is approximately $457,000. A project on this reach is expected to reduce TSS loading by approximately 110,600 pounds per year and TP loading by approximately 64 pounds per year. Annualized pollutant reduction costs associated with stabilizing this reach is estimated to be $0.29 per pound TSS to $500 per pound TP.

3.1.5.6 Reach R4E

Reach R4E between and Powers Boulevard and Lake Susan is unstable and is a high priority for stabilization, according to the updated CRAS score in Table 2.7. The estimated cost to stabilize this reach is approximately $502,000. A project on this reach is expected to reduce TSS loading by approximately 152,000 pounds per year and TP loading by approximately 87 pounds per year. Annualized pollutant reduction costs associated with stabilizing this reach is estimated to be $0.23 per pound TSS to $400 per pound TP.

3.1.6 Cost Share Projects

Cost share projects aimed at reduction of pollutant loading and runoff rates/volumes could be very effective at reaching the project goals. Cost share projects would involve teaming with landowners, both residential and commercial to implement stormwater BMPs. For future development, additional financial support could be provided to landowners if they provide treatment and or volume/rate reduction above that required by the RPBCWD regulatory program, city of Chanhassen, and MPCA’s construction stormwater permit. Teaming with homeowners interested in landscape improvements to their property, including the installation of rain gardens or other small BMPs in upland portions of the watershed, can be particularly effective. The cost share program has the added benefit of increasing awareness of stormwater issues through the teaming of BMP installation with private citizens. Implementation of cost share projects requires setting aside available funds and effectively broadcasting their availability.

4.0 Recommendations

This analysis reviewed three primary erosion sources to determine causes of sediment loss within the Upper Riley Creek watershed and subsequent deposition in downstream water bodies.

- Surface erosion- The analysis determined that minimal surface erosion was present within the Upper Riley Creek watershed.
- Hydrologic processes - Hydrologic changes in the watershed have led to increased transport of sediments originating from the impervious areas of the watershed.
- Channel processes- The hydrologic changes have also increased the rate and volume of runoff reaching Upper Riley Creek, resulting in bank and channel bed erosion.

The hydrologic analysis suggested that significant changes in the watershed would be needed in order for Upper Riley Creek to become stable in a way that mimics the pre-development conditions. Additional stormwater BMPs will provide improvements through peak rate reduction and extended detention, in addition to some abstraction through evapotranspiration from new or enlarged wet ponds; however many projects will need to be implemented in order to completely mimic the pre-development hydrology. Therefore, in-creek stabilization measures should be implemented in concert with stormwater BMPs to ensure Upper Riley Creek is stabilized, erosion of the banks and channel are minimized, and the pollutant load to downstream resources is reduced.

In order to counteract the hydrologic watershed changes, several stormwater BMP improvements have been proposed in conjunction with in-stream stabilization measures. The recommendations are summarized in Table 4.1.

Implementation of stabilization projects in reaches R4A, R4C, R4D and R4E are recommended because each reach has acute erosion issues that can be mitigated through stabilization projects. The analysis presented in Table 3.2 also indicates that these reaches have the most favorable costs for pollutant loading. Reach R4B can also provide reasonably cost effective pollutant removal through a restoration project; however it is a lower priority than the four reaches included in the recommendation due to a lower Tier I CRAS score.

The implementation of BMP options CH-1a, CH-1b, and CH-3a are recommended as feasible options for reducing pollutant loading and runoff rates to Upper Riley Creek. BMP options CH-3b and CH-3c have substantial storage and provide adequate sediment removal under existing conditions. The existing sediment removal effectiveness of these BMPs means that additional structural improvements result in minimal improvements to sediment capture. Runoff rate reductions in the stream as a result of improvements to CH-3b and CH-3c were not directly predicted through modeling, however they are anticipated to show additional benefits of implementing these BMPs.

As shown in Table 3.2, sediment loading reductions from the contributing watershed is not significantly improved if both CH-3b and CH-3c are implemented. Nonetheless, implementation of both projects with optimized outlet structures would significantly increase extended detention in the upper watershed, which would provide benefits to all downstream waterbodies. Therefore, either CH-3b or CH-3c is recommended for implementation to improve water quality and increase storage. Both provide similar benefits so the preference is dependent on which project is more feasible due to land acquisition and/or implementing in conjunction with other projects. Both projects could be implemented for additional rate reduction.

BMP options CH-2a, CH-2b, and CH-2c had high pollutant removal costs and may be subject to future expansion of the Chanhassen Public Works, and are therefore not recommended at this time.

In addition to the BMP improvements described above, smaller projects on individual parcels to improve stormwater management by increasing abstraction and/or reducing peak runoff rates will contribute to improved hydrologic conditions in the Upper Riley Creek subwatershed, and to an extent, the entire Riley Creek watershed. Cost-share opportunities that come about through redevelopment or property maintenance opportunities should be explored.

Table 4.1 **Recommended Upper Riley Creek Watershed Projects**

Improvement	Watershed	Pond	Modification Description	Construction Cost Estimate(1)	TP Loading: Load Reduction (lb/yr)	TP Loading: Cost/lb Reduced(2)	TSS Loading: Load Reduction (lb/yr)	TSS Loading: Cost/lb Reduced(2)
CH-1a	LS-19	3.95p	Fix berm	$ 86,000	4.1	$ 1,460	1,300	$ 0.63
CH-3a	LS-11	3.78	Expand pond, repair outlet, divert upstream ponds into this pond	$ 711,000	45.8	$ 1,160	14,695	$ 3.6
CH-3b	LS-16	3.14	Create new outlet structure and raise normal water level	$ 113,000	23.1	$ 350	2,478	$ 3.2
CH-3c	LS-29	3.13	Create new outlet structure and raise normal water level	$ 82,000	0.1	$ 47,280	84	$ 82.9
Reach R4A			Stream restoration	$ 456,000	47.5	$ 673	82,700	$ 0.39
Reach R4C			Stream restoration	$ 310,000	32.3	$ 680	56,200	$ 0.39
Reach R4D			Stream restoration	$ 457,000	63.6	$ 500	110,600	$ 0.29
Reach R4E			Stream restoration	$ 502,000	87.4	$ 400	152,000	$ 0.23

(1) A Class 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 25% project contingency, 30% for planning, engineering, design, and legal, and 7% for construction administration. Lower bound assumed at -25% and upper bound assumed at +40%.

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

5.0 References

1. **Barr Engineering Co.** *Creek Restoration Action Strategy: 2015 Report.* s.l. : Prepared for Riley Purgatory Bluff Creek Watershed District, 2015.

2. —. *Lower Minnesota River Watershed TMDLs: Riley-Purgatory-Bluff Creek Watershed District.* s.l. : Prepared for Minnesota Pollution Control Agency, October 2016.

3. **Wenck Associates, Inc.** *Lake Susan Use Attainability Assessment Update.* s.l. : Prepared for Riley Purgatory Bluff Creek Watershed District, 2013.

4. **Carver Soil and Water Conservation District.** *Susan, Ann, and Lucy Subwatershed: Stormwater Retrofit Assessment.* 2011.

5. **Rosgen, Dave.** *Watershed Assessment of River Stability and Sediment Supply (WARSSS).* Fort Collins, CO : Wildland Hydrology, 2006.

6. **Barr Engineering Co.** *100-Year Floodplain Vulnerability Evaluation: Engineer's Report.* s.l. : Prepared for Riley Purgatory Bluff Creek Watershed District, 2016.

7. **National Oceanic Atmospheric Agency.** *NOAA Atlas 14 Precipitation-Frequency Atlas of the United States Volume 8, Version 2.0 Midwestern States.* s.l. : U.S. Department of Commerce, 2013.

8. **Fischenich, J.C.** *Stability Thresholds for Stream Restoration Materials.* Vicksburg, MS : EMRRP Technical Notes Collection (ERDC TN-SR-29), U.S. Army Research and Development Center, 2001.

9. **Sylte, T.L.,and Fischenich, J.C.** *Rootwad composites for streambank stabilization and habitat enhancement.* Vicksburg, MS : EMRRP Technical Resource Collecation (ERDC TN-EMRRP-SR-21), U.S. Army Engineer Research and Development Center, 2000.

Appendices

Appendix A

Historical Imagery

The following historical images were obtained from one of three sources :
1. These images are from the UMN archive https://www.lib.umn.edu/apps/mhapo/
2. http://www.dnr.state.mn.us/maps/landview/index.html?layers=lakes+roads+cent_popplpt1
3. The following images were taken from Google Earth
4. https://gis.co.carver.mn.us/historical_aerial/

Figure 1 – 1937 [1]

Figure 2 – 1937 [1]

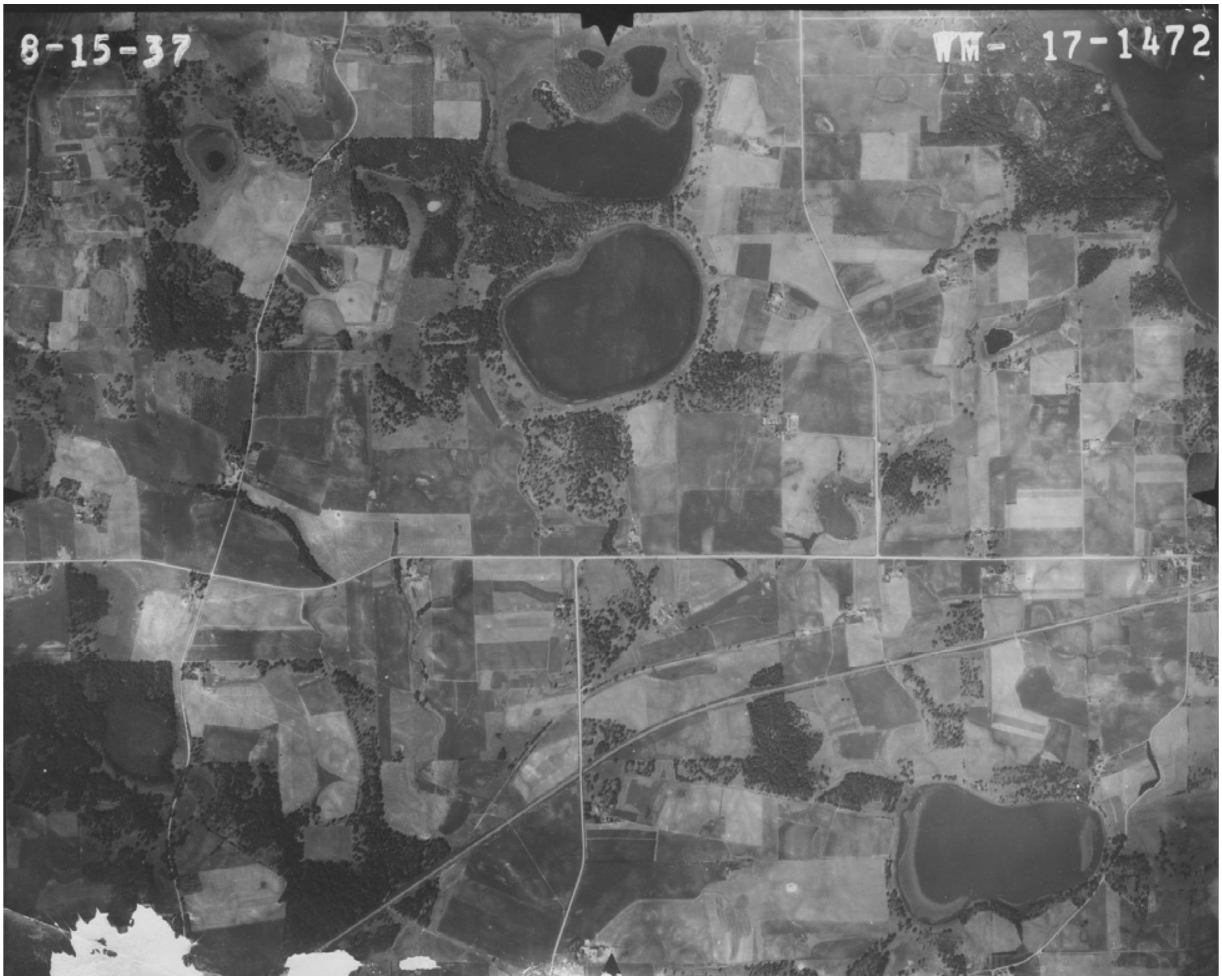


Figure 3 – 1937 [1]

Figure 4 – 1940 [1]

Figure 5 – 1947 [2]

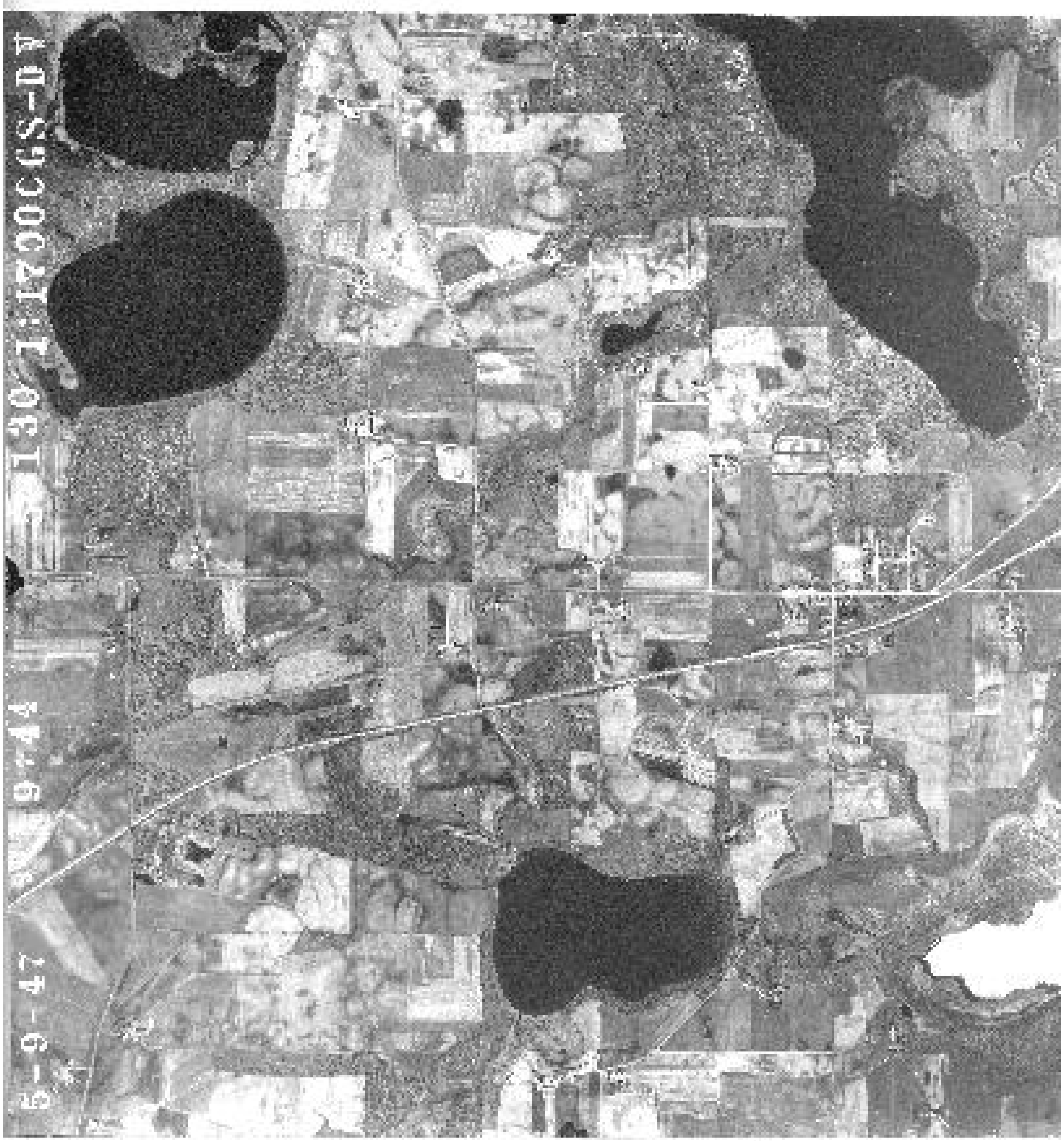


Figure 6 – 1947 [2]

