Vermillion River Watershed Joint Powers Organization

South Creek Subwatershed Fluvial Geomorphic Assessment Report

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Prepared for:

Vermillion River Watershed Joint Powers Organization
14955 Galaxie Avenue
Apply Valley, MN 55124

inter·fluve inc.
3602 Atwood Avenue, Suite 3
Madison, WI 53714

1. Introduction

In the summer of 2009, the Vermillion River Watershed Joint Powers Organization (VRWJPO) contracted with Inter-Fluve to conduct a fluvial geomorphic assessment of South Creek and its tributaries. The goals of this rapid assessment were to identify grade control points, nick points, accelerated erosion and habitat quality issues, improve understanding of bank stability and identify opportunities for restoration projects addressing geomorphic processes, habitat, and shading. This 2009 assessment also provides a comparison with the 1999 assessment of South Creek, which was completed by the MN DNR as part of the Vermillion River Assessment.

The report that follows is a brief summary of the data collected and outlines general stream conditions by reach for South Creek and its tributaries. This report is supplemented by completed reconnaissance and potential project forms. In 2007 and 2008, Inter-Fluve conducted similar fluvial geomorphic assessments on Sand Creek and the Credit River in Scott County, MN. Portions of the reports for these two assessments (Review of Geomorphology Principles and Management Recommendations) were used, with minor modifications, in this report. Please see the Scott County website for the complete Sand Creek and Credit River reports (http://www.co.scott.mn.us/wps/portal/ShowPage?CSF=1387&CSI=csc015524).

The fluvial geomorphic assessment was conducted in September 2009. During the assessment, 46 potential restoration projects were identified in the South Creek watershed. In order to prioritize these projects for funding allocation, we developed a ranking system for the restoration projects. This ranking system scores potential stream project sites based on 11 metrics (Table 1). Each metric contributes a value of 1 through 7 for the site, and the total of all of the metrics is the potential project score. Each project can be ranked by a single metric or multiple metrics, so priority can be a result of any combination of metrics chosen by the VRWJPO staff.

Table 1: Metrics for scoring potential projects.

Metric Score:	*1*	*3*	*5*	*7*
Infrastructure risk	No risk to infrastructure with no action, or no infrastructure present	Low to moderate infrastructure risk and minimal risk to public safety with no action, or inf. value <$100,000	Infrastructure at moderate but not immediate risk, moderate public safety risk, or infrastructure value <$200,000	Infrastructure at high or immanent risk of failure with no action. Public safety at risk or infrastructure value >$200,000
Erosion/channel stability	Minimal improvement to overall stream stability and function, <250 ft of channel bank	Low to moderate improvement of 250-1000 ft of channel bank	Moderate improvement 1000-2500 ft of channel bank	Significant improvement to overall stream stability and function or >2500 ft
Project complexity	Groundwater and surface water issues, professional specialty design services required, heavy oversight, major earthwork, EAW/EIS permitting	Surface water restoration, engineering plans required, earthwork involved, significant permitting	Moderately complex, no specialty engineering required, minor earthwork, some basic permitting	Elementary solution, shelf design, volunteer and hand labor implementation, no permits
Location	Mouth to lower ¼ of watershed	Lower ¼ to ½ of watershed	½ to upper ¾ of watershed	Upper ¾ to headwaters
Sediment/nutrient loading	No load reduction resulting	Some minor reduction in sediment pollution, increased filtration of nutrients	Moderate reduction in bank erosion and surface runoff entering stream through buffer or other BMPs > 30 ft	Major erosion control through significant BMP installation, stormwater detention, infiltration or buffer filter.
Project cost	> $300K	$201 - $300K	$51 - 200K	$0 - $50K
Aesthetic impact	No impact	Low impact	Moderate positive impact	High positive impact
Fish passage	No impact on fish passage	Low impact (eg. improve depth through culvert, minimal velocity reduction)	Moderate impact (removes perch or other small barrier, natural bottom culvert replacement)	High impact (dam removal)
Public Education	No public education value	Low value - Poor site access, difficult to see, small project	Moderate value - Good access, moderate demonstration value	High value - Easy access, cooperating landowner, good demonstration and high visual impact
In-stream Ecological Benefit	No in-stream ecological benefit	Low benefit - Spot location, small size	Moderate benefit - subreach based, moderate sized project	High benefit - Reach based, >1000 ft of stream
Riparian Ecological Benefit	No riparian ecological benefit	Low benefit - Spot location, small size	Moderate benefit - subreach based, moderate sized project	High benefit - Reach based, large riparian areas, floodplain scale

1.1 Summary of Vermillion River Watershed Standards

The VRWJPO adopted a Watershed Management Plan in 2005 and a set of amended Standards in 2008. The Standards are water quality outcomes that were put in place to guide activities in the Vermillion River watershed and cover six topics:

- Floodplain Alteration
- Wetland Alteration
- Buffers
- Stormwater Management
- Drainage Alteration
- Agriculture

The criteria associated with each of these Standards regulates all new development in the watershed including commercial, residential, and industrial construction, road crossings, drainage systems and river and habitat restoration. Having these Standards in place is extremely important for maintaining high quality aquatic and riparian habitat and improving habitat elsewhere. During our assessment of the South Creek watershed, we observed recently-constructed residential and commercial developments and all of these have stormwater detention basins associated with them to catch and filter runoff before it enters the stream system.

Sufficient riparian buffers are essential for high quality aquatic and riparian habitat, and the VRWJPO developed a classification scheme for waterways and wetlands with associated standards for buffer widths. The largest buffer is provided for the Conservation Corridor Lower and Upper Reaches with 150-ft average, and 100-ft minimum, buffer width. A 100-ft average and 65-ft minimum buffer width is required for Principal Connector channels in an Aquatic Corridor, and if the Principal Connector is a designated trout stream the buffer must be at least 100 ft. A 50-ft average and 35-ft minimum buffer width is required for Tributary Connector in the Aquatic Corridor. Water Quality Corridors require the smallest buffer at 30-ft average and 20-ft minimum widths (VRWJPO, 2008). The portions of South Creek and its tributaries that have continuous flow through most of the year are classified as trout stream Principal Connectors; elsewhere, the channels are principal or tributary connectors (Figure 1).