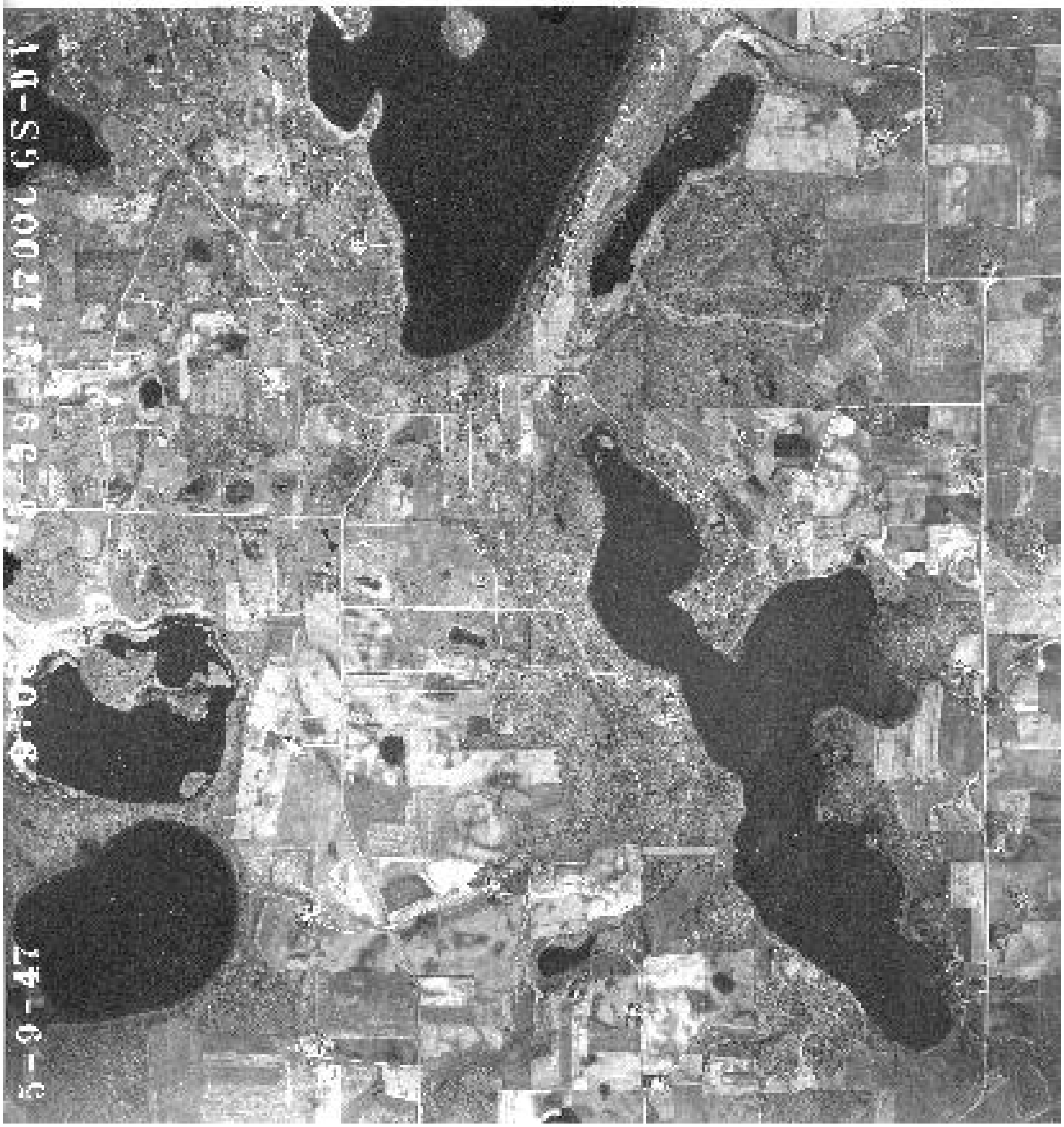


Figure 7 – 1947 [2]

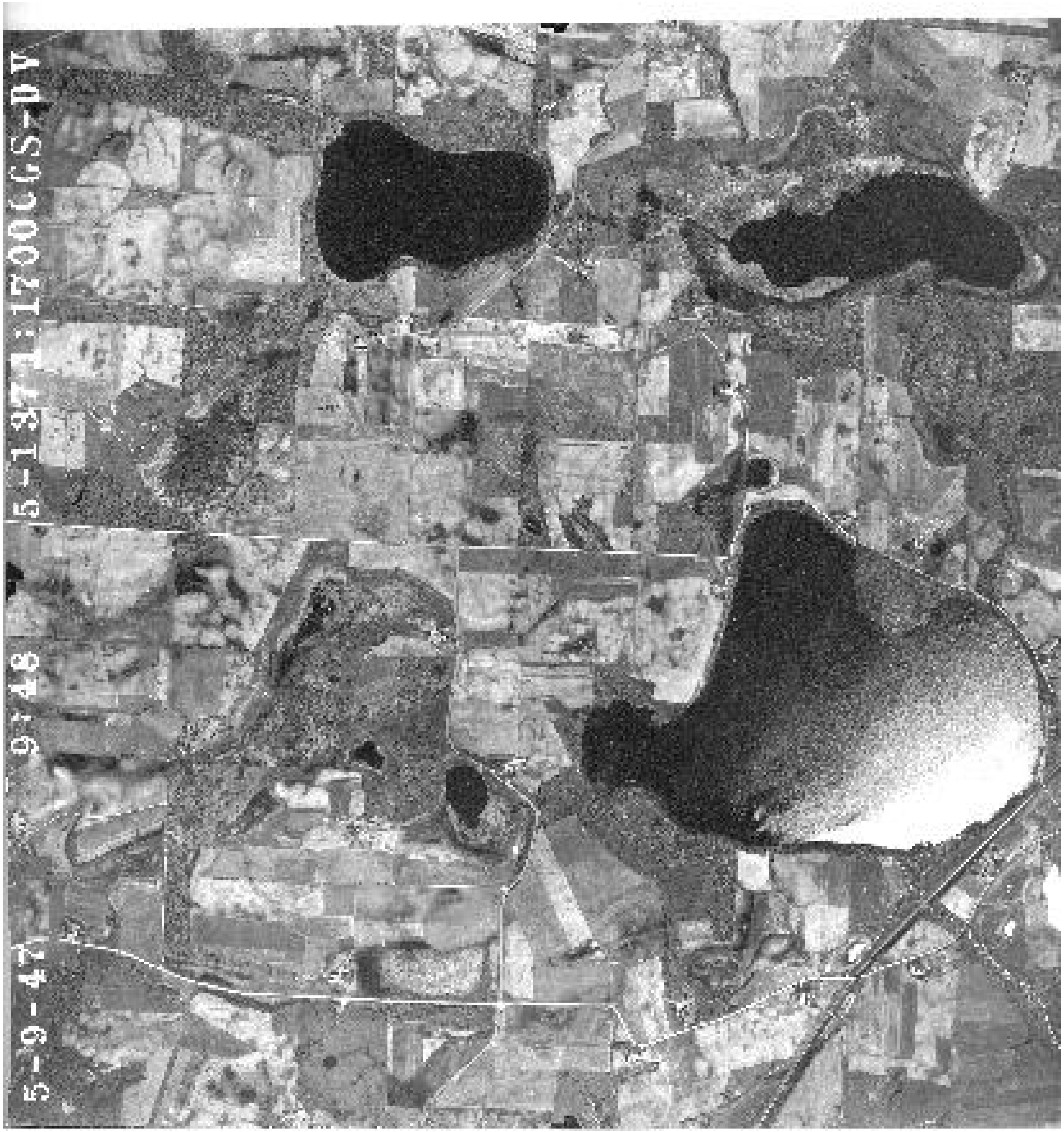


Figure 8 – 1951 [2]

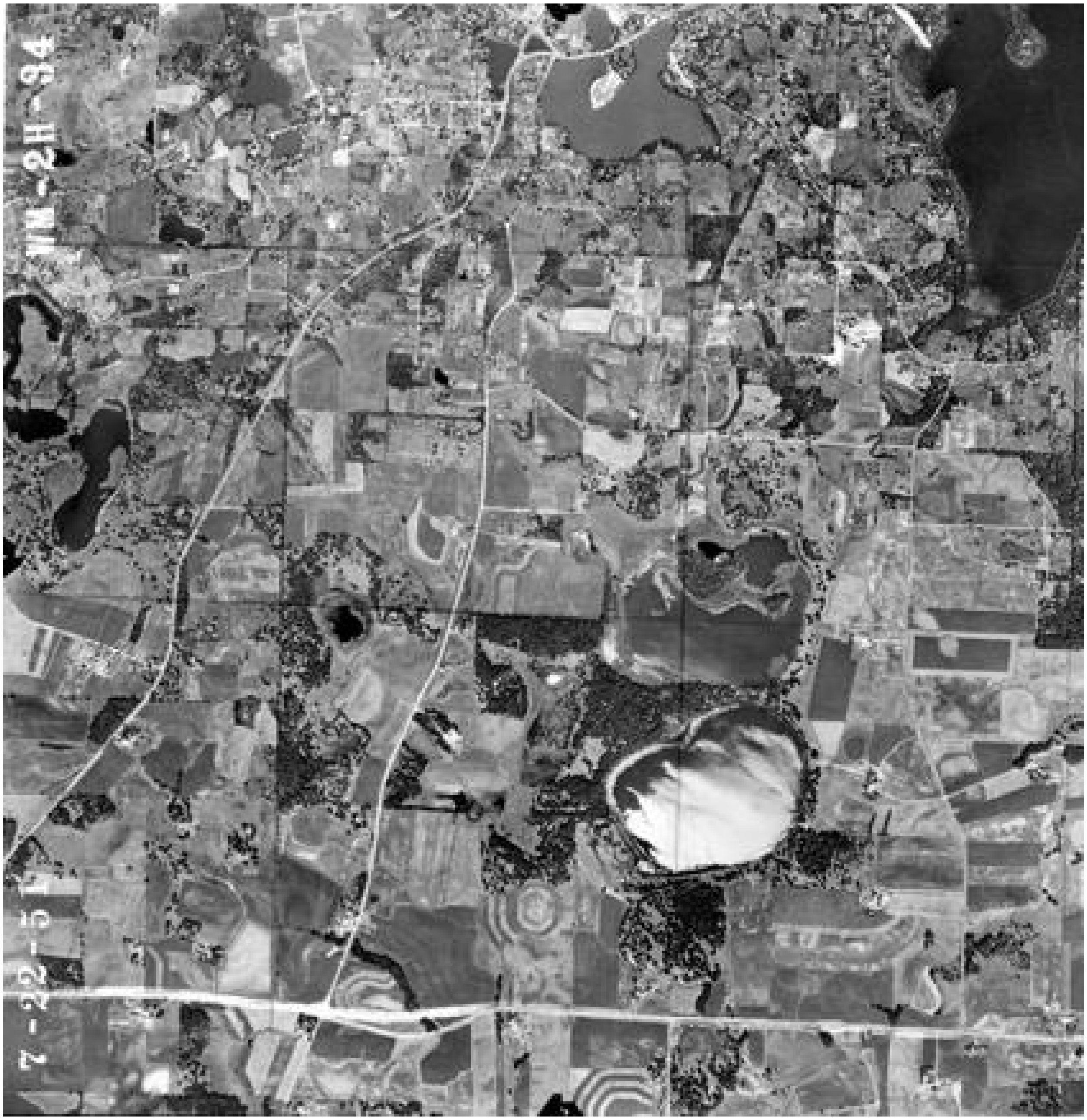


Figure 9- 1951 [2]

Figure 10- 1951 [2]

Figure 11- 1951 [2]

Figure 12- 1951 [2]

Figure 13- 1960 [1]

Figure 14- 1960 [1]

Figure 15- 1960 [1]

Figure 15- 1964 [1]

Figure 16- 1970[1]

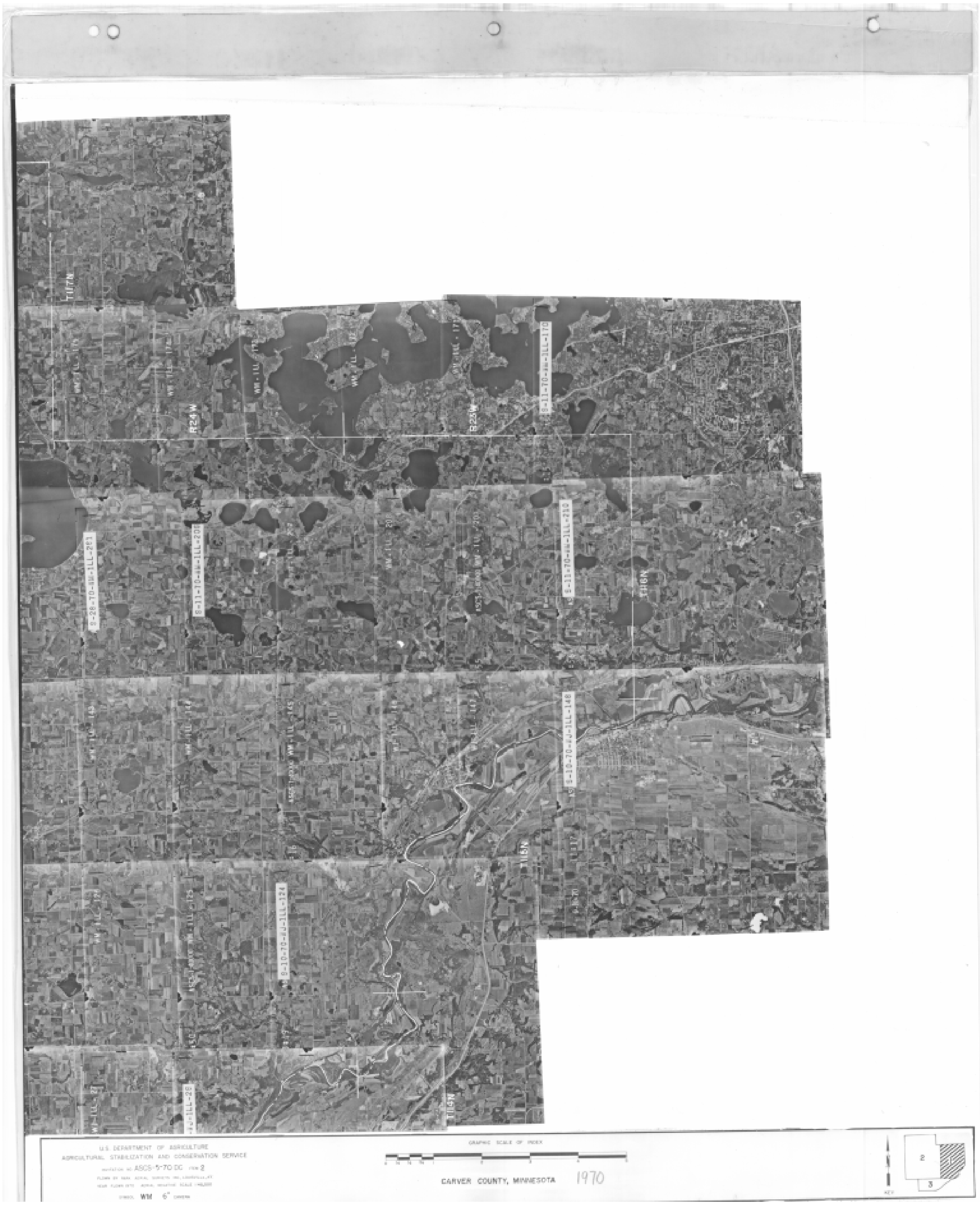


Figure 17- 1979 [4]

Figure 18- 1991 [3]

Figure 19- 2002 [3]

Figure 20- 2006 [3]

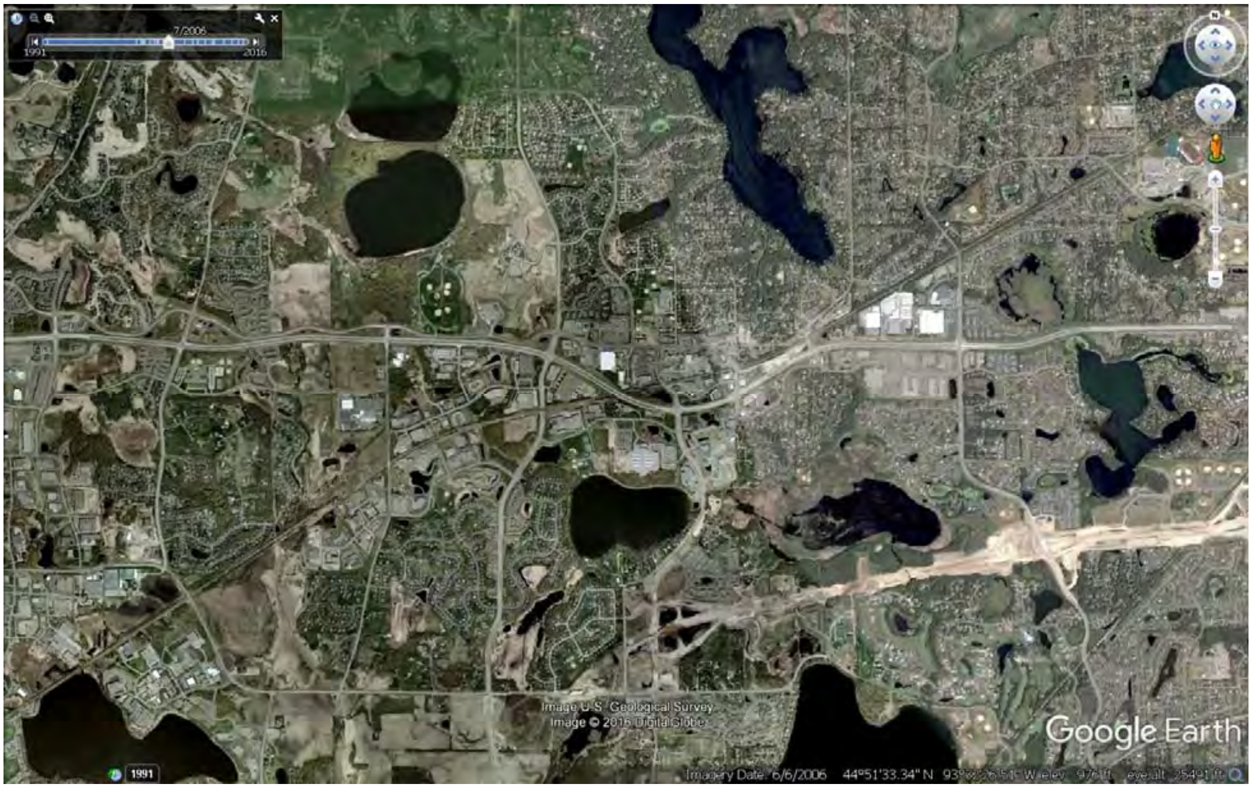


Figure 21- 2011 [3]