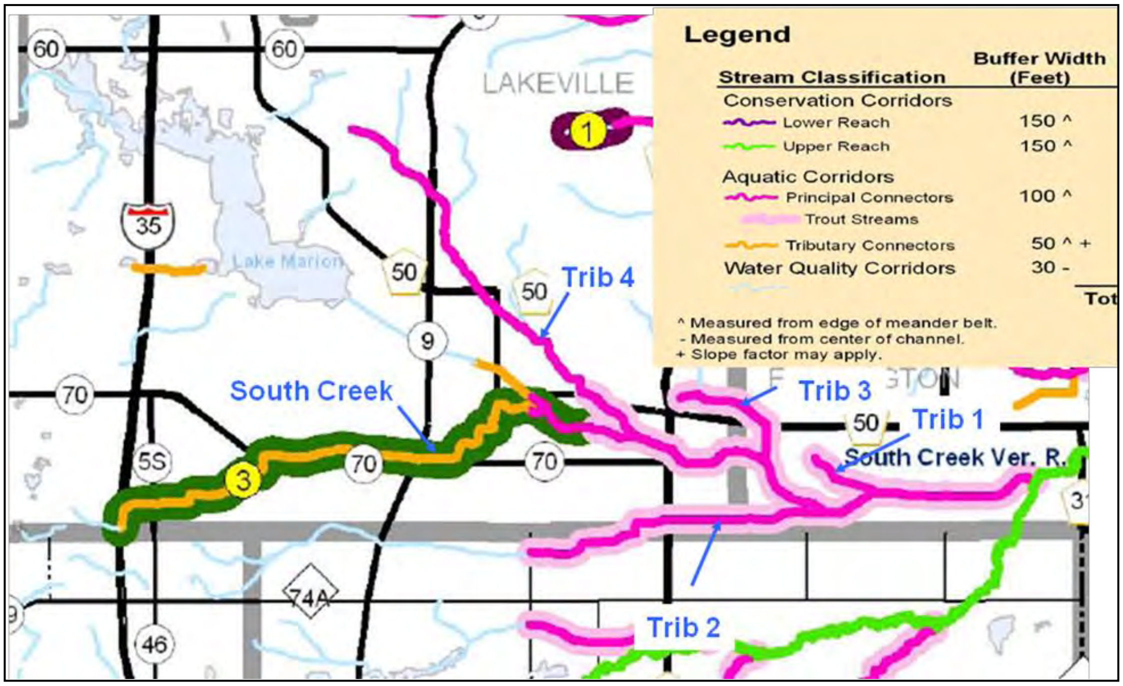

Figure 1: Stream classification and buffer width standards for South Creek and the four tributaries surveyed in this study (modified from VRWJPO, 2006).

1.2 <u>Review of Geomorphology Principles</u>

In order to fully visualize the relationships between habitat formation and stream ecology, it is important to have a basic understanding of fluvial geomorphology. This section discusses the principles behind fluvial processes and how they relate to stream habitat. Stable stream systems are in a delicate balance between the processes of erosion and deposition. Streams are continually moving sediment eroded from the bed and banks in high velocity areas such as the outside of meander bends and around logs and other stream features. In the slow water at the inside of meander bends or in slack water pools, some of this material is deposited. This process of erosion and deposition results in the migration of rivers within their floodplains. The process by which streams meander slowly within the confines of a floodplain is called *dynamic equilibrium* and refers mainly to this balance of sediment erosion and deposition. Streams typically have reaches that fall along the continuum of degradation (eroding) to aggradation (depositing) at any one time in the scale of channel evolution. The location and character of these individual reaches changes over time. When a stream channel is in equilibrium, it may move across the floodplain, erode and deposit sediment, but general planform geometry, cross-sectional shape, and slope remain relatively constant over human lifetimes.

Many factors can influence this equilibrium by altering the input of sediment and the quantity and timing of runoff. These factors include soil types, rooted vegetation that holds soil in place, flashy flows that erode banks, large rainfall events or increased sediment pollution that deposits sand or other fine sediment in the channel. When a channel loses its equilibrium due to changes in flood power and sediment load, it can in turn lose essential habitat features. The fundamental channel shaping variables in balance are slope, discharge (amount of water flow per time), sediment load and sediment size. The balance between the amount/size of sediment and slope/discharge is manifested in complex drainage networks of streams with a specific channel area and slope. Any change in one of the variables can upset this balance, resulting in either aggradation or degradation of the channel.

For example, given that the primary function of streams and rivers is to transport water and sediment downstream, changes in landuse that affect the timing of runoff can affect sediment transport. Clearing of watershed forests, row crop agriculture and urban development cause storm water to reach the stream channel faster, and increase the peak discharge in the stream. Geomorphically, an increase in stream discharge might result in an increase in channel incision or lateral bank erosion, and hence, the amount of sediment being transported downstream. These changes may also result in changes to channel slope. The stream's evolution will persist until it reaches a new dynamic equilibrium between the channel shape, slope, and pattern (Schumm 1984, Leopold et al. 1964).

In a comprehensive geomorphic assessment, the physical attributes of the stream channel are measured to determine its geomorphic stability and the processes and factors responsible for that instability. Parameters typically measured include channel planform and profile, cross-section geometry, slope, watershed landuse, riparian vegetation, soils, and channel erosion.

1.1.1. Channel dimension

The cross-sectional size and shape of a stream are products of evolutionary processes that have, over time, determined what channel size is necessary to accommodate the most frequent floods. Several parameters can be used to determine the effect of channel shape on stream flow, including channel width, depth, width to depth ratio, wetted perimeter (the length of cross-section perimeter contacting water), hydraulic radius (cross-sectional area divided by wetted perimeter), and channel roughness. The bankfull surface is a common measure used to scale cross-section features to allow for comparisons with different sections within the same watershed or in different watersheds. In a natural river in equilibrium, the bankfull surface is at the top of the banks, the point where water begins to spill out onto the floodplain. In rivers not in equilibrium, the bankfull surface can occur elsewhere on the cross-section.

1.1.2. Channel planform

Flowing water is constantly encountering friction from streambed and banks, and the energy of the stream is dissipated through work. This work is manifested mainly as the entrainment or movement of soil and sediment particles. Energy in linear systems such as rivers is dissipated in the manner that minimizes work (the rate of energy loss), the sine wave form. The energy of a straight line is thus dissipated over a lower slope by the formation of sinuosity, or the typical “S” shape of stream channels (Figure 2). The erosion and deposition of sediment balanced by the resistance of particles to erosion causes and maintains this condition. *Sinuosity* can be measured as either the stream slope/valley slope, or the thalweg length/valley length, where the thalweg is the highest energy point (usually approximated by the deepest point) in the stream channel (Leopold 1994).

Figure 2: 2003 aerial photograph showing the sinuous nature of the Minnesota River. Flow is from south to north.

1.1.3. Channel profile

The gradient or slope of a stream channel is directly related to its cross-sectional geometry, soils, and planform geometry. Higher gradient streams in hilly or mountainous areas tend to have a lower sinuosity and dissipate energy over turbulent step-pools of harder substrates whereas low gradient streams such as those common to the Midwest have a higher sinuosity and dissipate energy through lower slopes and regular riffle pool sequences. Degradation of streambeds caused by disturbance is problematic, for unlike lateral bank erosion that tends to be localized, changes in bed elevation can be felt over several miles. Channel incision, or downcutting, generally migrates upstream until a stable gradient is achieved.

1.1.4. Channel stability

As discussed in the above paragraphs, a channel in equilibrium may erode and deposit without being considered unstable. Some erosion in stream channels is normal, and a channel in dynamic equilibrium, balancing erosion with sediment transport, is considered stable. The stability of channel planform and profile are dependent on many factors, including soils, roughness, slope, and disturbance. The *vertical stability* of a channel refers to the state of incision or aggradation of the streambed.

Vertical instability often follows a certain pattern whereby changes in the bed elevation of a stream are translated upstream through a series of small vertical drops called *knickpoints* or *headcuts*. This situation can arise from the straightening of streams and an associated decrease in channel length or by direct changes in the bed elevation of a stream (eg. improper road crossing installation or decreased bed elevation in a main channel). This process of downcutting is called *incision*. A

Figure 3: A headcut and incised channel on a small stream in Scott County.

waterfall would be an extreme example of a knickpoint in bedrock. As a headcut moves upstream, the stream becomes more incised and the flood energy increases as more and more volume is confined to an incised or *entrenched* channel (Figure 3). Whereas prior to incision, the stream was able to dissipate its energy over a wide floodplain, after incision this energy is concentrated. Following incision, the stream typically begins to erode laterally with the end result being new floodplain formation at a lower grade. The Schumm channel evolution model demonstrates how a headcut creates an incised channel that becomes laterally unstable and eventually forms a new stable channel at a lower elevation (Figure 4).