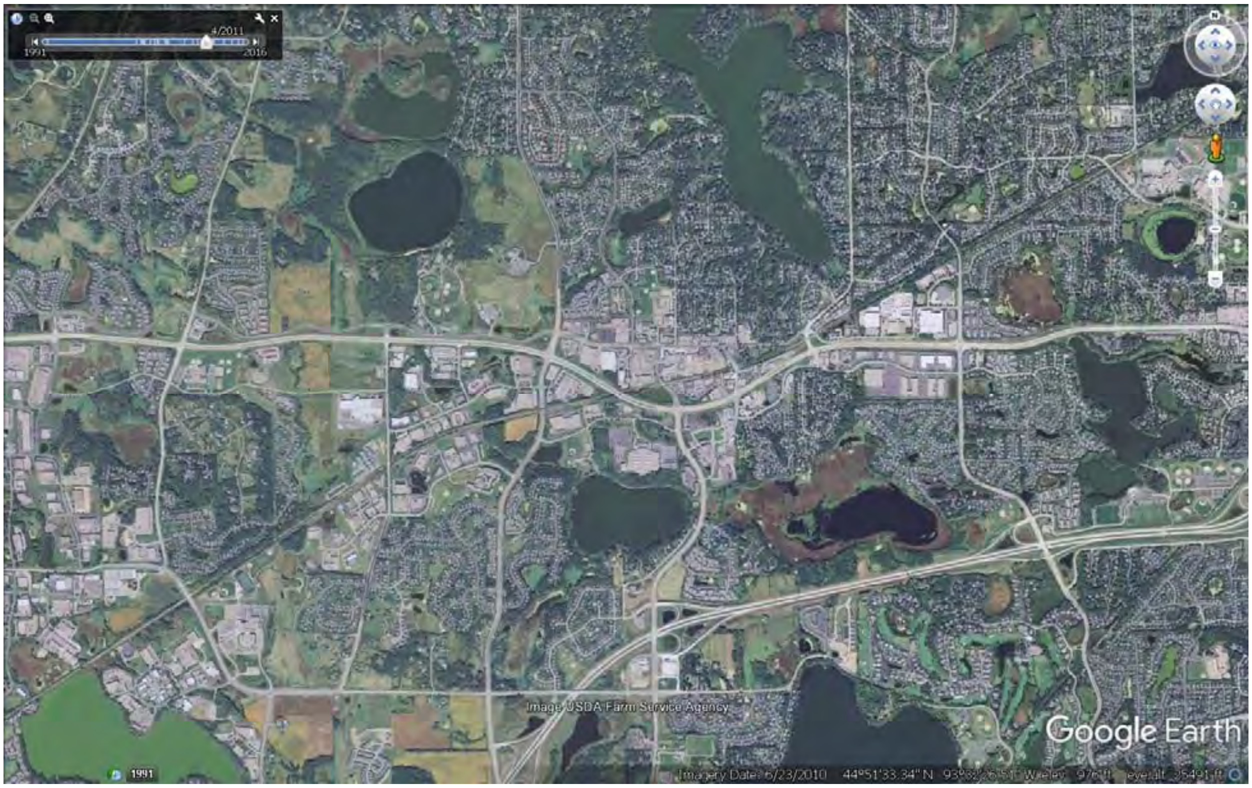


Figure 22- 2016 [3]

Appendix B

RPBCWD 2016 Creek Assessment Summaries

Riley Creek Assessment

Highway 5 to Railroad Bridge South of Park Road

Conducted by: RPBCWD staff [Josh Maxwell; Zach Dickhausen]
Conducted on: 9 November

Summary

Site/Scope

On the 9th of November at 1135, Riley Purgatory Bluff Creek Watershed District (RPBCWD) staff conducted a stream corridor assessment of R4A/R4B/R4C within Reach 4 of Riley Creek. Staff started at Highway 5 and walked downstream to the Railroad Bridge south of Park Road (approximately 0.65 stream miles). Staff walked both sides of the creek to assess overall stream conditions and to discover and prioritize possible restoration locations. Staff conducted a Modified Pfankuch Channel Stability Assessment and a Minnesota Pollution Control Agency (MPCA) Stream Habitat Assessment (MSHA) on the sub reach to better characterize the stream. A GPS, and a GPS-enabled camera were used to mark points and take photos.

- All pictures were taken <u>Facing Downstream</u> unless noted otherwise.
- <u>Right</u> and <u>Left</u> bank are defined by looking downstream.
- Erosion was defined as <u>Slight</u>, <u>Moderate</u>, or <u>Severe</u>.
- <u>Stream bank Erosion</u> was measured from the streambed to the top of the eroding bank.
- Vegetation was defined as <u>Sparse</u>, <u>Patchy</u>, or <u>Dense</u>.
- All measurements were recorded in <u>Meters</u>.
- All major erosion sites were labeled on the GPS by the erosion site number and reach (E#R4).

Weather Conditions

Wind: 5.8 mph
Temp: 14.3°C
Cloud Cover: 50%

Stream Features

This section of the stream passes through deciduous forests (R4A/R4C) and grass prairies/wetlands (R4B) with small business and industry set back about 20-50m. All subreaches had similar substrates overall (sand/silt) however the upper most section of R4A had more exposed gravel and a large portion of the center section of R4B was mainly clay. Slope gradients within the subreaches were relatively low starting around 40% in R4A and decreasing to 10%. The stream was fairly sinuous in R4A and R4C but was mostly straight in R4B. There was moderate stream development (riffle, run, pool) in subreach R4A and R4C, while relatively little in R4B. Habitat availability in R4A was diverse, lacking in R4B, and poor in R4C. R4A and R4C were nearly continuously eroding at levels ranging from 0.2-0.5m with some more major sites located on outside bends. R4B was relatively stable with very low levels of erosion.

Areas of Concern

Within subreach R4A and R4C there was nearly continuous incised channel ranging from 0.2-0.5m with R4C being the worse of the two. Additionally, there were multiple larger erosion sites measuring up to 2.7m tall of exposed banks, occurring most often on the outside bends of the left bank in both reaches. In R4C the two largest erosion area were a groundwater seepage area and a drainage ravine located near the end of the subreach. The area of most concern across all reaches was a large ravine formed from the drainage from a small business located at the top of the left bank in R4A (E1R4). The drainage had caused severe erosion and carved ravine down to the stream channel which is most likely contributing sediment during nearly all rain events. R4B was a relatively stable subreach with dense surrounding prairie grasses and clay substrates. Overall R4C was the most degraded subreach both for stability and habitat.

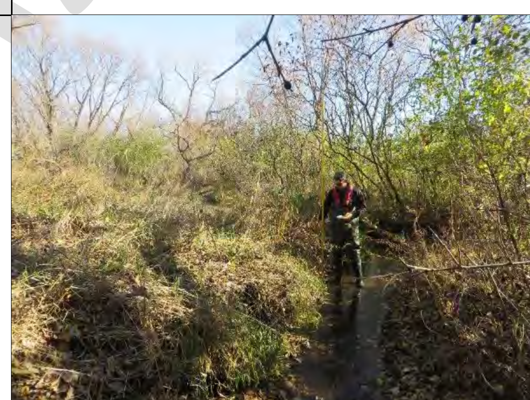
Subreach R4A–Highway 5 to Park Drive **MSHA:** 59.8 (Good); **Pfankuch:** 86 (Moderately Unstable)

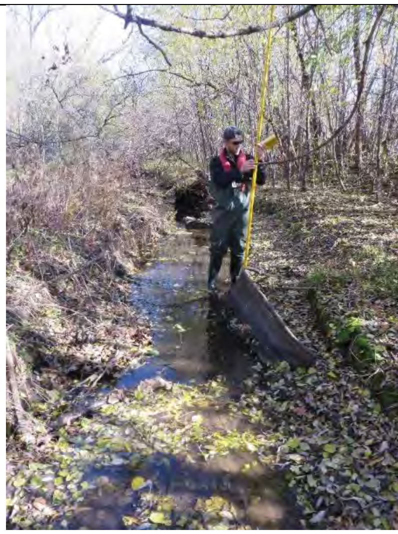
Staff began the creek walk downstream of the culvert under Highway 5 below Lake Ann Park (IMG_0183). Riprap had been placed to stabilize the area around the culvert, however, on the right side of the culvert facing upstream the drainage runoff from the road was causing some erosion, carving a small ravine (IMG_0185). Additionally, the culvert was undercut by 0.9m and an old degraded stormwater culvert entered on the left side of the culvert, draining into the center of the stream as seen facing upstream in IMG_0183. Directly downstream of the culvert, the right bank was eroded, which measured 2m by 5m (IMG_0184). Continuing downstream, the channel curved to the right causing erosion along the outside bend of the left bank measuring 2.2m by 8m (IMG_0186). The stream subreach is surrounded by a low density deciduous forest consisting of mainly smaller buckthorn, oaks, and other hardwoods, of which the leaves covered the mostly bare ground and stream. Small business/industry was set back from the stream edge about 15m from the right bank and 45m from the left bank. From IMG_0187 you can see that water levels were very low with an average stream depth of about 0.2m and a width of 2.5m. Small woody debris was common and scattered boulders were present, which most likely migrated from the upstream culvert (IMG_187). This subreach had good channel development (riffle/run/pool) and sinuosity which were both reduced near the end of the subreach. The substrate within the riffles was approximately 70% sand, 20% gravel, and 10% cobble (IMG_0188) which switched to 80% sand 20% gravel near the end of the reach. Within the pools, the predominate substrates were sand/silt (IMG_0189). Moving downstream, the channel shifted to the right again, causing more erosion on the outside bend (measuring about 2.3m by 10m) and exposing tree roots (IMG_0190). In IMG_0191 the stream is incised along the right bank by about 0.5m which was fairly continuous throughout the subreach. Soon after, the creek shifts right again with the left bank/outside bend eroding, which measured 1.6m by 4m (IMG_192). Near the next left curve, woody debris had concentrated to the point of blocking flow (IMG_193). Continuing downstream, a business draining near the top of the slope had formed a large eroding ravine along the left bank (IMG_0195). At the top of ravine, the erosion was more severe as seen in IMG_0196 (E1R4).

Nearing the City of Chanhassen Public Works, more herbaceous plants were present. The surrounding slopes flattened out (10-15% slope gradient) and groundcover density increased moderately. Along the right bank some erosion was occurring and a landscape tarp was exposed (IMG_0197). After the left turn, a large depositional zone of fine sediments was present (IMG_0198). As the stream paralleled public works along the right bank, the stream seemed confined and straighter, causing more erosive forces. Evidence of this is seen in IMG_0199 with erosion measuring 1.7 by 6m. After public works, the stream became even straighter, with only minor riffles and runs present (IMG_0200). Additionally, there was an increase in groundcover which consisted of terrestrial grasses. This was coupled with an overall decrease in the deciduous over story (IMG_0201). Near Park Drive, a large metal cattle tub was found along the right bank as seen in IMG_0202. This subreach ended at the culvert under Park Drive, which appeared to be approximately 40% filled with fine sediments (IMG_0203).

	**IMG-0183** Culvert under under Highway 5, photo taken facing upstream		**IMG-0184** Erosion on right bank, 2m x 5m
	**IMG-0185** Drainage from road causing small ravine erosion		**IMG-0186** Outside bend erosion on left bank, 2.2m by 8m
	**IMG-0187** Genreal stream photo		**IMG-0188** Riffle substrate, predominat-ely gravel

	**IMG-0189** Pool substrate, predomina-ntly sand/silt		**IMG-0190** Outside bend erosion on left bank, 2.3m x 10m
	**IMG-0191** Right bank erosion, 0.5m		**IMG-0192** Outsdie bend erosion of left bank, 1.6m x 4m
	**IMG-0193** Debris dam		**IMG-0195** Eroded ravine caused by uphill buisness drainage on left bank

	**IMG-0196** Erosion at top of ravine caused by buisness drainage		**IMG-0197** Landscape fabric and woody debris near public works
	**IMG-0198** Deposition of fine sediment		**IMG-0199** Large eroding bank, 1.7m by 6m
	**IMG-0200** Large depositional zone; increased groundcover, straightened channel		**IMG-0201** Increased herbaceous plants and groundcover

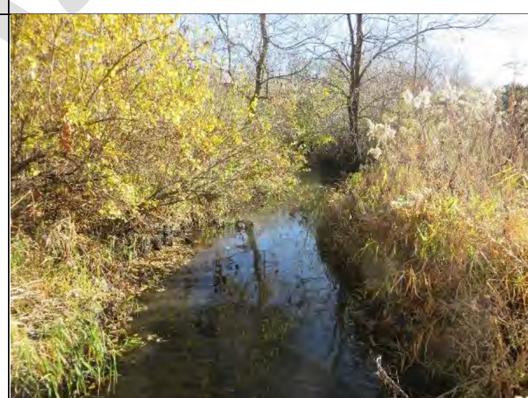
	**IMG-0202** General stream photo, large metal cattle tub		**IMG-0203** Culvert under Park Drive, about 40% filled with sediment

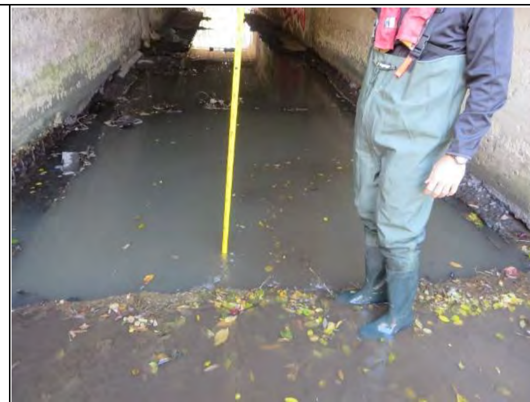
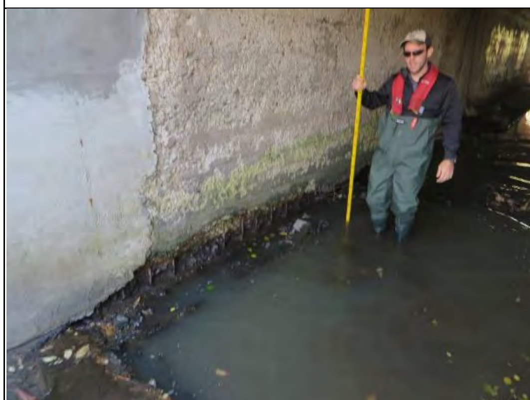
Subreach R4B–Park Drive to Park Road **MSHA:** 40 (Fair); **Pfankuch:** 48 (Good)

At the start of Reach 4, subreach B, the culvert under Park Drive was approximately 40% filled with sediment (IMG_0204). Facing downstream from Park Drive the banks are densely covered with herbaceous vegetation and graminoids with very sparse woody debris present (IMG_0205). Additionally, some of the surrounding vegetation was comprised of cattails and minor ponding was seen within the riparian zone (IMG_0206). The surrounding slopes were very low with the small businesses and stormwater ponds set back approximately 20m from the right bank and 50m from the left. No overhead canopy cover was present; however, the overhanging grasses did provide some shade over the stream. Substrate near the beginning of the subreach was sand/silt, but shortly after shifted to a clay/marl material. Continuing downstream, a tributary/drainage from the business park about 25m away entered the main stream channel on the left bank (IMG_0207). The banks in this subreach were characteristic of a small prairie stream, having steep banks (vertical in places) with dimensions measuring approximately 0.9m deep by 1m wide. There was evidence of a shifting channel present in the riparian zone and some bank sloughing was occurring which was caused by uncut bank failures (IMG_0208, IMG_0209, IMG_0211).

The channel then moved between two stormwater ponds and straightened (perhaps artificially straightened upon the ponds creation). Some stream cutting occurred in this section, measuring up to 0.4m along both banks (IMG_0210). The channel became wider at this point measuring 2.5m wide by 1.3m deep at approximate bank full. The North stormwater pond then emptied into the main channel, causing significant/severe erosion immediately on the side channel that drains to Riley Creek (IMG_0212). The culvert at the outlet of the stormwater pond was undercut by 1.2m. In this stretch the clay sediment formed mainly riffles and pools that were variable depth and contained random and unusual deep pockets. Near the north tributary entrance (IMG_0214), the channel substrate shifted to more sand/silt and the stream became a glide lacking any channel development (IMG_0213). After the tributary, the channel shifted south and widened, measuring 3m wide by 0.6m deep (IMG_0214). The surrounding bank vegetation was mostly small shrubs which slightly increased the amount of woody debris present in the channel. The stream eventually flowed past the District's regular water quality monitoring site and through the large cement culvert under Park Road (IMG_0216). The culvert showed signs of wearing with an apparent drop in the cement when entering the culvert, decaying cement walls, and exposed rebar (IMG_0217 & IMG_0218).

	**IMG-0204** Facing upstream, culvert under Park Drive, culvert 40% filled		**IMG-0205** General stream pic, sparse woody debris
	**IMG-0206** Dense herbacious vegetation and graminoids; some cattails present		**IMG-0207** Tributary from business park within 25m of left bank
	**IMG-0208** Evidence of bank sloughing		**IMG-0209** Bank undercut on both sides by about 0.4m

	**IMG-0210** Widening channel measuring 2.5m by 1.3m with some erosion (0.4 m)		**IMG-0211** Evidence of bank sloughing
	**IMG-0212** Stormwater pond outlet; significant erosion including 1.2m undercut		**IMG-0213** Channel with softer substrates and shifted to a glide
	**IMG-0214** North tributary entering from the left bank		**IMG-0215** Channel widens after tributary, 3m by 0.6m deep

	**IMG-0216** Box culvert under Park Road (R4 water quality sample site)		**IMG-0217** Culvert deterioration, drop off inside culvert
	**IMG-0218** Culvert deterioration and exposed rebar inside culvert		

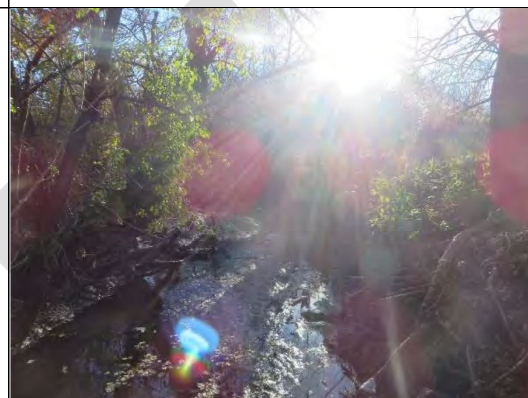
Subreach R4C–Park Road to Railroad Bridge **MSHA:** 38.7 (Fair); **Pfankuch:** 87 (Moderately Unstable)

Staff began this creek walk at the cement culvert under Park Road (IMG_0219). The stream flows out of mouth of this culvert, over a cement step to the natural streambed, and through an artificial rock riffle (IMG_0219). The immediate groundcover near the culvert consisted of more-than-patchy to dense woody vegetation, mostly shrubs/buckthorn and small trees, and moderately dense herbaceous cover. Cover type evolved to a more open, wooded habitat towards the end of the subreach, consisting of patchy oak/mixed-hardwood upper canopy with very sparse herbaceous/understory cover (IMG_0232-IMG_0238). Leaf litter covered the ground and stream in slow water areas. Small business development limited the riparian zone along both banks, keeping it quite narrow early on in this subreach (10-15 m). Near the end of the subreach the riparian zone did widen out to approximately 40-60 m and was bordered by the railroad tracks along the left bank. The slope gradient of the upper banks fluctuated throughout this reach, but on average it was less than 30%. The stream had good channel development, consisting of 35%/25%/40% riffle/run/pool, and had fair sinuosity early on, but rather good sinuosity along the last two thirds of creek.