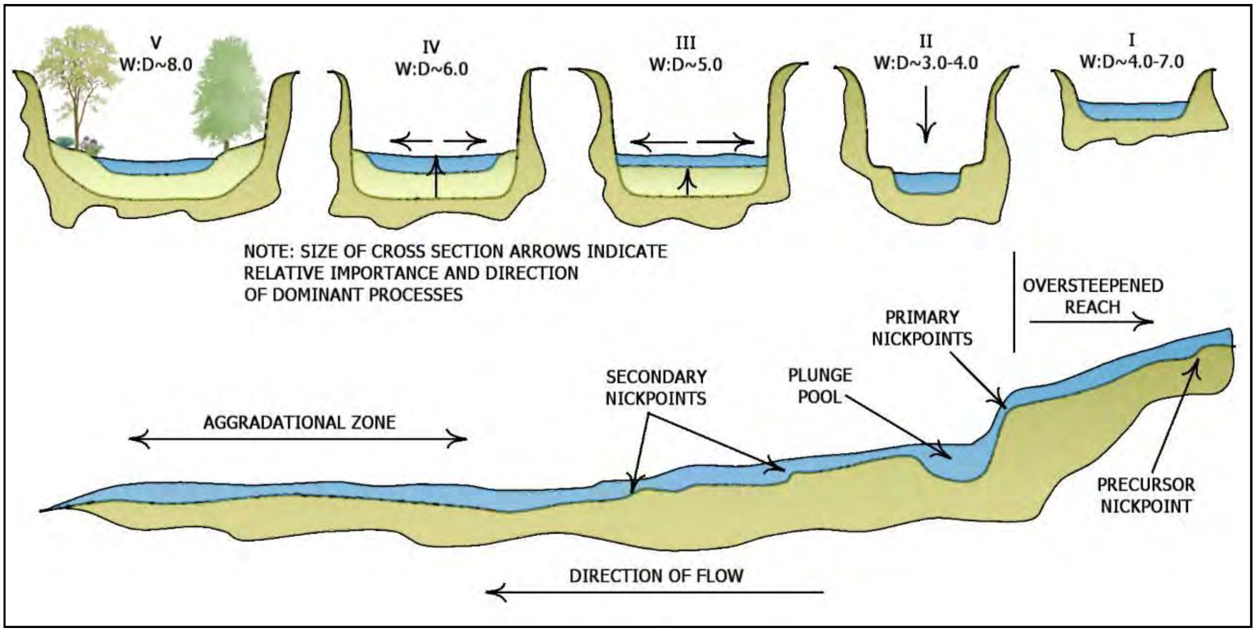

Figure 4: The Schumm channel evolution model (modified from Schumm, 1984).

Channels in equilibrium provide structure and complexity to support habitat for aquatic species. When a channel becomes unstable, aquatic species have a difficult time adjusting to rapidly changing conditions. Erosion and incision can remove habitat features, and deposition can fill pools and cover spawning gravels.

In a reconnaissance-level fluvial geomorphic assessment, a stream is examined for signs of channel instability such as active headcuts, bank erosion and channel scour, bed sediment type and stability, type, age and stability of bank and bar vegetation, algae, macrophyte and macroinvertebrate populations, type and sorting of various depositional features, floodplain deposition, type and consolidation of floodplain soils, and bank erodibility.

1.1.5. Sediment transport

One of the most common misconceptions about streams is that erosion is inherently bad. As discussed above, the dynamic equilibrium of streams involves the opposing forces of erosion and deposition, and this process is normal when equilibrium is maintained. As streams flow, particularly during rainfall or snowmelt events, they entrain particles from the channel bottom and banks. Particles small enough to become suspended in the water column are called *washload*, while particles that move along the channel bottom are called *bedload*. Together, these components make up the sediment transported in the channel. When this balance of erosion and deposition is upset by changing landuse, streams respond in various ways depending on the change. For instance, after clear cut logging, runoff from rainfall reaches the stream faster and the erosive power of a stream can increase, causing excessive incision and/or bank erosion in some areas. As that sediment moves downstream, it will eventually come to areas of low gradient and will be dropped out of the water column. Thus streams can erode excessively in some areas and deposit excess sediment in other areas of the same system. Both consequences of a disturbed sediment equilibrium can have detrimental effects on fish and wildlife habitat.

2. Data Collection / Methods

2.1 Existing Data

Inter-Fluve personnel collected and analyzed existing information about the South Creek Watershed, including aerial photographs, plat maps, and geologic maps. The 1999 Vermillion River Assessment was reviewed and all descriptions of South Creek and its tributaries were noted. Additionally, staff analyzed aerial photographs in a GIS to determine reach breaks based on land use and changes in valley form, soils, profile, planform, and road crossings.

The first land surveys in Dakota County resulted in plat maps from 1855. These maps indicate an active sinuous channel in the current location of South Creek from the Vermillion River to between Flagstaff Avenue and Cedar Avenue (Figure 5). There is no record of the channel continuing upstream in the watershed and no record of tributaries that are currently active in the South Creek watershed (Figure 1). There is a small wetland indicated on the map in the approximate location of the upstream portion of Tributary 1; there is currently an active pumpkin farm at this location and no indication of a wetland (Appendix A and B). These maps are not comprehensive and are not exact representations of the conditions in 1855, but they do offer insight into the likely planform of South Creek and conditions in the watershed. In 1855, South Creek was a relatively short creek that was very sinuous. There were no major wetland areas located in the watershed and there was not enough water to warrant mapping tributaries if they were present.

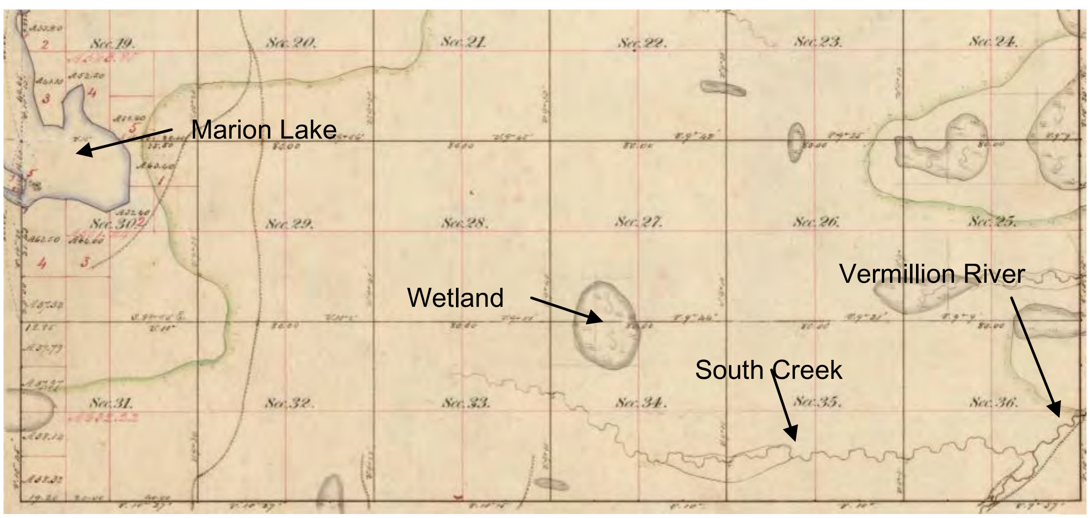

Figure 5: 1855 plat map showing South Creek flowing into the Vermillion River.

Most of the watershed is in the Lower Ordovician, Prairie Du Chien Group, though most of Tributary 4 is in the Middle Ordovician, St. Peter Sandstone Group. The Prairie Du Chien Group is a dolostone and is thin bedded and sandy. The dolostone may be karsted in some areas, which may have some impact on the disappearance of surface water in South Creek west of Hamburg Avenue. The St. Peter Sandstone is generally thick bedded with fine to medium-grained quartzose sandstone.

The surficial geology of the South Creek watershed is composed of floodplain alluvium and mixed outwash. The floodplain alluvium is located along South Creek in approximately the same location as the indicated channel on the 1855 plat maps. The floodplain alluvium is generally poorly bedded, moderately well sorted sand. The mixed outwash is sand, loamy sand and gravel from the Des Moines Lobe outwash deposits. This outwash is located along the remainder of South Creek and along all of the tributaries.

2.2 Fluvial Geomorphology

Inter-Fluve geomorphologists walked the lengths of South Creek and its tributaries. South Creek is 9 miles in length and there are about 10.8 miles of tributaries that were investigated. Information on soils, streamflow, stream bed grain size, observed aquatic biota, fish passage barriers, infrastructure, landuse, and vegetation was noted for each reach on reconnaissance forms. Digital photographs were also taken at many locations along each reach, at all road crossings, of all culverts, and of all potential restoration projects.

The reconnaissance form was developed by Inter-Fluve scientists and includes information on general channel and fluvial geomorphic conditions, sediment composition, depositional features, riparian vegetation and floodplain morphology, aquatic habitat structures, channel stability, channel geometry, and human impacts on the channel and floodplain. A sketch of a cross-section at a location typical for the reach is provided as well as a brief summary of conditions and a list of potential restoration projects.

2.3 Project Identification

Potential projects were identified in the field and evaluated and ranked based on 11 metrics. In this system, metrics refer mainly to the degree that a completed project will affect each metric. For example, an infrastructure risk score of 1 reflects that if nothing is done, there will still be no risk to infrastructure from channel instability, either because no infrastructure exists at the site or risk is extremely low. Conversely, a score of 7 indicates that if nothing is done, public safety and property are under immanent risk. This assessment included an evaluation of all culverts and road crossings for corrosion or decay as well as for their effect on local hydrology and habitat. Other metrics gauge the effect of potential projects on channel stability, ecological benefit, nutrient loading and fish passage. Because of the interconnectivity of river systems, Inter-Fluve believes strongly that watershed restoration and management should focus on the headwaters and move in a downstream direction. To incorporate this science into the project ranking, we have ranked headwaters projects higher, and scores for this metric decrease with distance from the headwaters.

Potentially expensive projects are scored lower, and more complicated larger projects score lower as well. Sediment and nutrient loading, erosion control and public education metrics are reflective of project size, and thus the ranking system allows for some cost versus benefit analysis. A relatively inexpensive project that can restore a large area or length of stream with manageable design and permitting will score among the highest under this system. The VRWJPO should use this ranking as a guide to determine which projects to focus on that accomplish their goals and objectives and stay within the available budget.

3. 1999 Vermillion River Assessment

In 1999, the Minnesota Department of Natural Resources conducted an assessment of the Vermillion River watershed, which includes South Creek and its tributaries. Two reaches of South Creek and three reaches of its tributaries were included in that report (VRWMC and MN DNR, 1999). All of those reaches had been straightened and channelized or ditched. Due to the straightening, all reaches had sinuosity values very close to 1. Channel stability scores ranged from fair to good, and bank erodability was generally moderate. The straightening and lack of woody riparian vegetation are cited as reasons for bank erosion.

The riparian vegetation along one reach of South Creek was woody, but grasses, forbs, and young shrubs dominated most of the banks that were surveyed. Reed canary grass was a common grass, ragweed and goldenrod were noted forbs, and woody vegetation consisted of willows, box elders, cottonwood, and oak.

A limited number of species typical of cold water streams were found in South Creek or its tributaries. Three of the five reaches did contain brown trout, but most of the habitat was less than optimal for adult trout. The dominant substrates were sand and gravel, and lack of woody debris or a source of woody debris was a concern in three reaches. One reach of a tributary of South Creek only ran intermittently and does not provide fish or aquatic invertebrate habitat.

4. Existing Conditions

Inter-Fluve geomorphologists conducted a rapid geomorphic assessment of the South Creek watershed in Dakota County. Channels were divided into reaches based on channel planform and adjacent land use. Twenty miles of channel in the watershed were divided into 16 reaches (Appendix A). The average reach length was 1.25 miles, but reaches ranged from 0.50 miles to 2.75 miles in length (Table 2). This assessment included many road crossings, and all culverts were evaluated.

Table 2: Length of reaches in South Creek and its tributaries.

Reach	Length (miles)	Distance from Mouth (miles)	Tributary (Reach)	South Creek Station at Confluence (ft/miles)	Length (miles)	Distance from Mouth (miles)
1	1.66	0	Tributary 1 (1)	6600/1.25	0.70	0
2	0.98	1.66	Tributary 2 (1)	8750/1.66	1.16	0
3	1.06	2.63	Tributary 2 (2)	--	1.21	1.16
4	0.51	3.69	Tributary 2 (3)	--	2.78	2.37
5	0.97	4.20	**Tributary 2 Total**	**--**	**5.15**	**5.15**
6	0.63	5.17	Tributary 3 (1)	12000/2.27	0.83	0
7	2.42	5.80	Tributary 3 (2)	--	0.64	0.83
8	0.81	8.22	**Tributary 3 Total**	**--**	**1.48**	**1.48**
Total	**9.03**	**9.03**	Tributary 4 (1)	19600/3.71	1.36	0
			Tributary 4 (2)	--	2.14	1.36
			Tributary 4 Total	**--**	**3.50**	**3.50**
			Total		**10.83**	

4.1. South Creek

The 9 miles of South Creek was divided into eight reaches. The average reach length was 1.1 miles, but reach lengths ranged from 0.5 miles to 2.4 miles. South Creek is primarily straightened and ditched through agricultural fields, industrial and commercial complexes, and housing developments, which has impacted its geomorphology, channel stability, riparian zone, and habitat.

Straightening and ditching South Creek has resulted in a lack of channel complexity and, thus, aquatic habitat. Native riparian vegetation only occurs in a few locations along the channel. Sections of reaches 3, 6, and 7 have been restored, but reed canary grass has re-invaded. Large populations of this invasive grass were observed throughout the watershed, and the grass is overhanging the channel in many places, including the restored sections.

In several instances, channel connectivity is interrupted, but this is most significant in reach 5 where the channel is ephemeral. Downstream of reach 5, the primary water source is drainage from downtown Lakeville that flows through a long pipe to South Creek.

4.1.1 South Creek, Reach 1

Figure 6: South Creek, Reach 1, station 5150, looking downstream.