Early on, the riffle substrate consisted mainly of gravel and sand which shifted to mainly sand/silt for most of the subreach (IMG_0220). Staff did encounter multiple points of moderate to moderately severe bank erosion. The first site was along the right bank and measured 1.7m by 8m long (IMG_0221). There was also a large silt deposit at this point as seen in IMG_0221. Downstream was another erosion site on the left bank with a large amount of silt deposited in front of it; the bank erosion measure 1.5m tall by 8m long (IMG_0222). There was a dense patch of woody debris just downstream of this erosion site which can be partially seen in IMG_0222. Before reaching the IWCO walking bridge, which crosses the stream, staff encountered more woody debris and a stormwater culvert on the left bank. Underneath the IWCO bridge many large boulders had been placed to ensure the stability of the bridge (IMG_0223-IMG_0225). There was also slight erosion occurring near the footings of the bridge on both banks which could eventually threaten the integrity of it (IMG_0224 & IMG_0225). During the previous creek walk in 2014, the erosion was observed to be much more severe. After the bridge, staff observed more incising, about 1-1.5m along both banks (IMG_0227). Another large silt deposit was seen in the middle of the stream in IMG_0227, as well as silt deposition along the left bank and heavy woody debris in the background. From here the channel widened and formed a glide for a long stretch. The channel bankfull dimensions were estimated at 3.6m by 1m deep (IMG_0228) with current conditions at 2.7m by 0.3m deep. Staff soon encountered more heavy woody debris and small downed trees in front of a stormwater culvert (which was undercut 0.8m) along the left bank (IMG_0229).

At this point the channel became rather sinuous. The substrate shifted to consist of sand and silt, and there were still many points of deposition along the creek. Channel development improved and pools within the channel were on average four times wider than riffles. The banks continued to be incised about 1m along both banks (IMG_0231& IMG_0233). This is also where the surrounding cover thinned-out and the vegetation shifted from a somewhat dense woody understory to open understory with a patchy deciduous over story (IMG_0232). Staff encountered a large woody debris dam with major pooling behind it (IMG_0231) and another stormwater culvert soon after on the right bank. After this, three sites of major erosion were observed. The first site occurred on the left bank, measuring 2.7m by 6m long (IMG_0232). A downed tree with hand-placed planks making a rudimentary walking bridge can also be seen in IMG_0232. The second major bank erosion site occurred on the right bank, measuring 3.8m by 5m long (IMG_0234). The erosion in this site was possibly caused by groundwater seepage. Before the last major erosion site and the end of the subreach, staff encountered a couple more spots with heavy woody debris and some silt/sand deposition (IMG_0235). The last erosion site was on the right bank before the box culvert running under the railroad bridge (IMG_0238). The ravine had junk scattered/dumped in it (IMG_0238). The walk ended at the box culvert running under the railroad bridge; cement inside the culvert was degraded, exposing rebar (IMG_0236 & IMG_0237).

	**IMG-0219** Culvert under Park Road facing upstream		**IMG-0220** Coarse gravel substrate
	**IMG-0221** Right bank erosion measuring 1.7m by 8m wide; silt deposit right bank		**IMG-0222** Erosion on left bank measuring 1.5m by 8m wide; reduced riparian zone

	**IMG-0223** Woody debris dam and IWOC bridge		**IMG-0224** Boulders under IWOC bridge left bank
	**IMG-0225** Under IWOC bridge right bank		**IMG-0226** General stream photo
	**IMG-0227** Both banks incised, 1-1.5m; deposition bar		**IMG-0228** Channel widens and forms long glide: 2.7m x 0.3m.
	**IMG-0229** Stormwater culvert on left bank, undercut 0.8m.		**IMG-0230** General stream photo; depositon along channel

	**IMG-0231** Large woody debris dam		**IMG-0232** Erosion on left bank measuring 2.7m by 6m wide; downed tree with wood plank bridge
	**IMG-0233** General stream photo		**IMG-0234** Possible groundwater seepage area; causing erosion measuring 3.8m by 5m wide
	**IMG-0235** Woody debris and silt/sand deposition		**IMG-0236** Box culvert underneath the railroad bridge
	**IMG-0237** Exposed rebar inside culvert		**IMG-0238** Erosion from drainage on right bank; lots of dumped junk

Riley Creek Assessment

Railroad Bridge to Lake Susan

Conducted by: RPBCWD staff [Josh Maxwell; Zach Dickhausen; Nicole Sullivan]

Conducted on: 21, 28 November 2016

Summary

Site/Scope

On the 21st of November at 1407 and on the 28th of November at 1302, 2016, Riley Purgatory Bluff Creek Watershed District (RPBCWD) and a student volunteer from the University of Minnesota conducted a stream corridor assessment of the subreaches R4D and R4E, within Reach 4 of Riley Creek. Staff started at the railroad bridge south of Park Road and north of Lake Drive West and ended at Lake Susan (approximately 0.65 stream miles). Staff walked both sides of the creek to assess overall stream conditions and to discover and prioritize possible restoration locations. Staff conducted a Modified Pfankuch Channel Stability Assessment and a Minnesota Pollution Control Agency (MPCA) Stream Habitat Assessment (MSHA) on the subreach to better characterize the stream. A GPS, and a GPS-enabled camera were used to mark points and take photos.

- All pictures were taken <u>Facing Downstream</u> unless noted otherwise.
- <u>Right</u> and <u>Left</u> bank are defined by looking downstream.
- Erosion was defined as <u>Slight</u>, <u>Moderate</u>, or <u>Severe</u>.
- <u>Stream bank Erosion</u> was measured from the streambed to the top of the eroding bank.
- Vegetation was defined as <u>Sparse</u>, <u>Patchy</u>, or <u>Dense</u>.
- All measurements were recorded in <u>Meters</u>.
- All major erosion sites were labeled on the GPS by the erosion site number and reach (E#R4).

Weather Conditions

Wind: Unknown
Temp: -1.11° C
Cloud Cover: Unknown

Stream Features

The stream in this section passed through mainly deciduous forests and small industrial/business and residential developments, before ending at Lake Susan. Substrates in this section consisted of mainly fine sand and silt, silt being the predominant type. There were many occurrences of gravel/sand/silt deposition occurring on point bars, along channel banks, and near obstructions. Slope gradients started at 40 to 60% during the first half of subreach R4D, but decreased to less than 10% for the remainder of the section. The stream showed some sinuosity and channel during the first half of R4D, but was mainly straight and a glide for much of the section.

Areas of Concern

There were several occurrences of erosion along the banks, along with consistent cutting along the right bank throughout the majority of subreach R4D. Several occurrences of erosion measured greater than 2m high. Staff observed quite a bit of deposition throughout R4D as well, including one bar measuring 3.5m long, and another measuring almost 6m long. The subreach was not very sinuous throughout its entire length. Subreach R4E was extremely incised with banks continuously eroding measuring up to

2m in height. Evidence of some bank sloughing was found across bot reaches however R4E was considerably worse. At the end of R4E, there was also evidence of heavy deposition from the creek as seen by the delta extending 30m into the lake.

Subreach R4D–Railroad Bridge to Powers Blvd **MSHA:** 42.5 (Fair); Pfankuch: 95 (Unstable)

Staff began this subreach at the box culvert underneath the railroad bridge south of Park Road and north of Lake Drive West (IMG_0240). The slope gradient along much of this subreach was somewhat steep, averaging between 40 and 60% on both banks (IMG_0239). The vegetation was mainly deciduous forest that was sparse to patchy, with some very sparse herbaceous ground cover. Small business/industrial development on average was set back from the creek 20-50m. Channel development (riffle, run, pool) was fair, with only a few riffles and runs. Overall the stream could be considered a glide, caused by a series of woody debris dams that elevated water levels. Around 50-75% of the right bank was eroded, while 25-50% of the left bank displayed erosion.

Right away there was continuous cutting along the right bank measuring about 0.5m high (IMG_0239). Moving downstream staff came upon the first woody debris/leaf litter dam which was small (IMG_0242). Early on channel development was good because of the increased flow concentrated at the culvert (IMG_0242). Gravel was present in small amounts during this stretch of the subreach, but the substrate consisted mostly of sand and silt (IMG_0246). One of the larger woody debris dams had a considerable amount of water pooling behind it (IMG-0249). Along this patch of woody debris was some deposition, as well as some erosion measuring about 2.5m tall by 6m long on the right bank (IMG_0250). Staff continued to monitor sediment types along stream; in one riffle, they observed a gravel/sand mixture (IMG_0254). Further down the stretch, a more severe patch of erosion was present on the left bank measuring 3.3m high by 9m long (IMG_0255).

The vegetation along the banks soon shifted from patchy trees to dense herbaceous vegetation and graminoids; here the creek width and depth decreased (IMG_0259). At this point, a grated stormwater culvert was present on the right bank, which was undercut 0.6m and formed a small channel to the stream (IMG_0257 & IMG_0258). After the stormwater culvert, the right bank was experiencing a significant amount of bank sloughing (IMG_0257 IMG_0259). Soon, the vegetation composition on the banks shifted back towards patchy, woody vegetation with patchy herbaceous ground cover. The slope gradient around the stream greatly decreased by this point, to below 10%. Staff began to encounter more woody debris and deposition bars after this vegetation shift took place (IMG_0260 & IMG_0261). One deposition bar measured 3.5m long (IMG_0262). Staff also observed a short section of the right bank with 0.5m of undercutting. Another patch of erosion was present on the right bank, 1.4m high by 4m long (IMG_0261). For the rest of the subreach, staff observed continuous cutting along the right bank (IMG_0296). During this stretch, woody debris and downed trees above the stream continued to occur (IMG_0300, IMG_0306, IMG_0309). One of these occurrences created a debris dam that was holding back approximately 0.3m of water (IMG_0300). After the debris dam, there was a small stretch of stream where the left bank had continuous cutting about 0.7m high (IMG_0304). Before ending the subreach at Powers Blvd, the stream was trying to straighten by cutting through the narrow point on a small horseshoe curve (IMG_0311 & IMG_0312). The subreach ended at the culvert running underneath Powers Blvd (IMG_0315).

	**IMG-0240** Culvert under the railroad bridge (facing upstream)		**IMG-0239** Cutting along right bank, about 0.5m high
	**IMG-0242** Woody debris and leaf litter		**IMG-0243** Continued cutting along right bank; cutting on left bank
	**IMG-0246** Sediment is 50/50 sand/silt		**IMG-0249** Woody debris dam forming large pool; erosion on right bank
	**IMG-0250** Erosion 2.5m x 6m long on right bank.		**IMG-0253** Deposition and woody debris; erosion left bank

	**IMG-0254** Gravel and sand in a riffle		**IMG-0255** Large erosion patch, 3.3m x 9m on right bank
	**IMG-0257** Stormwater culvert channel enterance along right bank		**IMG-0258** Stormwater culvert along right bank, undercut 0.6m
	**IMG-0259** Decrease in width and depth; increase in grasses; evidence of sloughing, right bank		**IMG-0260** Woody debris and gravel deposition bar
	**IMG-0261** Woody debris dam; erosion 1.4m x 4m long on right bank		**IMG-0262** Large deposition area on left bank, 3.5 m long

	**IMG-0264** Large stretch of deposition along right bank, 6m long		**IMG-0296** Stream is incised 0.5 to 0.6m
	**IMG-0300** Woody debris dam holding back about 0.3m of water		**IMG-0304** Consistent cutting along left bank, about 0.7m high
	**IMG-0306** Downed trees adding to woody debris		**IMG-0309** Dense woody debris/down ed trees above stream
	**IMG-0311** Channel trying to cut through hosreshoe curve, right bank		**IMG-0312** Channel trying to cut through horseshoe curve, right bank

	**IMG-0315** Culvert under Powers Blvd; debris buildup		

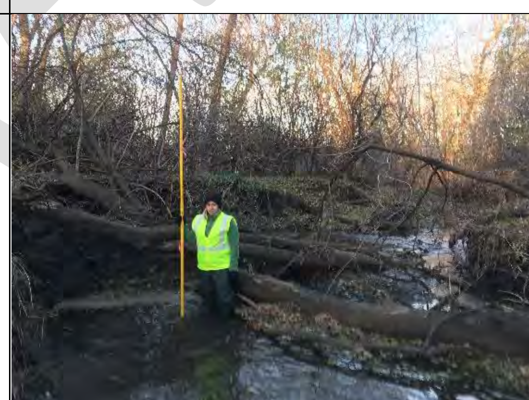
Subreach R4E–Powers Blvd to Lake Susan MSHA: 28 (Fair); Pfankuch: 100 (Unstable)

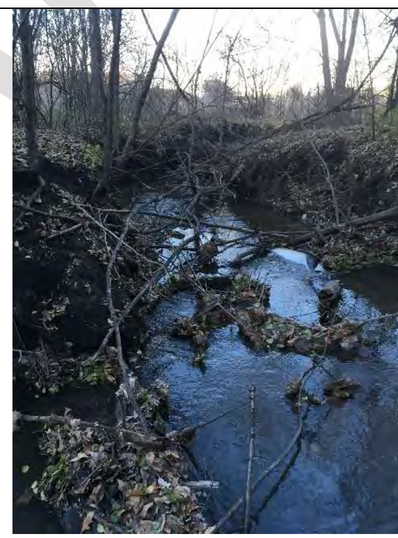
Staff began this subreach at the culvert under Powers Blvd. Below the culvert the stream flowed through a large artificial rock riffle (IMG_0316). Residential housing was set back about 10m from the creek along the right bank, and Lake Susan Park Pond was 10-30m back from the left bank. Substrate consisted of a marl/clay-like sediment which changed to deposited sand/silt. The surrounding slope gradient was below 10%. Surrounding vegetation was mainly patchy to dense woody vegetation, with sparse herbaceous cover. There stream was severely incised and actively eroding for nearly 100% of its length. The channel was straight with no channel development (considered a glide).

Just downstream from the culvert, the drainage off Powers Blvd and the recreational trail created a channel to the stream with some erosion occurring (IMG_0317). At this point there was also the presence of gravel and sand deposition along the right bank. Continuing downstream, the left bank had extensive erosion occurring, starting at 1.5m tall by about 20m long, increasing to 1.8m tall further downstream (IMG_0319 & IMG_0320). A stormwater culvert then entered on the right bank draining into the stream over riprap (IMG_0321). As the stream continued on, woody debris and deposition bars began to appear. There was a dense patch of woody debris with several small trees downed over the stream (IMG_0323), with a 2m long sand/silt depositional bar. Staff soon observed erosion 1.6m tall by 6m long occurring on the right bank (IMG_0324). There was also more erosion on the left bank, 1.5m by 5m long with more silt/sand deposition below (IMG_0325). There continued to be intermittent sediment deposits and woody debris along the stream. At one point, woody debris caused some damming of the stream (IMG_0326).

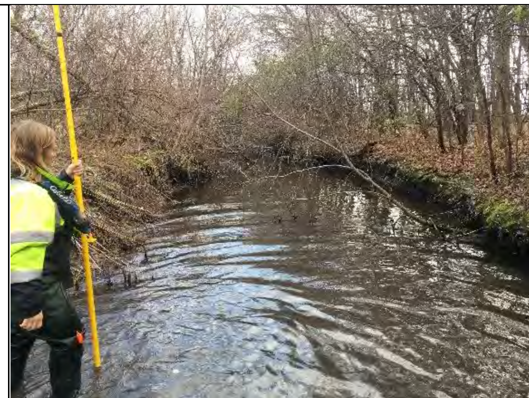
Further downstream, signs of major sloughing from the past (partially healed over) were present on both banks (IMG_0328 & IMG-0331). The stream was significantly incised at this point and actively contributing sediment to the channel bank (IMG_0329). When the stream shifted northeast, staff noticed an unidentified metal pipe/cable about three inches in diameter protruding from the bank over/in the stream (IMG_0330). The stream soon straightened out with uniform depth and width (IMG_0332-IMG_0334). At this point the creek was about 2.25m wide by 0.4m deep and the approximate bankfull height was 2.5m by 1.6m(IMG_0334). There was a stretch of continuous sandy deposition, and some evidence of bank sloughing along the right bank (IMG_0333). Some gravel was found intermittently in creek bed, but most was highly imbedded.