Reach 1 of South Creek extends 8,750 feet from the confluence of South Creek and the Vermillion River to the confluence of South Creek and Tributary 2. Reach 1 is primarily a straightened ditch through farm fields with little riparian vegetation (Figure 6). The channel in this reach has a bankfull width of 10-12 ft, and there is little or no floodplain through most of the reach. This reach has minimal bank erosion, but many of the banks are slightly undercut. Channel substrate is predominantly sand and small gravel. The channel has adjusted to its current planform, however, and the overhanging grasses and undercut banks provide up to 50% in-stream cover. There is a 30-ft buffer between the channel and row crops composed primarily of grasses, especially reed canary grass. Woody vegetation such as willow, cottonwood, and buckthorn occur in some locations. The water is cool to the touch, even on hot days in September. One large (1.3 ft) dead trout was seen at Station 4700 and other smaller live fish were seen elsewhere. In general, the in-stream habitat in this reach is fair, but there is little riparian habitat.

This reach basically corresponds to Segment 24 of the 1999 Vermillion River report (South Creek from the confluence of the Vermillion River to Flagstaff Ave.). Our study confirms many of the earlier findings and little has changed through the reach. There is still no sinuosity and little native riparian vegetation. The only portion with a wide floodplain and secondary growth riparian vegetation is just upstream of the Reach 1 boundary to Flagstaff Ave. The portion of Segment 24 that was studied in detail in 1999 was the area with a wide riparian corridor immediately downstream from Flagstaff Ave, so the assessment of stream stability are not representative of the straightened ditch with no riparian vegetation prevalent elsewhere.

Recommendations for management in reach 1 include increasing sinuosity along the entire reach. Between stations 1000-3000 and 4500 and 8300, creating a native riparian buffer with native forbs, grasses, shrubs and trees would improve riparian and in-stream habitat. At station 4600, a corrugated metal pipe on the left bank is perched above the bed and causing bank erosion and a scour pool. The corrugated metal pipes running beneath a dirt driveway at station 5150 are in good condition but are restricting flood flows. Woody debris is caught between the culverts and passage during high flows is likely difficult for fish species.

4.1.2 South Creek, Reach 2

Reach 2 of South Creek begins where South Creek and Tributary 2 diverge at station 8750, and it continues 5150 feet to station 13900. Reach 2 is primarily a straightened ditch through farm fields with little riparian vegetation. There is little or no floodplain through most of the reach, minimal bank erosion and very little variation in the sandy substrate. The channel has adjusted to its current planform, however, and the overhanging grasses and undercut banks provide up to 80% in-stream cover. The water temperature was cool, even on hot days in September.

Figure 7: South Creek, Reach 2, station 8800, looking upstream. Downstream from Flagstaff Ave.

Figure 8: South Creek, Reach 2, station 10700, looking upstream. Upstream from Flagstaff Ave.

There are several differences between the sections of the reach that are downstream and upstream of station 9500/Flagstaff Ave. Downstream from the Flagstaff Ave crossing, minor channel migration and channel widening is occurring with bank erosion apparent on both channel banks (Figure 7). The bankfull width in this section is 25-30 ft, and the floodplain extends for about 30 ft on each side of the channel. Large woody debris provides some habitat complexity, though there is little overhanging vegetation, undercut banks, or substrate variability. Minor riffle-pool sequences add additional channel complexity. Upstream of the Flagstaff Ave crossing, the bankfull width is only 8 ft. There is little to no floodplain, large woody debris, canopy cover or channel complexity (Figure 8). Reed canary grass and aquatic vegetation provide nearly 100% in-stream cover. Residual pools are deep, and undercut banks provide additional cover. The channel does migrate slightly within the confined high banks of the ditch. There is no riparian buffer (or less than 10 ft) between row crops or mowed grass and the channel.

Recommendations for management focus on the section of reach 2 that is between stations 9500 and 14000. These recommendations include increasing sinuosity and channel complexity and creating a native riparian buffer. At station 13100, a vehicle crossing has resulted in some bank erosion and sedimentation.

4.1.3 South Creek, Reach 3

Reach 3 of South Creek is a recently restored reach between stations 13900 and 19500. The channel has a bankfull width of 8-10 ft, and the floodplain is about 50 ft wide. The channel is highly sinuous and uniform in planform. Channel bends and riffles between pools provide increased channel complexity compared to unrestored reaches. The banks are stable, though there is some minor erosion on the upstream side of a few logs, stumps and boulders placed on the outside of bends for erosion control and habitat complexity. The restoration efforts have improved habitat potential (Figure 9), but there is little substrate variability. Cover in this reach is provided by overhanging reed canary grass and the pieces of large woody debris

Figure 9: South Creek, Reach 3, station 14200, looking upstream; boulders and rootwads on outside of bend in pool.

(LWD) near the banks. The native vegetation species planted include goldenrods, asters, willows, and cottonwoods. However, reed canary grass has become established because of the large seed bank upstream and adjacent to the restored reach. In the straighter, narrower portions of the stream, the reed canary grass overhangs and covers 95-100% of the channel (Figure 10). Where willows are growing close together and close to the channel, the impact of reed canary grass is less. As the riparian vegetation matures and the shrubs and trees provide additional cover, reed canary grass will likely become less pervasive. Where shade trees and taller shrubs are not located, the invasive grass may outcompete the native species. Evidence of beaver is very apparent with a lodge, small dams, and cut willows.

Figure 10: South Creek, Reach 3, station 15800, looking upstream; reed canary grass choking the channel.

The portion of this reach downstream from Cedar Ave. corresponds to Segment 39 of the 1999 Vermillion River Assessment. The restoration efforts have improved the channel complexity and habitat quality throughout this reach that was described as straightened and ditched in 1999 (VRWMC and MN DNR, 1999). The reach was formerly dominated by reed canary grass with no mature tree cover. Currently, reed canary grass is prevalent and threatens to overwhelm the newly planted native riparian vegetation. However, if the planted willows and cottonwoods and other shade trees are able to grow and proliferate, the shade may result in decreased coverage by reed canary grass.

Managing the reed canary grass in this reach will help the existing restoration fulfill its potential. Additionally, two petroleum pipes and one fiber optic line cross the channel at or below water line. The location of utility pipes in the channel may be a safety hazard and may be, or have the potential to be, negatively impacting water flow and water quality.

4.1.4 South Creek, Reach 4

Reach 4 of South Creek is between stations 19500 and 22200. The channel in Reach 4 has been straightened and ditched with about 2 ft of historic incision. Most of the channel has a bankfull width between 8 and 12 ft. The channel is currently stable and has adjusted to its current planform. Tributary 4 joins South Creek at the downstream extent of Reach 4 in an area with a wide floodplain and mature riparian vegetation. The two short stretches with mature riparian vegetation (stations 19500 to 19800 and 20000 to 20200) maintain wider channels, active channel migration, 70-80% canopy cover, large woody debris, and channel complexity. The habitat in these stretches is relatively complex with pools, scour pools, and riffles (Figure 11). There is little substrate variation, however, with sand and gravel in the riffles and some fine sediment along with sand in the pools. The woody debris creates extensive in-stream cover.

Figure 11: South Creek, Reach 4, station 20200, looking downstream.

Figure 12: South Creek, Reach 4, station 20550, looking upstream.