The creek soon came to the Lake Susan Park Pond outlet located on the left bank (IMG_0335). The channel to the stream had significant erosion occurring and the culvert was undercut 0.2 m (IMG_0335). From Lake Susan Park Pond the stream remained a glide, widened, deepened, and became more straight. (IMG_0336 & IMG_0338). Herbaceous vegetation increased (patchy-dense) on the left bank; on the right bank, vegetation was a mixture of moderately dense woody and herbaceous vegetation. Staff observed some drainage forming a channel along the left bank which was suspected to be stormwater from Lake Susan Park. Soon after the drainage channel, the Creek ran under a walking bridge, which was part of a path around Lake Susan Park (IMG_0339). At the end of the subreach, the creek drained into Lake Susan (IMG_0341). A large, sand/silt delta had formed from continuous sediment deposition at the outlet of the creek; the delta reached about 30m into the lake (IMG_0342).

	**IMG-0316** Photo of culvert under Powers Blvd and artificial riffle (facing upstream)		**IMG-0317** Drainage eroding a channel and entering stream on the right bank
	**IMG-0319** Erosion along the left bank, 1.5m tall by 20m long		**IMG-0320** Continuous erosion along left bank increased to 1.8m tall
	**IMG-0321** Stormwater culvert on right bank; boulders at culvert		**IMG-0323** Heavy woody debris and downed trees; continued erosion along left bank

	**IMG-0324** Erosion on right bank measuring 1.6m by 6m long		**IMG-0325** Erosion 1.5m by 5m long; sand/silt deposition
	**IMG-0326** Woody/leafy debris dam; erosion left bank		**IMG-0327** Signs of major bank sloughing, partially healed over; right bank
	**IMG-0328** Signs of major bank sloughing, partially healed over; right bank		**IMG-0329** Severely incised channel; small woody debris

	**IMG-0330** Metal pipe/cable about 3 inches in diameter across channel		**IMG-0331** Major bank sloughing and severely incised channel
	**IMG-0332** Channel straightens; glide		**IMG-0333** Sandy/silt deposition along right bank; some evidence of bank sloughing on right bank
	**IMG-0334** General stream photo		**IMG-0335** Culvert draining LSPP into the creek, undercut 0.2m; left bank

	**IMG-0336** General stream photo; channel widens and deepens		**IMG-0338** General stream photo
	**IMG-0339** Walking trail bridge over the stream		**IMG-0341** Riley Creek entering Lake Susan
	**IMG-0342** Sand/silt deposition creating delta projecting about 30m into Lake Susan		

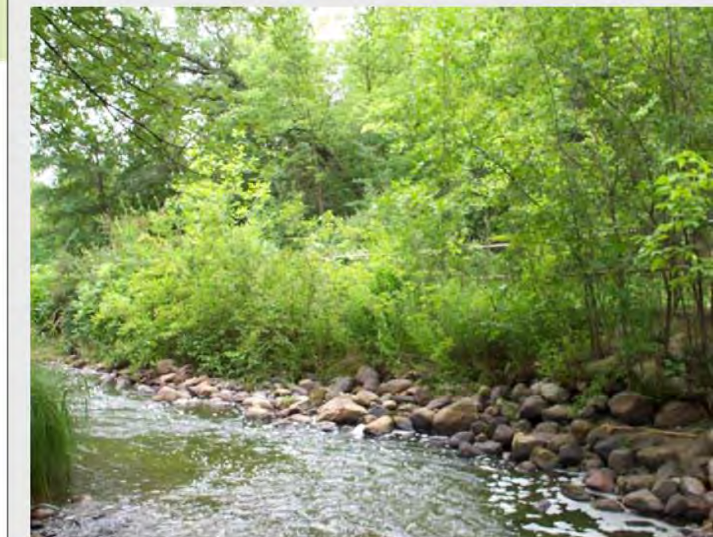
Appendix C

Typical Streambank Stabilization Methods

Stream Stabilization Plan

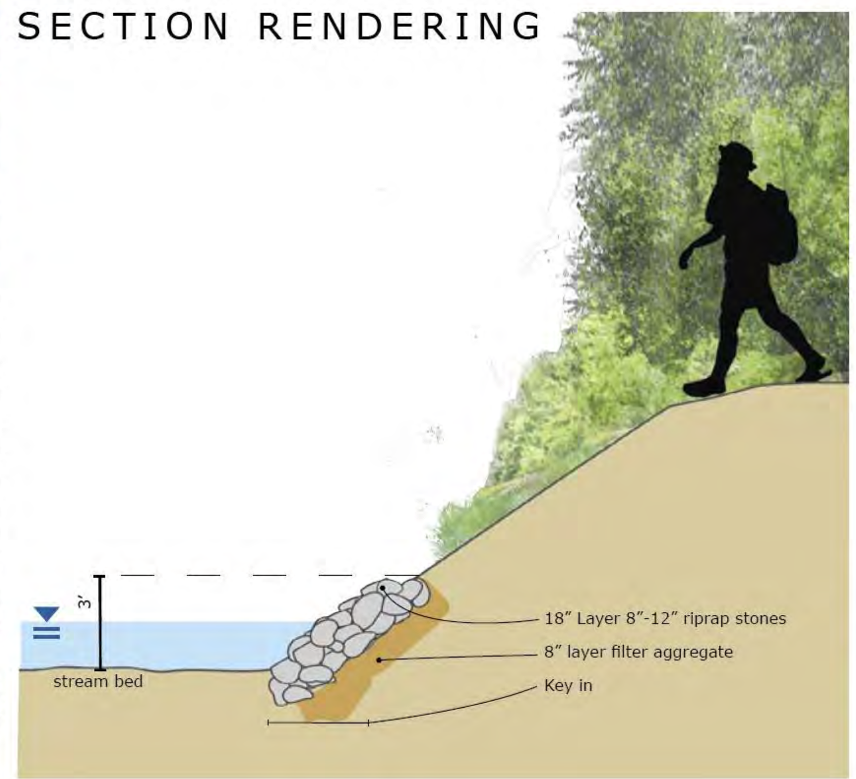
Stone Toe Protection is constructed from cobble-sized rock on the creek edges. It extends to approximately the bankfull level, which will protect the channel banks for flow events that occur every 1 to 2 years or less. The material will extend into the ground to resist scour. Coarse gravel is used to separate the larger rock material from underlying soil. Stone toe protection is typically used in conjunction with revegetation of the upper banks.

SIMILAR PROJECTS



Stone toe protection has been used extensively in Nine Mile Creek's Lower Valley, in conjunction with deflector dikes, grade control measures and stabilization of large bank failures. Following the 1987 "super storm," the proposed design allowed the stream to continue its course while taking measures to protect areas where water flow was eroding valley walls. The resulting measures have stabilized the stream channel and valley walls while blending seamlessly with the natural environment.

SECTION RENDERING



EXISTING CONDITIONS

Fluvial bank erosion is caused by water in the stream moving past the streambanks. The shear stress caused by the flow entrains soil particles into the flow, causing the stream bank to erode away. This is the most common type of erosion that occurs in streams. Virtually all streams experience this type of erosion as their flow path evolves over time. However, the rate of fluvial bank erosion can increase when the stream is out of equilibrium with its watershed. Increased flow from a watershed will increase the rate of fluvial bank erosion. In many cases, it appears to be a part of the natural process of stream evolution. In places where the channel is confined by the valley walls, however, fluvial bank erosion can lead to failure of the high banks. It can also undermine storm sewer inlets.

MATERIALS

Materials will consist of cobble-sized material with coarse gravel filter layer to provide separation from the underlying soil. Natural fieldstone material will be used.

Stone Toe Protection

Bank Protection

BARR

Stream Stabilization Plan

Rock vanes are constructed from boulders on the creek bottom. They function by diverting channel flow toward the center and away from the bank. They are typically oriented in the upstream direction and occupy no more than one third of the channel width. Vanes are largely submerged and inconspicuous. The rocks are chosen such that they will be large enough to resist movement during flood flows or by vandalism, with additional smaller rock material to add stability. Rock vanes function in much the same way as root wads in that they push the stream thalweg (zone of highest velocity) away from the outside bend. They also promote sedimentation behind the vane, which adds to the toe protection.

Vanes can also be constructed from both banks, forming an upstream-pointing "V." In this configuration, the vane protects both banks and also provides grade control.

SIMILAR PROJECTS

Here is an example of a stabilization project designed for a 1,000-foot long, 20-foot high streambank that was severely eroded. The channel was directed away from the bank toe by installing six rock vanes. The bank was planted with native vegetation and protected with erosion control blanket, while the terrace above the bank was graded to redirect surface runoff to a less vulnerable area. The restored streambank withstood significant flooding during 2001, and has become nicely vegetated (see picture above).

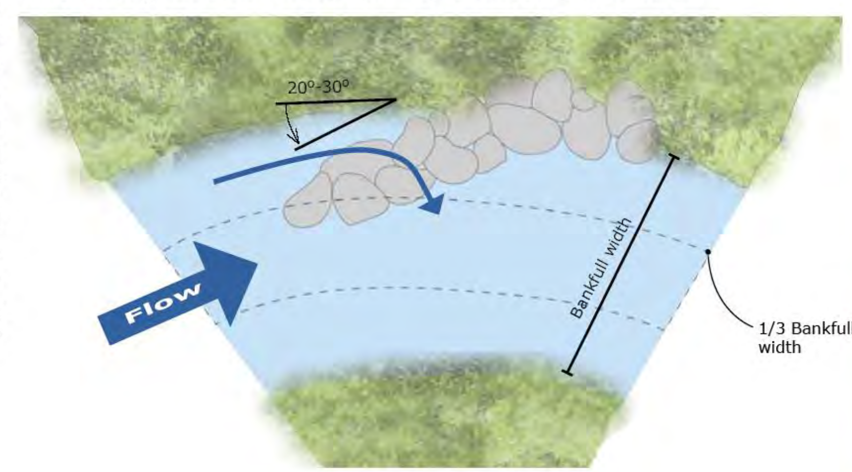
MATERIALS

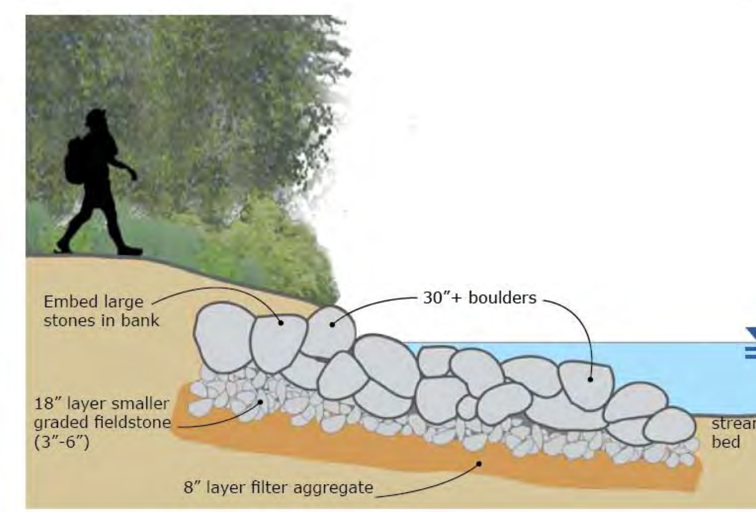
Materials will consist of various gradations of rock, ranging from large, 3-foot boulders to coarse gravel.

EXISTING CONDITIONS

Fluvial bank erosion is caused by water in the stream moving past the streambanks. The shear stress caused by the flow entrains soil particles into the flow, causing the stream bank to erode away. This is the most common type of erosion that occurs in streams. Virtually all streams experience this type of erosion as their flow path evolves over time. However, the rate of fluvial bank erosion can increase when the stream is out of equilibrium with its watershed. Increased flow from a watershed will increase the rate of fluvial bank erosion. In places where the channel is confined by the valley walls, however, fluvial bank erosion can lead to failure of the high banks. It can also undermine storm sewer inlets.

PLAN/SECTION RENDERING





Rock Vanes

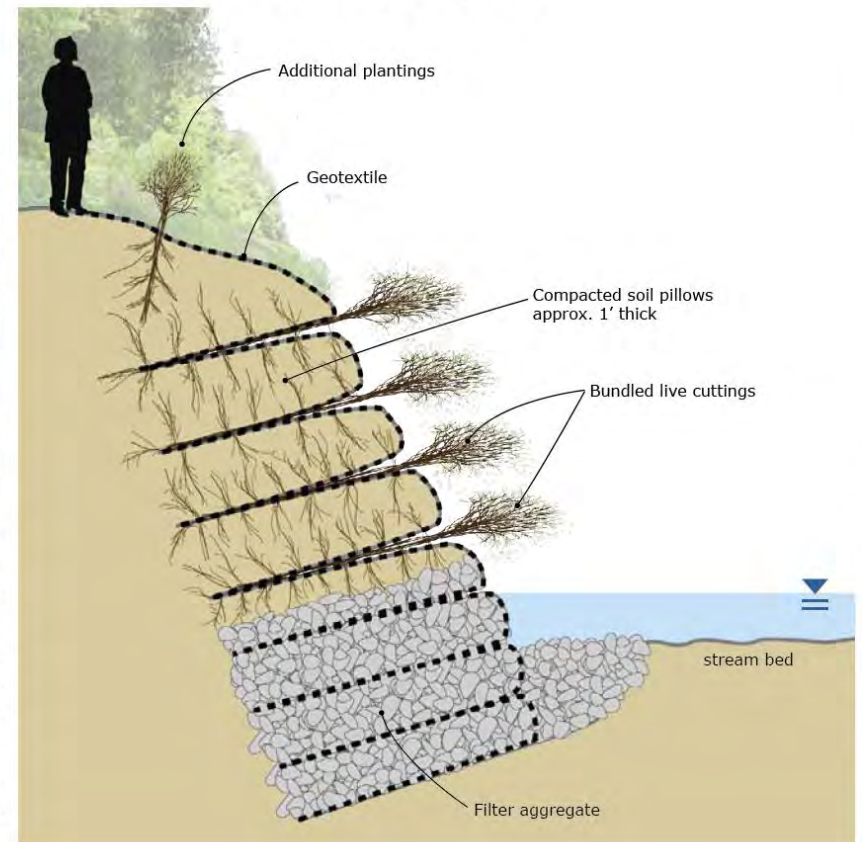
Bank Protection

BARR

Stream Stabilization Plan

Soil Pillows are utilized in a bioengineering method known as Vegetated Reinforced Slope Stabilization (VRSS). The method combines rock, geosynthetics, soil and plants to stabilize steep, eroding slopes in a structurally sound manner. VRSS typically involves protecting layers of soils with a blanket or geotextile material (e.g. erosion control blanket) and vegetating the slope by either planting selected species (often willow or dogwood species) between the soil layers or by seeding the soil with desired species before it is covered by the protective material. In either case, with adequate light and moisture, the vegetation grows quickly and provides significant root structure to strengthen the bank. This method tends to be labor intensive and, therefore, relatively expensive.

SECTION RENDERING



In places where the channel is confined by the steep valley walls, however, fluvial bank erosion can lead to failure of the high banks. It can also undermine storm sewer inlets.
For sites where groundwater seepage is a problem and where it is desirable to maintain steep banks, soil pillows are a feasible solution.

EXISTING CONDITIONS

Fluvial bank erosion is caused by water in the stream moving past the streambanks. The shear stress caused by the flow entrains soil particles into the flow, causing the stream bank to erode away. This is the most common type of erosion that occurs in streams.
Virtually all streams experience this type of erosion as their flow path evolves over time. However, the rate of fluvial bank erosion can increase when the stream is out of equilibrium with its watershed. Increased flow from a watershed will increase the rate of fluvial bank erosion.

SIMILAR PROJECTS

The Mill Creek Restoration Project utilized soil bioengineering design to stabilize 175 linear feet of severely eroding streambanks within the Caldwell Recreation Park in southeastern Ohio. The work included two 25-foot vegetated reinforced soil slope (VRSS) sections, two 50-foot fill bank sections protected with woven coir and direct woody plantings, and a 12.5-foot tie-in on the upstream and downstream end of streambank work area.

MATERIALS

Materials consist of graded rock for the lower layers of the structure and for internal drainage, if necessary. Geotextile fabric is used to wrap the soil. Plants, such as willow or dogwood, or seed mixture is used for planting in and between the soil pillows.

Soil Pillows

Bank Protection

BARR

Stream Stabilization Plan

EXISTING CONDITIONS

Channel incision occurs when there is an imbalance between the sediment supply and the sediment carrying capacity of the stream. Erosion will occur when the sediment carrying capacity of a stream exceeds the sediment supply. In streams with cohesive banks and steep channel slope, the erosion will first occur primarily on the channel bottom because that is where the erosive forces are the strongest. As the channel deepens, the stream will gradually become wider as the banks eventually fail. The stream will gradually return to equilibrium; however, the process can take many years and significant amounts of erosion will occur during the process.

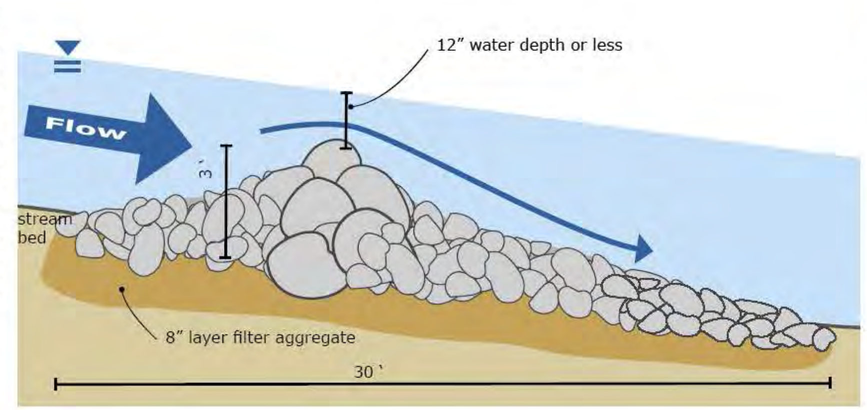
Grade control measures are used where channel downcutting has occurred. Various types of weirs are commonly used to provide grade control on streams, particularly in steeper systems. Weirs can be constructed of sheetpile, concrete, or natural materials such as rock. In most cases, natural rock is used to emulate natural riffles. Large boulders would comprise the core of the structure, with smaller rock material placed on the upstream and downstream sides of the boulders to provide a gradual transition to the channel.

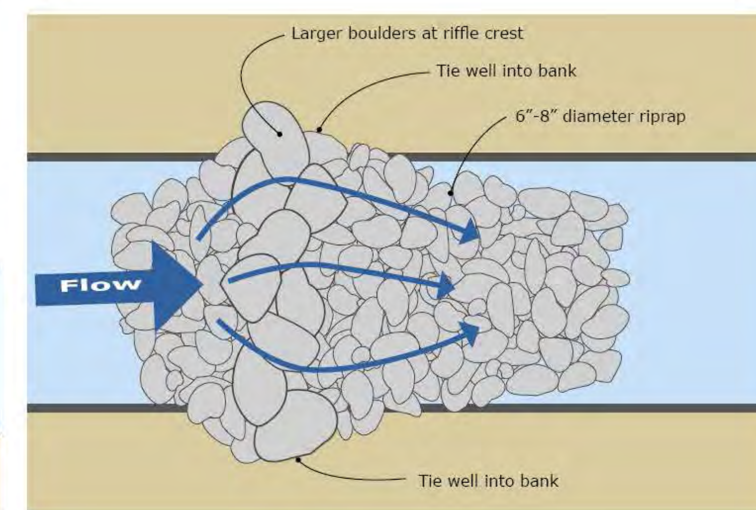
The riffles will serve to raise the surface of the water profile, and will reconnect the stream to its floodplain areas. Following the installation of the riffles, pools will be created upstream of the riffles. However, these pools will fill with sediment over time, which will in effect raise the channel bottom to the desired elevation.

MATERIALS

Materials will consist of various gradations of rock, ranging from large, 3-foot boulders to coarse gravel.

SECTION/PLAN RENDERING





SIMILAR PROJECTS

Following the 1987 "super storm," a rapids was constructed on Nine Mile Creek downstream of the 106th Street Bridge. The rapids was one of several grade-control structures that were installed on a three-mile stretch of creek in the lower valley. The proposal allowed the stream to continue its course while taking measures to protect areas where water flow was eroding valley walls. Protection measures included applying porous deflector dikes, burying sheetpile walls parallel to the creek to prevent undercutting of slopes, installing weirs (rock or capped sheetpile) to limit stream-bed degradation, and improving storm-sewer outlets.

Constructed Riffle

Grade Control

BARR

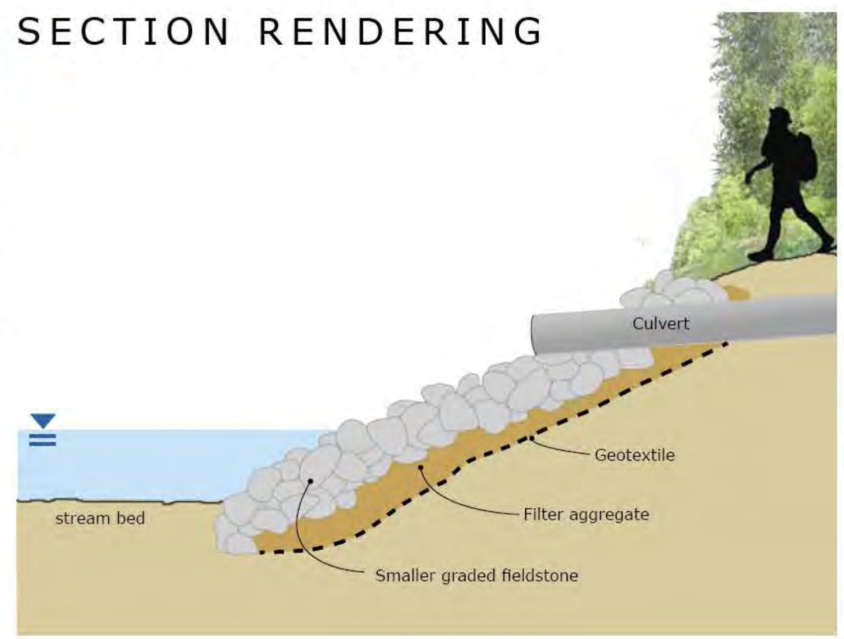
Stream Stabilization Plan

Culvert Stabilization is somewhat unique to each situation, depending on the site circumstances. Most sites require additional rock placement with a granular filter layer (rather than filter fabric). Some cases may require re-alignment and/or lowering of the outlet to better align with the stream channel. Typically, outlets should be aligned in the downstream channel direction so that flow doesn't impinge on the opposite bank. It is usually desireable for the culvert to enter the stream at or just above the normal water level in order to minimze the potential for undercutting.

EXISTING CONDITIONS

Erosion is frequently observed at culvert outlets for a variety of reasons, including insufficient erosion protection at the culvert outlet, streambank erosion, and channel downcutting, which leaves the culvert perched above the channel. Filter fabric is often used at culvert outlets to separate riprap protection from underlying soils, however the fabric provides a slippery surface for the riprap, which commonly slides into the channel.

SECTION RENDERING



SIMILAR PROJECTS

There are many culvert stabilization designs used on various streams and rivers. Because they are often small projects, the work is often performed by local municipalities or completed as part of a larger project.

MATERIALS

Materials consist of rock materials ranging from graded riprap (either fieldstone, or, for steep slopes, angular) and granular filter material (typically coarse gravel). If necessary, additional pipe, manholes and end sections may be necessary.

Culvert Stabilization

Bank Protection

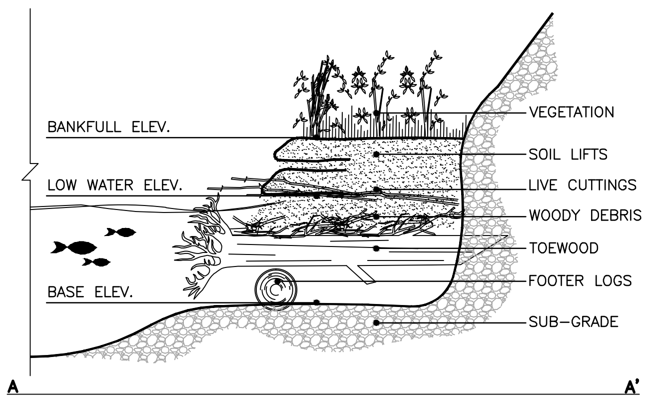
BARR

1. INSTALLATION SUMMARY

TOEWOOD BENCH CONSTRUCTION WILL BE DONE IN DRY WEATHER CONDITIONS AFTER STREAM HAS BEEN DIVERTED AND SITE DEWATERED.

ENGINEER OR OWNER'S REPRESENTATIVE MUST BE PRESENT FOR INSTALLATION OF TOEWOOD BENCH.

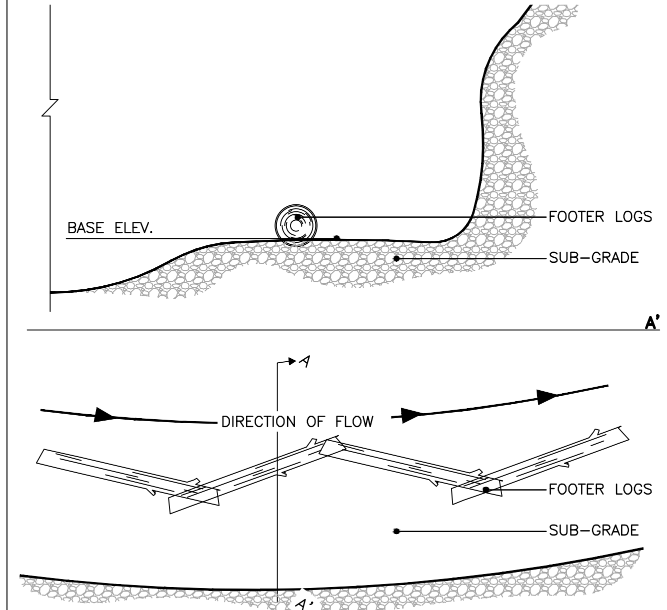
THE DRAWINGS ON THIS PAGE ARE NOT TO SCALE.



2. SUBGRADE AND FOOTER LOGS

SPECIFICATION:
- 8" TO 1' DIAMETER
- LIMBS REMOVED
- APPROX 10' LENGTH

PLACEMENT:
- EXCAVATE TO BASE ELEVATION – CONTRACTOR SHALL MAKE EFFORT TO SEPARATE GRANULAR AND FINE FILL NATIVE MATERIAL FOR USE IN STEPS 4 AND 6.
- PLACE FOOTER LOGS 30 DEGREES FROM PARALLEL TO STREAM FLOW WITH ENDS STACKED CREATING A ZIG ZAG PATTERN (PLAN VIEW BELOW)
- MAINTAIN AVERAGE ELEV. OF 1' ABOVE BASE ELEV.

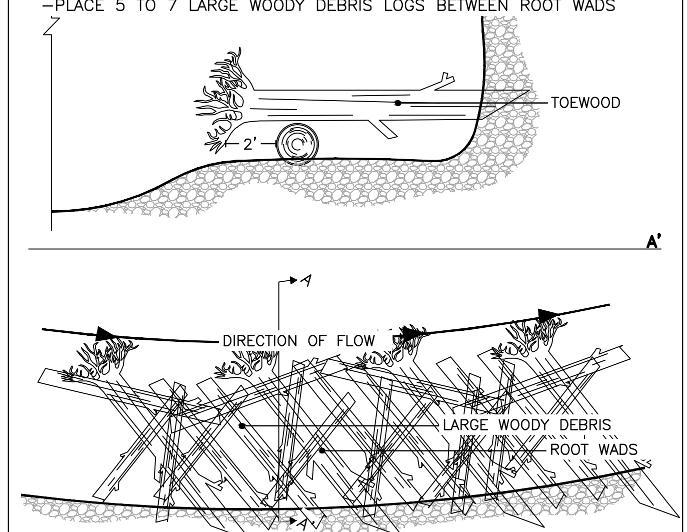


3. ROOT WADS & LRG WOODY DEBRIS

ROOT WAD SPECIFICATION:
- 10" MIN DIAMETER
- LENGTH INDICATED IN DESIGN CROSS SECTION OR 10' MIN.
- LIMBS REMOVED
- ROOT WADS LEFT INTACT
- ENDS SHARPENED TO A POINT

LARGE WOODY DEBRIS SPECIFICATION:
- 8" MIN DIAMETER

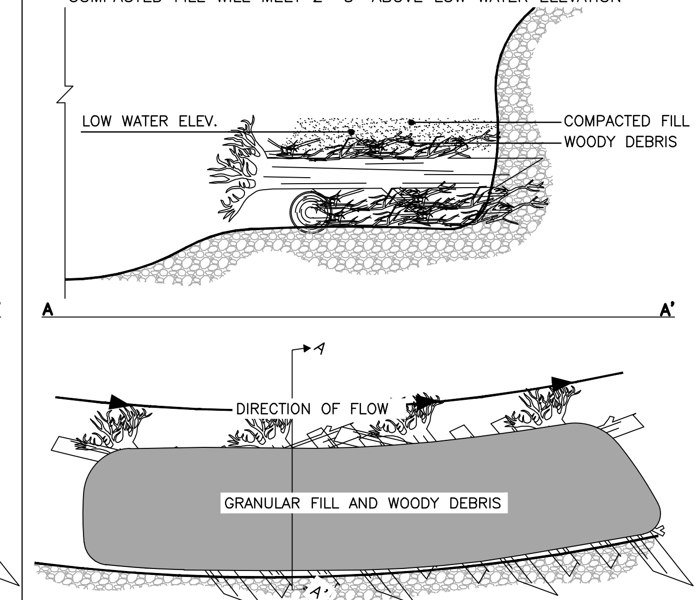
PLACEMENT:
- PLACE ROOT WADS HORIZONTALLY ON TOP OF FOOTER LOGS, OVERHANG ROOT WAD LOGS 2'
- ANGLE ROOTWADS UPSTREAM
- DRIVE SHARPENED TRUNKS MIN. 3' INTO BANK OR DIG IN .
- PLACE 1 ROOT WAD PER FOOTER LOG
- PLACE 5 TO 7 LARGE WOODY DEBRIS LOGS BETWEEN ROOT WADS



4. WOODY DEBRIS & GRANULAR FILL

SPECIFICATION:
- WOODY MATERIAL (COMPOSED OF SMALL LIMBS AND BRANCHES, APPROX. 4" MAX DIAMETER AND SMALLER)
- DO NOT USE ROTTEN WOODY MATERIAL
- NATIVE GRANULAR FILL

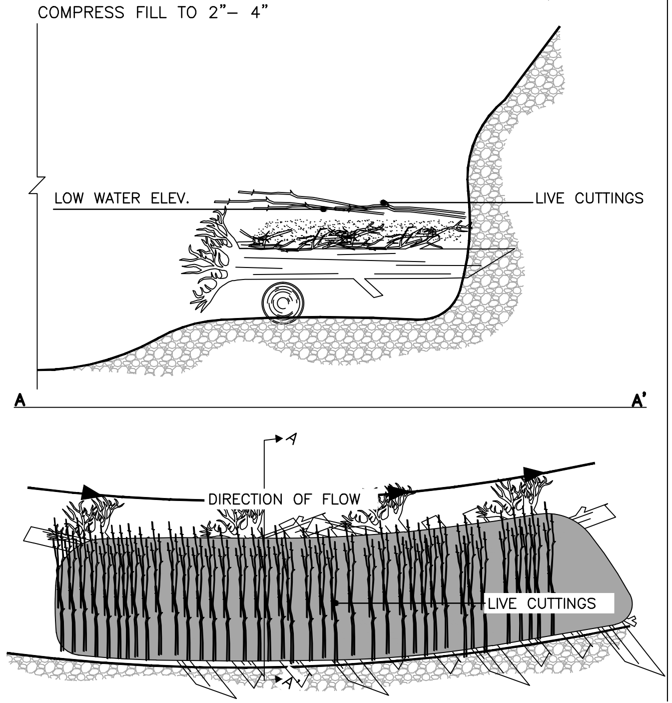
PLACEMENT:
- FILL BETWEEN FOOTER LOGS AND TOEWOOD WITH WOODY DEBRIS
- STACK WOODY DEBRIS TO LOW WATER ELEVATION
- LAYER NATIVE GRANULAR FILL ON TOP OF WOODY DEBRIS
- COMPACT SO THAT SETTLING OF FILL IS MINIMIZED BUT DEBRIS IS NOT DISPLACED
- COMPACTED FILL WILL MEET 2"-5" ABOVE LOW WATER ELEVATION



5. LIVE CUTTINGS

SPECIFICATION:
- SEE LIVE CUTTING DETAIL

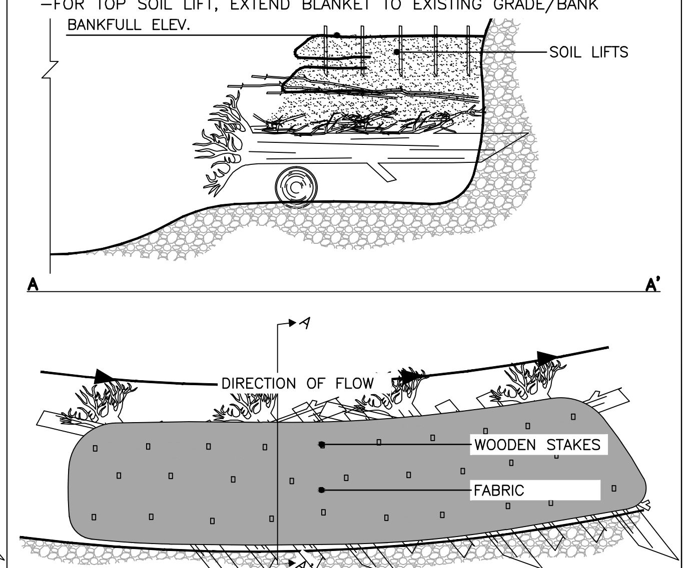
PLACEMENT:
- LAY CUTTINGS WITH A DENSITY OF 10 CUTTINGS PER LINEAL FOOT
- TOPS OF CUTTING WILL POINT TOWARD CHANNEL
- TRIM EXPOSED ENDS OF CUTTINGS, LEAVE NO MORE THAN 6" EXPOSED
- DEPOSIT NATIVE FILL OVER CUTTINGS AND WATER LIBERALLY, COMPRESS FILL TO 2"- 4"



6. SOIL LIFTS

SPECIFICATION:
- NATIVE FILL (FINE)
- 1' FORMS
- MIN 6.5' WIDE ROLANKA BIOD-MAT 70, GEOCOIR 700, OR EQUAL LINED WITH MNDOT CAT II EROSION CONTROL BLANKET WITH NATURAL NETTING
- 18" WOODEN STAKES (2X4 CUT AT ANGLE), PLACED AT 3' SPACING