Elsewhere downstream of station 21000 (Hamburg Ave crossing) the channel is narrow with vertical banks, reed canary grass overhangs most of the channel, the floodplain is narrow or non-existent and there is no canopy cover (Figure 12). There are some undercut banks and overhanging grasses that create in-stream cover. Upstream of station 21000, algae coated the water surface in pools and thick fine sediment covered the channel bed. When this sediment was disturbed, a gaseous and putrid odor was observed emanating from the water. Three grade control structures occur between the pools to prevent further incision or headcutting. These structures would likely not present passage problems to trout but may deter passage of other species. Even if passage was possible, there is little habitat available upstream as the natural channel is dry and the source of water comes through a long pipe from city runoff. Upstream of station 21000, the channel flows through a small wetland with cattails and reed canary grass. The floodplain in this meadow reaches 30 to 50 ft in width.

Figure 13: South Creek, Reach 4, station 22100, looking upstream. Main channel is on the left side of the figure, but the main water source is from city drainage through the pipe on the right.

The channel splits at the upstream end of reach 4 at station 22200. A 4-ft high levee crosses the channel at this location and blocks all fish passage. This levee is covered with 1-ft^2 concrete tiling and was constructed more the 20 years ago to prevent further headcutting of the channel. At the time of this assessment, the channel upstream of this levee was dry until station 24200. Downstream, water flowed to the main channel from a side channel on river left and this channel was fed by water draining the city of Lakeville through a large pipe (Figure 13).

Along this entire reach, the channel could be made more sinuous and the native riparian buffer increased. At station 19650, there is gully erosion on the right bank, which should be stabilized and vegetated.

4.1.5 South Creek, Reach 5

Figure 14: South Creek, Reach 5, station 23600, looking upstream at dry channel and open field.

The channel in Reach 5 is a manipulated channel between stations 22200 and 27300 with little habitat potential. The channel has been straightened and ditched throughout the reach. At the time of the survey, surface water in the channel disappeared at station 24200 and the channel between stations 24200 and 22200 was completely dry through an open field (Figure 14). A 4-ft levee and concrete tiles separate this dry channel from the channel downstream at station 22200 (Figure 15). The source of the water downstream is runoff from the city of Lakeville and flows through a 6-ft concrete pipe just to the left of the main channel at station 22200. Upstream of station 24200, existing water is in stagnant pools with minimal flow between. The channel is narrow, 6-8 ft, with little riparian vegetation except in a few short stretches. Between stations 24500 and 25400, the grass is mowed to within about 10 ft of the channel. Between stations 26650 and 27300, the channel is narrow and elevated above the level of the pond. In this stretch, the channel is bounded by about 4-ft levees. Overall, there is little channel or habitat complexity. A small cobble/boulder check dam acts as a grade control at station 26650.

Figure 15: South Creek, Reach 5, station 22200, looking downstream with the levee and tiling in the foreground.

Many management projects would improve reach 5. Removal of the tiled levee across the channel at station 22200 would improve fish passage and channel connectivity. A fish-friendly grade control could be built to replace the levee. Increasing the sinuosity and native riparian vegetation throughout this reach will improve channel and habitat complexity. Because there is little room for restoration between station 24500 and 26700, the straightened channel could be changed to a more sinuous channel but still kept within the confines of the narrow valley walls.

4.1.6 South Creek, Reach 6

Reach 6, extending from station 27300 to 30600, is a restored reach with a highly sinuous planform (Figure 16). The tight bends in the channel are connected by narrower channels (6-8 ft bankfull width) with sand and gravel riffles. These riffles do not have any large gravel or cobbles for habitat, but the water depth is lower and these act as grade controls. The pools on the outside bends are deeper and contain about a foot of deposited fines on the bed. The banks here are stabilized by placed boulders and root wads and logs. Some of these have some erosion on the upstream end, but flows in this

Figure 16: South Creek, Reach 6, station 28600, looking upstream at sinuous channel.

reach never appear to be high enough to cause excessive erosion. The planted riparian vegetation is apparent, but only a few willows appear to have survived invasion by reed canary grass and smooth brome grass. Reed canary grass overhangs the channel, especially in the riffles between bends where it covers nearly 100% of the channel.

Management projects for this reach include managing the reed canary grass and increasing native riparian vegetation.

4.1.7 South Creek, Reach 7

Reach 7 is a straightened ditch with variable channel geometry, floodplain width, and habitat availability. This reach extends from station 30600 to 43400, and conditions change frequently along the reach. Between stations 30600 and 32100, the channel is narrow (4 ft) with low banks and flows through the backyards of multiple landowners. Many landowners have mowed to the channel edge, manage gardens on the floodplain, and have placed small footbridges and cobble check dams across the channel (Figure 17). Where the floodplain is not mowed to channel edge, there is about 10% canopy cover and 30% in-stream cover from overhanging reed canary grass. The channel is mostly glides and pools with sand and small gravel, but there are some larger gravels and cobbles creating riffles upstream.

Figure 17: South Creek, Reach 7, station 31200, looking upstream at small check dam and mowed riparian area.

Between station 32100 and 33000, the channel is wider (8 ft) and is entrenched within 4-8 ft banks. There is about 40% canopy cover and much of the channel is covered by overhanging reed canary grass. Between stations 32600 and

Figure 18: South Creek, Reach 7, station 32700, looking upstream at erosion around boulder grade control and fabric on banks.

33000, restoration of the channel is on-going. The channel is sinuous within the high banks, and riffles of small gravel have been regularly placed. Between the small riffles, the pools are filled with more than one foot of fine grained material. Fabric is visible on the channel banks but erosion continues where the banks are steep and vegetation has not become established. There are a few cobble and boulder grade controls attached to the banks; excessive erosion has caused some of these structures to unravel, especially at station 32700 (Figure 18). Planted native riparian vegetation was noticeable, but reed canary grass is also abundant. The restoration in this section is not complete and it is likely some of the erosion and vegetation problems will be fixed during future stages of the project.

Figure 19: South Creek, Reach 7, station 41200, looking downstream.

Between stations 33000 and 34900, the channel is less entrenched, but there is little riparian vegetation. There are gardens on the floodplains, and some landowners have mowed close to the channel edge. Between station 34900 and 38300, the channel is generally incised 2-3 ft with some bank erosion. There is about 80% canopy cover and good quality in-stream cover with the multiple log jams and large woody debris. A large cobble riffle was built at station 37100, likely for grade control. This 15-ft long riffle/cascade is probably a passage barrier, but it has stemmed some incision upstream and created an upstream pool as well. We were not granted landowner permission to assess the channel between stations 38400 and 40500.

Between stations 40500 and 41700, the channel is generally incised about 2 ft and is 6 ft in width. It meanders slightly within a densely-forested riparian corridor (Figure 19). Box elder and buckthorn are the dominant vegetation. Large and small woody debris are in the channel (approximately 5 pieces per 100 ft). Bed material is variable with mostly sand and small gravel, but larger gravel and cobbles create riffles. At station 41700, four willow trees 12-20 inches in diameter are growing in the channel near the right bank. Their roots, along with those of two box elders have grown across the channel and are preventing further upstream incision and migration of a headcut (Figure 20). The water in the channel currently flows over the roots into a small pool and then down a cobble and gravel riffle.

Figure 20: South Creek, Reach 7, station 41750, looking upstream at roots preventing further incision.

The culvert at station 42100 is partially buried but undersized. It has created a large backwater and wetland area. The channel upstream of this culvert to station 42600 is about 15 ft wide, up to 3-4 ft deep and covered in duckweed (Figure 21). There is a cobble riffle at station 42600, and the channel narrows upstream from this point. Woody debris and tree roots growing through the channel creates a degree of grade control that has prevented further incision. The riparian corridor between stations 42100 and 43400 is about 50-100 ft wide with mature willows (12-20 inches diameter at breast height (DBH)) and cottonwoods (20-30 inches DBH). At the time of the survey, the channel was dry upstream of station 42900.

Figure 21: South Creek, Reach 7, station 42300, looking downstream at backwatered pool.

Restoration in this reach should focus on the construction sinuous channels and the planting of native vegetation to increase the riparian buffer. Wetlands could be created where there is available space. These wetlands would provide storage in this low-gradient reach as well as habitat variability. The continuous water flow moving through these wetlands and the planted native wetland vegetation would prevent the water temperature from increasing before flowing downstream. An established buffer where landowners have mowed to the channel edge would increase canopy and instream cover and habitat potential. Additionally, some of the culverts and corrugated metal pipes are damaged and/or undersized and need replacement.

4.1.8 South Creek, Reach 8

Figure 22: South Creek, Reach 8, station 43950, looking upstream at field with dry channel.

Reach 8, between stations 43400 and 47700, contains the headwaters of South Creek. There is no viable in-stream habitat because there is no distinct channel through much of the reach, and there is no water through much of the year (Figure 22). Where the channel is evident, it is stable with no apparent incision or aggradation. The banks are less than 1ft tall and composed of sand and small gravel. Elsewhere, the channel is in the form of a shallow swale. Downstream from HWY 35, the riparian area is dominated by reed canary grass; upstream from HWY 35, there is canopy cover along a narrow riparian corridor.

We do not recommend any restoration projects in this reach because of the lack of a defined channel and water for most of the year.

4.2 South Creek Unnamed Tributary 1

Figure 23: Tributary 1, Reach 1, station 150, looking downstream.

Tributary 1 is an ephemeral stream that has been historically straightened and ditched through much of its length. It is made up of one reach that extends 3700 feet (0.7 miles) and meets South Creek at station 6600. Tributary 1 is a rectangular or trapezoidal ditch with a 4-ft bankfull width from the mouth to about station 900 and from about station 2500 to 3100 (Figure 23). Elsewhere, the channel is a barely detectable swale in the middle of, or between, row crops. There is little habitat available in this reach. A few residual pools were located near the confluence with the main stem. Overhanging grasses provided the only cover. Habitat could be improved near the mouth of the tributary to attract fish and other aquatic species. Increased sinuosity and riparian vegetation would improve this alcove habitat.

4.3 South Creek Unnamed Tributary 2

Tributary 2 is the longest of South Creek's tributaries (5.15 miles) and flows into South Creek at station 8750 of the main stem. Tributary 2 is primarily a straightened ditch with about 2 ft of historic incision. The channel only contains water during portions of the year, so there is not year-round, viable in-stream habitat. During the time of the survey, the channel was dry upstream of station 5100. The portion of reach 1 that is downstream of station 1100 and flows into the main stem of South Creek has the most canopy cover and habitat complexity. As the canopy cover disappears upstream, the channel is nearly 100% covered with overhanging reed canary grass. The channel is narrow in reaches 2 and 3, which have been straightened and contain very little native riparian vegetation. The channel rarely has water in these two reaches.

4.3.1 South Creek, Unnamed Tributary 2, Reach 1

Reach 1 of Tributary 2 flows 6100 feet from Cedar Ave to station 8750 of South Creek. Downstream of station 1100, the channel has a bankfull width of 6-10 ft and a 20-50 ft floodplain. There is good in-stream and riparian habitat with large and small woody debris creating cover and habitat complexity (Figure 24). Riparian vegetation, such as box elder, willow, and cottonwood also creates canopy cover in this section, and active channel migration creates some channel complexity. This short section of channel is mostly comprised of pools and glides, but there are a few small gravel riffles.

Figure 24: Tributary 2, Reach 1, station 600, looking downstream at active channel.

Upstream of station 1100, there is little canopy cover, and the narrow, 2-ft wide, channel is generally covered with overhanging reed canary grass (Figure 25). The floodplain is much smaller in this section, sometimes only 2-5 ft wide. Channel banks are vertical and although there is some channel sinuosity within the high walls of the ditch, there is no large-scale channel migration. Water flow from tiling and farm ditches increases downstream flow at station 3400, but the general lack of continuous flow negates most of Tributary 2 as a viable source of habitat. The culverts, riprap, and concrete wall at station 6000 are a complete passage barrier to all in-stream aquatic species (Figure 26). The hydrology in this area should be studied to determine if restoration projects are worthwhile.

Figure 25: Tributary 2, Reach 1, station 1200, looking upstream at straightened channel.

If space is available, increasing the sinuosity of the stream upstream from Flagstaff Ave. would greatly improve channel and habitat complexity. Alternatively, the creation of a wetland containing sinuous channels would also provide improved channel and habitat complexity in addition to water storage. The riprap and concrete wall at stations 6000-6100 should be investigated to determine if they can be altered to allow passage. This should only be done if the channel is restored, water storage is possible and more continuous water flow is available in this reach.

Figure 26: Tributary 2, Reach 1, station 6100 looking at riprap dam and pool downstream from culvert (top) and at concrete wall and riprap upstream from the culvert (bottom).

Reach 1 includes Segments 25 and 26 that were studied in the 1999 Vermillion River Assessment. Little has changed since the earlier assessment. The channel is still straightened and there is still little native riparian vegetation and little in-stream habitat.

4.3.2 South Creek, Unnamed Tributary 2, Reach 2

Figure 27: Tributary 2, Reach 2, station 11500, looking downstream at channel between runways.

Reach 2 of Tributary 2 is primarily a straightened ditch that rarely contains water. It extends from station 6100 to 12500, and about half of this reach runs through the Airlake Airport (Figure 27). An airport staff member escorted us across the runways to the channel and said he remembers water being in the channel only a few times in the many years he has worked at the airport. The dry channel has a bankfull width of 2 ft and reed canary grass is pervasive in and near the channel. Although the entire reach needs to be restored, we do not recommend any restoration projects because of the airport and the need to keep vegetation height and bird populations low.

This reach contains Segment 38 that was analyzed during the 1999 Vermillion River Assessment. Nothing has changed since this earlier assessment, which described the segment as dry, stable, narrow bankfull width, and dominated by reed canary grass.

4.3.3 South Creek, Unnamed Tributary 2, Reach 3

Figure 28: Tributary 2, Reach 3, station 12500, looking upstream at dry channel between row crops.

Reach 3 of Tributary 2, from stations 12500 to 27200, is primarily a straightened ditch that only rarely contains water. The ditch is only 2 ft wide at most locations and is covered with overhanging reed canary grass. It flows through row crops planted within 20-40 ft of the channel (Figure 28). Between stations 17800 and 18300, the grass is mowed to the channel edge and along the channel bed as the channel flows through a Frisbee golf course (Figure 29). At stations

17600-17800, the golf course owners have created a pond with an overgrown outflow channel and a 2-ft corrugated metal pipe inlet. There is no viable in-stream or riparian habitat in this reach as there is no water for most of the year. Upstream of this reach, there is some wetland habitat.

Figure 29: Tributary 2, Reach 3, station 18100, looking downstream at dry channel and mowed lawn in Frisbee golf course.