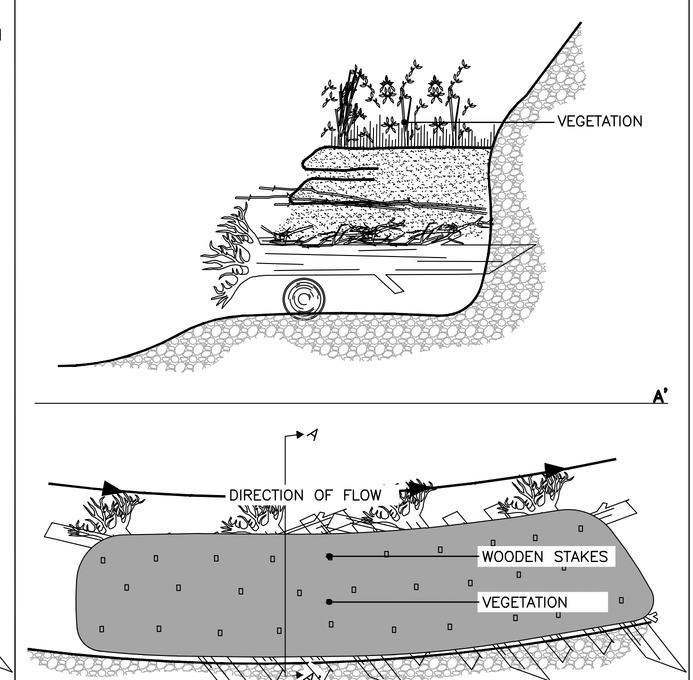
PLACEMENT:
- PLACE FORM
- LAY MIN 2.5' OF FABRIC (COCONUT BLANKET AND LINER) ALONG BENCH
- PLACE 1' OF FILL ON TOP OF MAT AND COMPACT
- WRAP FILL WITH REMAINING BLANKET AND SECURE WITH STAKES
- REPEAT UNTIL BANKFUL ELEVATION IS MET, STEP EACH LIFT BACK 1'
- FOR TOP SOIL LIFT, EXTEND BLANKET TO EXISTING GRADE/BANK



7. VEGETATION

SEE VEGETATION PLAN FOR DETAIL

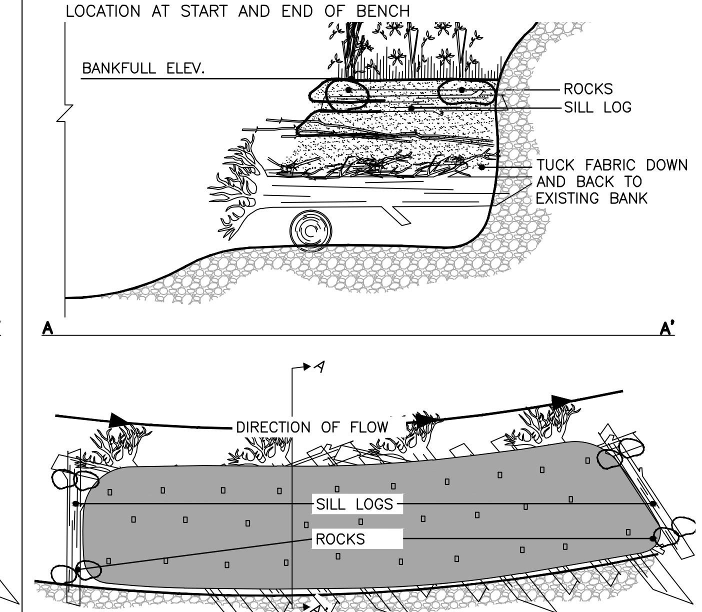
IF SEED IS CALLED FOR:
- PLANT SEED INSIDE OF SOIL LIFT PRIOR TO COVERING IN FABRIC
- PLANT SEED ON THE FACE OF EACH SOIL LIFT AS WELL AS ACROSS THE TOP SOIL LIFT



8. SILL LOGS & TERMINATION

SPECIFICATION:
- 10" MIN DIAMETER
- LIMBS REMOVED
- LENGTH DETERMINED BY WIDTH OF TOEWOOD BENCH

PLACEMENT:
- PLACE ONE SILL LOG AT THE START AND END OF THE TOEWOOD BENCH PERPENDICULAR TO THE DIRECTION OF FLOW.
- PLACE LARGE ROCKS ON TOP OF SILL LOG, TOP OF ROCK WILL MEET BANKFULL ELEVATION
- TUCK SOIL LIFT BLANKET DOWN AND BACK TOWARDS EXISTING BANK
- TRANSITION BANKFULL ELEVATION TO EXISTING GRADE AT DETERMINED LOCATION AT START AND END OF BENCH



NO.	BY	CHK.	APP.	DATE	REVISION DESCRIPTION

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.

SIGNATURE ____

PRINTED NAME ____

DATE ____ REG. NO. ____

CLIENT
BID
CONSTRUCTION

RELEASED TO/FOR

A	B	C	0	1	2	3

DATE RELEASED

BARR

Corporate Headquarters: Minneapolis, Minnesota Ph: 1-800-632-2277

Project Office:
BARR ENGINEERING CO.
4700 WEST 77TH STREET
MINNEAPOLIS, MN.
55435-4803
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www.barr.com

Scale	AS SHOWN
Date	2/10/2015
Drawn	GGN
Checked	JDW
Designed	GGN
Approved	JDW

TOE WOOD

EXAMPLE DETAIL

BARR PROJECT No.

CLIENT PROJECT No.

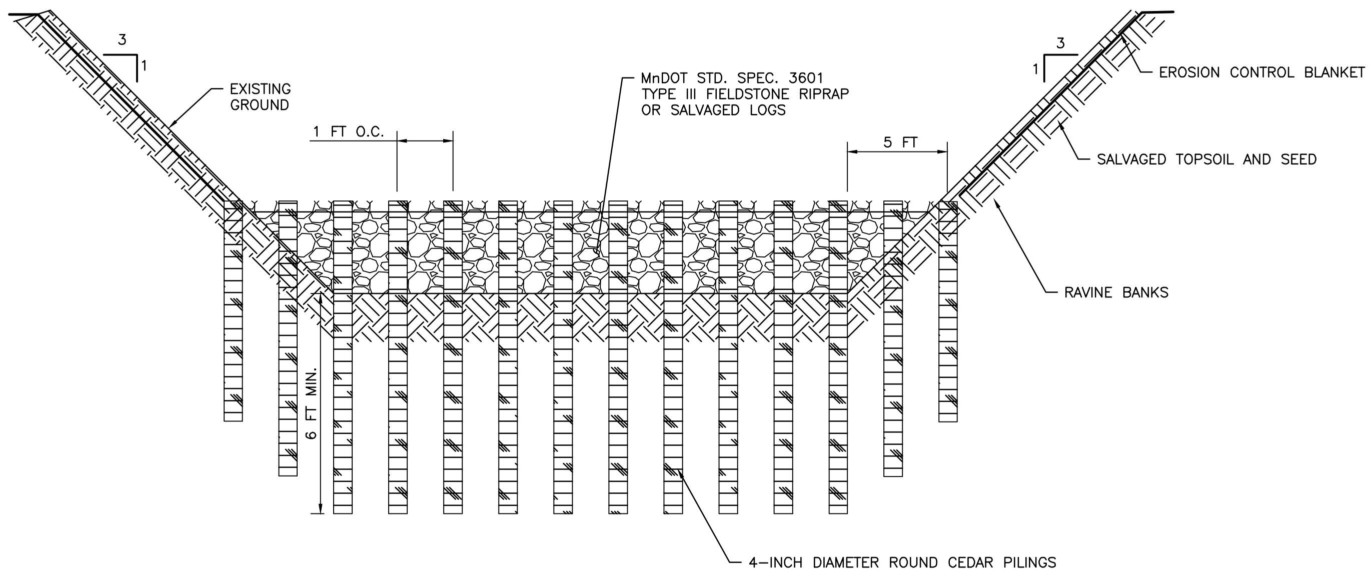
DWG. No. C1.0

REV. No. 0

CADD USER: Adam K. Howard FILE: P:\MPLS\23 MN\27\2327051\WORKFILES\CIP\CAPITAL PROJECTS\2017 PLYMOUTH CREEK ANNAPOLIS THRU PLYMOUTH CR PK 2017CR-P\FEASIBILITY STUDY\REPORT\APPENDICES\APPENDIX E\TOEWOOD.DWG PLOT SCALE: 1:2 PLOT DATE: 12/17/2015 12:31 PM

Images in Drawing ...\JDW.tif
M:\Design\23270140.00\23270140000_C9.dwg Plot at 1 07/06/2015 16:12:46

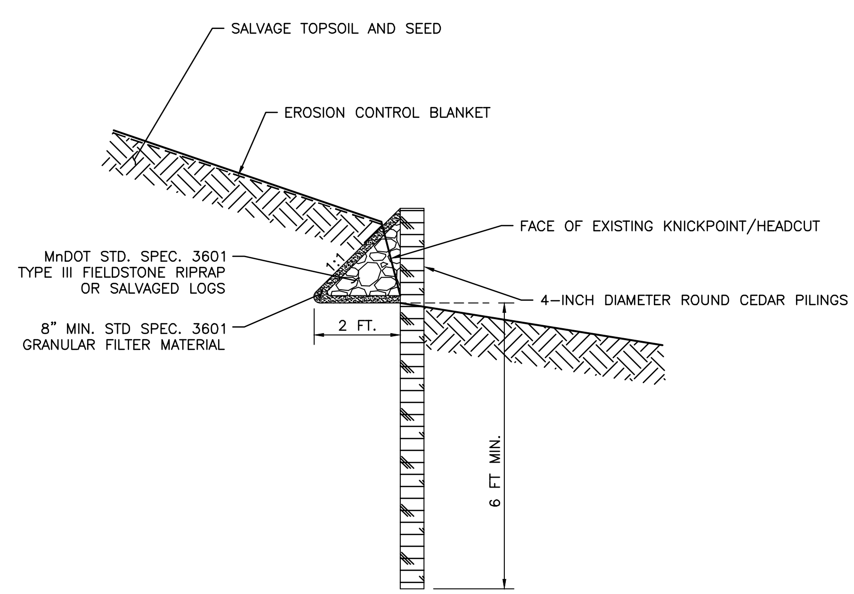
CADD USER: ADAM K. HOWARD FILE: P:\MPLS\23 MN\27\23270531\WORKFILES\TASK ORDERS_TO_14_LOWER_RILEY_FEASIBILITY_STUDY\FEASIBILITY STUDY\FEASIBILITY STUDY REPORT\APPENDICES\APPENDIX I - STABILIZATION EXAMPLES\CEDARPILINGS.DWG PLOT SCALE: 1:2 PLOT DATE: 10/9/2016 3:25 PM



1 DETAIL: CEDAR PILINGS
NOT TO SCALE

CEDAR PILINGS SPECIFICATIONS:

1. CEDAR PILING MATERIAL: 4-INCH DIAMETER ROUND NORTHERN WHITE CEDAR; CUT FROM LIVE, GROWING TREES; MANUFACTURED IN ACCORDANCE WITH Mn/DOT STD. SPEC. 3413C
2. DRIVE POSTS AT THE SPACING AND TO THE PENETRATION DEPTHS SHOWN ON THE DRAWINGS
3. TOP OF POSTS APPROXIMATELY 0.5-FT. ABOVE CHANNEL BOTTOM.
4. IN THE EVENT THAT POSTS CANNOT BE DRIVEN, EXCAVATE A NARROW TRENCH, BACKFILL WITH GRANULAR FILL AT LEAST 4 FEET IN DEPTH, AND THEN DRIVE POSTS TO THE ELEVATIONS SHOWN ON THE DRAWINGS. BACKFILL TO EXISTING GRADE WITH GRANULAR FILL.
5. EXCAVATE 2 FEET BEHIND PILINGS AND BACKFILL WITH 8" MnDOT STD. SPEC 3601 GRANULAR FILTER MATERIAL AND TYPE III FIELDSTONE RIPRAP AS SHOWN ON DRAWING.
6. BACKFILL WITH EXISTING MATERIAL TO EXISTING GRADE.
7. ON ALL DISTURBED BANKS AND AREAS REPLACE SALAVAGED TOPSOIL, RE-VEGETATE AND STABILIZE WITH EROSION CONTROL BLANKET AS SPECIFIED IN THE CONTRACT DOCUMENTS.



2 SECTION: CEDAR PILINGS
NOT TO SCALE

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PRINTED NAME ______
SIGNATURE ______
DATE ______ LICENSE # ______

CLIENT / BID / CONSTRUCTION / PERMITTING
RELEASED TO/FOR — A B C 0 1 2 3 — DATE RELEASED

BARR
Corporate Headquarters: Minneapolis, Minnesota Ph: 1-800-632-2277

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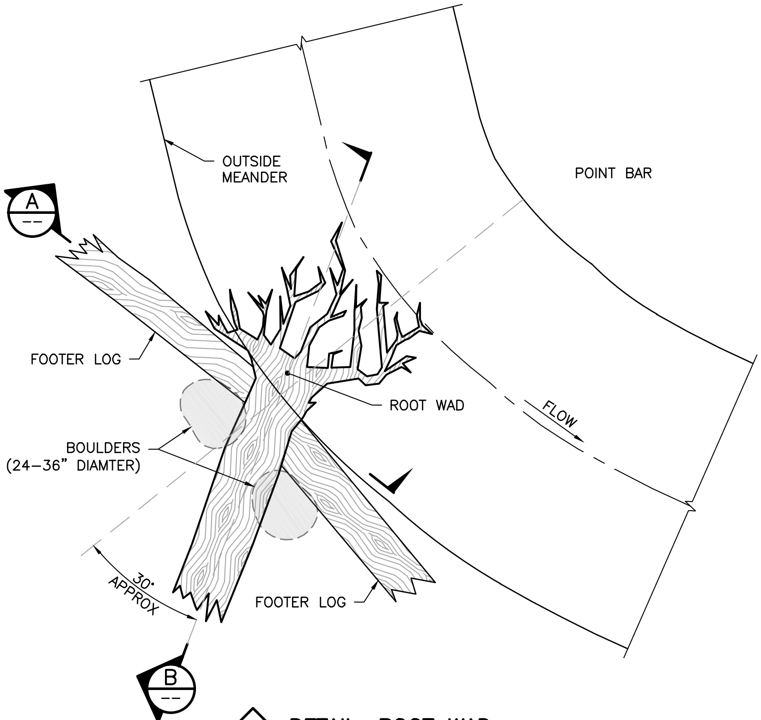
Scale	AS SHOWN
Date	6/15/16
Drawn	JPP
Checked	LAD
Designed	JPP
Approved	LAD

CEDAR PILES AND RIPRAP APRON DETAILS

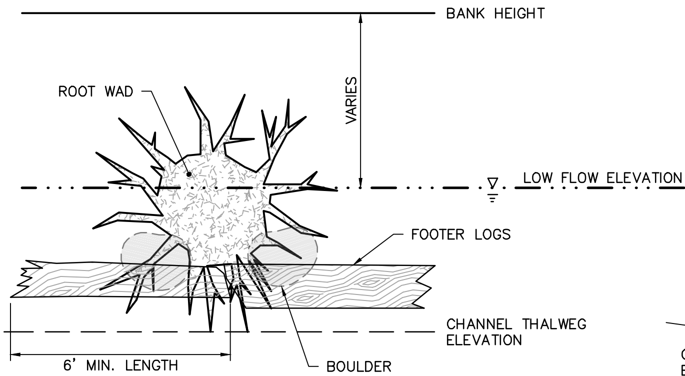
BARR PROJECT No.
CLIENT PROJECT No.
DWG. No.
REV. No. 0



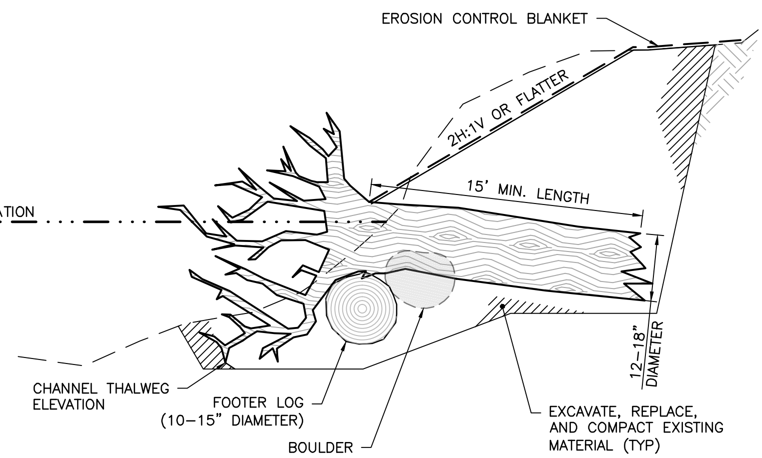
DETAIL: ROOT WAD
NOT TO SCALE

GENERAL NOTES:

1. THE ENGINEER MUST BE NOTIFIED AT LEAST 3 DAYS PRIOR TO ROOT WAD INSTALLATION AND MUST BE ON SITE DURING INSTALLATION.
2. TO THE EXTENT POSSIBLE, ROOT WADS SHOULD BE CREATED FROM TREES THAT WILL BE REMOVED FROM THE SITES WITHIN THE PROJECT AREA.
3. CONSTRUCTION SHOULD PROCEED FROM DOWNSTREAM TO UPSTREAM IN AREAS WHERE MORE THAN ONE ROOT WAD WILL BE INSTALLED AS SHOWN ON THE DRAWINGS.
4. EXCAVATE A TRENCH ALONG THE STREAMBANK TOE FOR THE FOOTER LOGS.
5. PLACE THE FOOTER LOGS INTO THE TRENCH, WITH THE TOPS OF THE LOGS AT SPECIFIED ELEVATIONS FOR EACH SITE.
6. EXCAVATE A TRENCH IN WHICH TO PLACE THE ROOT WAD. IN SOFT SOILS IT MAY BE POSSIBLE TO DRIVE THE ROOT WAD INTO THE BANK WITH EQUIPMENT AFTER SHARPENING THE END TO A POINT. CARE SHALL BE TAKEN NOT TO DAMAGE THE ROOT WAD.
7. THE ROOT WAD MUST BE PLACED IN THE BANK SO THAT THE BACK OF THE ROOT FAN RESTS AGAINST THE FRONT OF THE FOOTER LOG.
8. THE ROOT FAN MUST BE PLACED SUCH THAT THE FAN IS ANGLED UPSTREAM AS SHOWN AND AS DIRECTED BY THE ENGINEEER.
9. MOVING UPSTREAM, THE PROCESS IS REPEATED FOR EACH ADDITIONAL ROOT WAD AS SHOWN ON THE DRAWINGS.
10. LARGE BOULDERS ARE PLACED ON EITHER SIDE OF THE TRUNK OF EACH ROOTWAD.
11. PLACE BACK FILL OVER THE BOULDERS AS NECESSARY WITH A COARSE FILTER AGGREGATE (MN/DOT STANDARD SPECIFICATION 3142.2H) AND MATCH EXISTING GRADE WITH 6" OF TOPSOIL.
12. REVEGETATE AND STABILIZE WITH EROSION CONTROL BLANKET AS SPECIFIED FOR EACH SITE AS SHOWN IN THE DRAWINGS AND DIRECTED BY THE ENGINEER.
13. TRIM THE ROOTS THAT EXTEND ABOVE THE STREAM BANK TO A HEIGHT SLIGHTLY BELOW BANK HEIGHT AS DIRECTED BY THE ENGINEER.



A SECTION: ROOT WAD
NOT TO SCALE



B SECTION: ROOT WAD
NOT TO SCALE

CADD USER: ADAM K. HOWARD FILE: M:\DESIGN\23821067.00\SR_BANK PROTECTION – ROOT WAD.DWG PLOT SCALE: 1:1 PLOT DATE: 10/9/2016 3:34 PM

BARR

CREATED BY: PEB
LAST EDITED BY: PEB, 10/9/16
KNOWLEDGEABLE PERSONS:
JTL2, TEM, PJH2, JDW

STREAM RESTORATION DETAILS
BANK PROTECTION
ROOT WAD

Appendix D

Cost Estimates

Preliminary Cost Estimate for Project CH-1a

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Mobilization	LS	1	$ 4,576	$ 4,580
Control of Water	LS	1	$ 798	$ 800
Erosion Control	LS	1	$ 1,198	$ 1,200
Rock Erosion Control Construction Entra	EACH	1	$ 1,200	$ 1,200
Topsoil Import	CY	75	$ 33	$ 2,480
Seeding and Mulch	ACRE	0.10	$ 8,000	$ 800
Erosion Control Blanket	SY	100	$ 3	$ 300
12" RCP Culvert	LF	75	$ 31	$ 2,330
Outlet structure	EACH	1	$ 10,000	$ 10,000
Furnish and Install Fieldstone Riprap	TON	28	$ 100	$ 2,850
Channel stabilization	L.F.	100	$ 230	$ 23,000
System for water re-use	EACH	1		
One-Year Establishment Maintenance Period	LS	1	$ 798	$ 800
			Construction Total	**$ 50,000**
			Construction Total w/ Contingency (25%)	$ 62,500
			Planning, Engineering, Design &Legal (30%)	$ 18,750
			Construction Management (7%)	$ 4,375
			Project Total	**$ 86,000**
			Total w/ Construction Lower Bound (-25%), Legal, and Engineering	**$ 65,000**
			Total w/ Construction Upper Bound (+40%), Legal, and Engineering	**$ 120,000**
			Annual Maintenance Cost	**$ 1,700**
			Annual Maintenance Cost Lower Bound (-2%)	**$ 1,300**
			Annual Maintenance Cost Upper Bound (+2%)	**$ 2,400**

Preliminary Cost Estimate for Project CH-2a

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Mobilization	LS	1	$ 4,106	$ 4,110
Control of Water	LS	1	$ 915	$ 910
Erosion Control	LS	1	$ 1,372	$ 1,370
Rock Erosion Control Construction Entra	EACH	1	$ 1,200	$ 1,200
Clearing and Grubbing	ACRE	0	$ 7,000	$ 480
Select Tree Removal (>4")	EACH	12	$ 400	$ 4,800
Grading	SY	333	$ 4	$ 1,330
Seeding and Mulch	ACRE	0.1	$ 8,000	$ 550
Furnish and Install Fieldstone Riprap	TON	31	$ 100	$ 3,110
36" RCP Culvert	LF	150	$ 76	$ 11,400
Manhole	EACH	1	$ 5,000	$ 5,000
Outlet Structure	EACH	1	$ 10,000	$ 10,000
One-Year Establishment Maintenance Period	LS	1	$ 915	$ 910
Construction Total				**$ 45,000**
Construction Total w/ Contingency (25%)				$ 56,250
Planning, Engineering, Design &Legal (30%)				$ 16,875
Construction Management (7%)				$ 3,938
Project Total				**$ 77,000**
Total w/ Construction Lower Bound (-25%), Legal, and Engineering				**$ 58,000**
Total w/ Construction Upper Bound (+40%), Legal, and Engineering				**$ 108,000**
Annual Maintenance Cost				**$ 1,500**
Annual Maintenance Cost Lower Bound (-2%)				**$ 1,200**
Annual Maintenance Cost Upper Bound (+2%)				**$ 2,200**

Preliminary Cost Estimate for Project CH-2b

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Mobilization	LS	1	$ 40,752	$ 40,750
Control of Water	LS	1	$ 14,299	$ 14,300
Erosion Control	LS	1	$ 21,448	$ 21,450
Rock Erosion Control Construction Entra	EACH	1	$ 1,200	$ 1,200
Clearing and Grubbing	ACRE	2	$ 7,000	$ 14,000
Select Tree Removal (>4")	EACH	30	$ 400	$ 12,000
Excavate/Salvage Soil	CY	333	$ 7	$ 2,330
Excavation/Dispose of Soil	CY	10,100	$ 22	$ 222,200
Grading	SY	5,000	$ 4	$ 20,000
Plant Shrubs	EACH	30	$ 50	$ 1,500
Plant Trees	EACH	10	$ 250	$ 2,500
Seeding and Mulch	ACRE	1	$ 8,000	$ 11,900
Erosion Control Blanket	SY	7,200	$ 3	$ 21,600
Furnish and Install Fieldstone Riprap	TON	155	$ 100	$ 15,540
48" RCP Culvert	LF	150	$ 142	$ 21,300
36" RCP Culvert	LF	150	$ 76	$ 11,400
One-Year Establishment Maintenance Period	LS	1	$ 14,299	$ 14,300
			Construction Total	**$ 448,000**
			Construction Total w/ Contingency (25%)	$ 560,000
			Planning, Engineering, Design &Legal (30%)	$ 168,000
			Construction Management (7%)	$ 39,200
			Project Total	**$ 767,000**
			Total w/ Construction Lower Bound (-25%), Legal, and Engineering	**$ 575,000**
			Total w/ Construction Upper Bound (+40%), Legal, and Engineering	**$ 1,074,000**
			Annual Maintenance Cost	**$ 15,300**
			Annual Maintenance Cost Lower Bound (-2%)	**$ 11,500**
			Annual Maintenance Cost Upper Bound (+2%)	**$ 21,500**

Preliminary Cost Estimate for Project CH-2c

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Mobilization	LS	1	$ 7,114	$ 7,110
Control of Water	LS	1	$ 1,795	$ 1,790
Erosion Control	LS	1	$ 2,692	$ 2,690
Rock Erosion Control Construction Entra	EACH	1	$ 1,200	$ 1,200
Clearing and Grubbing	ACRE	0.2	$ 7,000	$ 1,610
Select Tree Removal (>4")	EACH	10	$ 400	$ 4,000
Grading	SY	1,111	$ 4	$ 4,440
Seeding and Mulch	ACRE	0.2	$ 8,000	$ 1,840
Furnish and Install Fieldstone Riprap	TON	8	$ 100	$ 780
12" RCP Culvert	LF	1,000	$ 31	$ 31,000
Manhole	EACH	4	$ 5,000	$ 20,000
One-Year Establishment Maintenance Period	LS	1	$ 1,795	$ 1,790
Construction Total				**$ 78,000**
Construction Total w/ Contingency (25%)				$ 97,500
Planning, Engineering, Design &Legal (30%)				$ 29,250
Construction Management (7%)				$ 6,825
Project Total				**$ 134,000**
Total w/ Construction Lower Bound (-25%), Legal, and Engineering				**$ 101,000**
Total w/ Construction Upper Bound (+40%), Legal, and Engineering				**$ 188,000**
Annual Maintenance Cost				**$ 2,700**
Annual Maintenance Cost Lower Bound (-2%)				**$ 2,000**
Annual Maintenance Cost Upper Bound (+2%)				**$ 3,800**

Preliminary Cost Estimate for Project CH-3a

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Mobilization	LS	1	$ 37,728	$ 37,730
Control of Water	LS	1	$ 13,238	$ 13,240
Erosion Control	LS	1	$ 19,856	$ 19,860
Rock Erosion Control Construction Entra	EACH	1	$ 1,200	$ 1,200
Clearing and Grubbing	ACRE	2.50	$ 7,000	$ 17,500
Select Tree Removal (>4")	EACH	10	$ 400	$ 4,000
Excavation/Dispose of Soil	CY	9410	$ 22	$ 207,020
Grading	SY	2556	$ 4	$ 10,220
Topsoil Import	CY	1222	$ 33	$ 40,330
Plant Shrubs	EACH	30	$ 50	$ 1,500
Plant Trees	EACH	10	$ 250	$ 2,500
Seeding and Mulch	ACRE	0.50	$ 8,000	$ 4,000
Erosion Control Blanket	SY	2556	$ 3	$ 7,670
Furnish and Install Fieldstone Riprap	TON	92	$ 100	$ 9,200
Repair existing outlet structure	EACH	1	$ 3,000	$ 3,000
36" RCP Culvert	LF	300	$ 76	$ 22,800
One-Year Establishment Maintenance Period	LS	1	$ 13,238	$ 13,240
Construction Total				**$ 415,000**
Construction Total w/ Contingency (25%)				$ 518,750
Planning, Engineering, Design &Legal (30%)				$ 155,625
Construction Management (7%)				$ 36,313
Project Total				**$ 711,000**
Total w/ Construction Lower Bound (-25%), Legal, and Engineering				**$ 533,000**
Total w/ Construction Upper Bound (+40%), Legal, and Engineering				**$ 995,000**
Annual Maintenance Cost				**$ 14,200**
Annual Maintenance Cost Lower Bound (-2%)				**$ 10,700**
Annual Maintenance Cost Upper Bound (+2%)				**$ 19,900**

Preliminary Cost Estimate for Project CH-3b

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Mobilization	LS	1	$ 5,969	$ 5,970
Control of Water	LS	1	$ 2,095	$ 2,090
Erosion Control	LS	1	$ 3,142	$ 3,140
Rock Erosion Control Construction Entra	EACH	1	$ 1,200	$ 1,200
Clearing and Grubbing	ACRE	3.00	$ 7,000	$ 21,000
Select Tree Removal (>4")	EACH	30	$ 400	$ 12,000
Plant Shrubs	EACH	30	$ 50	$ 1,500
Plant Trees	EACH	5	$ 250	$ 1,250
Erosion Control Blanket	SY	20	$ 3	$ 60
Grading	CY	30	$ 12	$ 360
Build new outlet structure	EACH	1	$ 15,000	$ 15,000
One-Year Establishment Maintenance Period	LS	1	$ 2,095	$ 2,090
			Construction Total	**$ 66,000**
			Construction Total w/ Contingency (25%)	$ 82,500
			Planning, Engineering, Design &Legal (30%)	$ 24,750
			Construction Management (7%)	$ 5,775
			Project Total	**$ 113,000**
			Total w/ Construction Lower Bound (-25%), Legal, and Engineering	**$ 85,000**
			Total w/ Construction Upper Bound (+40%), Legal, and Engineering	**$ 158,000**
			Annual Maintenance Cost	**$ 2,300**
			Annual Maintenance Cost Lower Bound (-2%)	**$ 1,700**
			Annual Maintenance Cost Upper Bound (+2%)	**$ 3,200**

Preliminary Cost Estimate for Project CH-3c

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Mobilization	LS	1	$ 4,321	$ 4,320
Control of Water	LS	1	$ 1,516	$ 1,520
Erosion Control	LS	1	$ 2,274	$ 2,270
Rock Erosion Control Construction Entra	EACH	1	$ 1,200	$ 1,200
Clearing and Grubbing	ACRE	2.50	$ 7,000	$ 17,500
Select Tree Removal (>4")	EACH	20	$ 400	$ 8,000
Plant Shrubs	EACH	20	$ 50	$ 1,000
Plant Trees	EACH	20	$ 250	$ 5,000
Erosion Control Blanket	SY	20	$ 3	$ 60
Furnish and Install Fieldstone Riprap	TON	33	$ 100	$ 3,280
grading	CY	30	$ 12	$ 360
Build new outlet structure	EACH	1	$ 1,500	$ 1,500
One-Year Establishment Maintenance Period	LS	1	$ 1,516	$ 1,520
Construction Total				**$ 48,000**
Construction Total w/ Contingency (25%)				$ 60,000
Planning, Engineering, Design &Legal (30%)				$ 18,000
Construction Management (7%)				$ 4,200
Project Total				**$ 82,000**
Total w/ Construction Lower Bound (-25%), Legal, and Engineering				**$ 62,000**
Total w/ Construction Upper Bound (+40%), Legal, and Engineering				**$ 115,000**
Annual Maintenance Cost				**$ 1,600**
Annual Maintenance Cost Lower Bound (-2%)				**$ 1,200**
Annual Maintenance Cost Upper Bound (+2%)				**$ 2,300**

Preliminary Cost Estimate for Stabilizing Reach R5

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Stabilization	L.F.	3303	$ 150	$ 495,440
			Construction Total	**$ 495,000**
			Construction Total w/ Contingency (25%)	$ 618,750
			Planning, Engineering, Design &Legal (30%)	$ 185,625
			Construction Management (7%)	$ 43,313
			Project Total	**$ 848,000**
			Total w/ Construction Lower Bound (-25%), Legal, and Engineering	**$ 636,000**
			Total w/ Construction Upper Bound (+40%), Legal, and Engineering	**$ 1,187,000**
			Annual Maintenance Cost	**$ 17,000**
			Annual Maintenance Cost Lower Bound (-2%)	**$ 12,700**
			Annual Maintenance Cost Upper Bound (+2%)	**$ 23,700**

Preliminary Cost Estimate for Stabilizing Reach R4A

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Stabilization	L.F.	1771	$ 150	$ 265,680
			Construction Total	**$ 266,000**
			Construction Total w/ Contingency (25%)	$ 332,500
			Planning, Engineering, Design &Legal (30%)	$ 99,750
			Construction Management (7%)	$ 23,275
			Project Total	**$ 456,000**
			Total w/ Construction Lower Bound (-25%), Legal, and Engineering	**$ 342,000**
			Total w/ Construction Upper Bound (+40%), Legal, and Engineering	**$ 638,000**
			Annual Maintenance Cost	**$ 9,100**
			Annual Maintenance Cost Lower Bound (-2%)	**$ 6,800**
			Annual Maintenance Cost Upper Bound (+2%)	**$ 12,800**

Preliminary Cost Estimate for Stabilizing Reach R4B

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Stabilization	L.F.	1823.68	$ 150	$ 273,550
			Construction Total	**$ 274,000**
			Construction Total w/ Contingency (25%)	$ 342,500
			Planning, Engineering, Design &Legal (30%)	$ 102,750
			Construction Management (7%)	$ 23,975
			Project Total	**$ 469,000**
			Total w/ Construction Lower Bound (-25%), Legal, and Engineering	**$ 352,000**
			Total w/ Construction Upper Bound (+40%), Legal, and Engineering	**$ 657,000**
			Annual Maintenance Cost	**$ 9,400**
			Annual Maintenance Cost Lower Bound (-2%)	**$ 7,000**
			Annual Maintenance Cost Upper Bound (+2%)	**$ 13,100**

Preliminary Cost Estimate for Stabilizing Reach R4C

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Stabilization	L.F.	1203.76	$ 150	$ 180,560
			Construction Total	**$ 181,000**
			Construction Total w/ Contingency (25%)	$ 226,250
			Planning, Engineering, Design &Legal (30%)	$ 67,875
			Construction Management (7%)	$ 15,838
			Project Total	**$ 310,000**
			Total w/ Construction Lower Bound (-25%), Legal, and Engineering	**$ 233,000**
			Total w/ Construction Upper Bound (+40%), Legal, and Engineering	**$ 434,000**
			Annual Maintenance Cost	**$ 6,200**
			Annual Maintenance Cost Lower Bound (-2%)	**$ 4,700**
			Annual Maintenance Cost Upper Bound (+2%)	**$ 8,700**

Preliminary Cost Estimate for Stabilizing Reach R4D

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Stabilization	L.F.	1777.76	$ 150	$ 266,660
			Construction Total	**$ 267,000**
			Construction Total w/ Contingency (25%)	$ 333,750
			Planning, Engineering, Design &Legal (30%)	$ 100,125
			Construction Management (7%)	$ 23,363
			Project Total	**$ 457,000**
			Total w/ Construction Lower Bound (-25%), Legal, and Engineering	**$ 343,000**
			Total w/ Construction Upper Bound (+40%), Legal, and Engineering	**$ 640,000**
			Annual Maintenance Cost	**$ 9,100**
			Annual Maintenance Cost Lower Bound (-2%)	**$ 6,900**
			Annual Maintenance Cost Upper Bound (+2%)	**$ 12,800**

Preliminary Cost Estimate for Stabilizing Reach R4E

Item Description	Unit	Estimated Quantity	Unit Price	Extension
Stabilization	L.F.	1954.88	$ 150	$ 293,230
			Construction Total	**$ 293,000**
			Construction Total w/ Contingency (25%)	$ 366,250
			Planning, Engineering, Design &Legal (30%)	$ 109,875
			Construction Management (7%)	$ 25,638
			Project Total	**$ 502,000**
			Total w/ Construction Lower Bound (-25%), Legal, and Engineering	**$ 377,000**
			Total w/ Construction Upper Bound (+40%), Legal, and Engineering	**$ 703,000**
			Annual Maintenance Cost	**$ 10,000**
			Annual Maintenance Cost Lower Bound (-2%)	**$ 7,500**
			Annual Maintenance Cost Upper Bound (+2%)	**$ 14,100**