Creating wetland habitat throughout this reach would improve the storage capacity and improve wetland and channel habitat. Although the stream will likely remain ephemeral, viable habitat would remain for longer portions of the year. Narrow wetlands could be created within the current riparian width if wider wetlands were not possible.

4.4. South Creek Unnamed Tributary 3

Tributary 3 has two reaches and is 1.5 miles in length. It meets South Creek at station 12000. Reach 1 of Tributary 3 flows through agricultural fields, has little to no aquatic or riparian habitat, and is ephemeral. Reach 2 flows through housing developments, where, when the grass is not mowed to the channel edge, some native riparian trees do provide canopy cover. A berm halfway through reach 2 restricts migration of aquatic species but creates wetland habitat.

4.4.1 South Creek, Unnamed Tributary 3, Reach 1

Reach 1 of Tributary 3, extending from station 0 to 4400, is a straightened ditch with little to no habitat. The 2-ft wide channel has a 10-ft floodplain and is surrounded by row crops and covered with overhanging reed canary grass

Figure 30: Tributary 3, Reach 1, station 2100, looking upstream.

(Figure 30). The banks are steep and composed of sand. There is no channel or habitat complexity, no canopy cover, no substrate variability. Tributary 3 is an ephemeral stream that needs increased sinuosity and complexity and a riparian buffer to improve in-stream and riparian habitat.

4.4.2 South Creek, Unnamed Tributary 3, Reach 2

Reach 2 of Tributary 3, from station 4400 to 7800, flows through a residential mobile home development and a newer development with large houses and lawns. The channel is straightened throughout and has been manipulated. Downstream from station 5600, the channel has low banks and good canopy cover with willow, cottonwood, box elder, and silver maple. The channel has a 3-4 ft bankfull width and has some channel complexity. Lawns are mowed to the channel edge in some locations, but this area is generally in good condition. Between stations 5600 and 7200 are two wetlands, which are separated by a road crossing at station 6600. A berm of riprap just upstream of the culvert at station 6600 creates a backwater and additional wetland habitat. The two wetlands are not connected because of this berm, through which only water can flow. The wetlands are in good condition, though, and contain many wetland plant species (Figure 31). Upstream of station 7200, the channel is ditched and covered with overhanging reed canary grass.

Figure 31: Tributary 3, Reach 2, station 7200, looking downstream towards wetlands in residential development.

Management projects could include increasing sinuosity and channel complexity between stations 4400 and 5600 and increasing the riparian buffer between stations 4800 and 5300.

4.5 South Creek Unnamed Tributary 4

Tributary four measured 3.5 miles and meets the main stem of South Creek at station 19600. Tributary 4 is ephemeral, and water was not in much of the channel at the time of this survey. Reach 1 is a straightened ditch through fields and developments with little aquatic or riparian habitat. Reed canary grass is pervasive through this reach. Reach 2 has been highly manipulated with a series of constructed detention basins and wetlands. Though they restrict movement of aquatic species, these structures create wetland environments that sustain some native wetland vegetation.

4.5.1 South Creek, Unnamed Tributary 4, Reach 1

Reach 1 of Tributary 4, between stations 0 and 7200, is a straightened ditch through residential developments and agriculture fields. This is an intermittent stream with little available habitat. The channel is covered with overhanging reed canary grass, and box elders, willows and cottonwoods provide minimal shade in only a few short sections of channel. The channel has been straightened and is only 2 ft in width with 1-ft tall banks and a 15-ft floodplain, but the 6-8 ft levee walls are far enough apart to allow for channel migration and interaction with the floodplain (Figure 32). The long culvert between stations 1900 and 2300 that diagonally crosses Lakeville Blvd. is a complete fish passage barrier. It is too long for passage and contains no appropriate habitat within the culvert.

Figure 32: Tributary 4, Reach 1, station 3900, looking downstream at footbridge crossing the dry channel.

Although there is minimal water flow through this reach, we recommend creating a small wetland upstream of Lakeville Blvd. A small wetland would improve water storage and would provide good in-stream wetland habitat. Wetland vegetation and hyporheic water flow would help prevent increases in water temperature before flowing downstream. Downstream of Lakeville Blvd. we recommend increasing the sinuosity of the channel and increasing the riparian buffer with native trees and shrubs. The culvert under Lakeville Blvd is too long for fish passage, but a sinuous channel downstream will provide habitat for fish migrating from South Creek. Elsewhere, we recommend increasing the riparian buffer and canopy cover by planting native riparian shrubs and trees. This will help maintain low water temperatures when water is flowing and will also be aesthetically pleasing.

4.5.2 South Creek, Unnamed Tributary 4, Reach 2

Reach 2 of Tributary 4, extending from station 7200 to 18500, is a straightened ditch broken up by constructed detention basins. There is no year-round continuous flow through this reach, and many dams and grade control structures prevent fish passage. The dams and grade control structures, however, create detention basins to capture stormwater runoff from new residential and commercial developments. These detention basins provide good wetland habitat and many wetland plant species were observed (Figure 33). Through much of the wetland area, there is no distinct channel. Where the channel is distinct, the bankfull width is 2 ft, and the floodplain is 30 ft. The channel flows through James Jensen Park from stations 7800 to 8700. Here, the grass is mowed close to the channel banks, and there is no riparian buffer (Figure 34). From station 8900 to 9400, there is greater canopy cover, comprised predominantly of buckthorn, box elder, willow, and cottonwood, and less reed canary grass. Multiple detention basins are located between Station 9400 and Dodd Boulevard. Between Dodd Boulevard and Ipava Ave, Tributary 4 enters a dense cattail marsh and upstream of Ipava Ave, the channel ends in a wetland surrounded by

Figure 33: Tributary 4, Reach 2, station 9600, looking upstream at dam and detention basins in residential and commercial area.

Figure 34: Tributary 4, Reach 2, station 7950 looking upstream at dry channel through James Jensen Park.

Figure 35: Tributary 4, Reach 2, station 18500 looking downstream at wetland in the headwaters of the tributary.

recent residential development (Figure 35).

We do not recommend any channel restoration projects in this reach. There is not enough water in the system to provide continuous flow for fluvial species, so the created wetlands from dams and grade control structures are a good way to provide wetland and lacustrine habitat. We do recommend increased riparian buffer in James Jensen Park. Planting native shrubs and trees would provide additional canopy cover.

5. Management Recommendations

The following descriptions outline the project types shown in the Priority Project ranking system. Many projects involve some aspect of more than one of the types listed. The ranking system lists infrastructure as a project type, meaning that some infrastructure (building, road, bridge etc.) would be affected by the project. No specific description is given below.

5.1. Project type – Natural channel restoration/ Relocation

Channel relocation is also called natural channel restoration, natural channel design, or re-meandering and all involve actually building a portion of stream channel different from the existing plan and profile. Inter-Fluve typically refers to channel relocation projects when discussing the movement of a channel to avoid some planned infrastructure. For instance, when new roads are constructed, it is sometimes cost effective to move a stream channel out of the path of the road or to construct a more stable crossing alignment. These situations are often good opportunities to restore channelized reaches into a more geomorphically and ecologically stable configuration (Figure 36).

Figure 36. This segment of Spring Creek in the Black Hills was relocated and restored as part of new highway construction (photo Inter-Fluve).

Natural channel restoration projects involve the construction of a meandering channel with habitat and geomorphic features mimicking natural forms. Gravitational forces, the rotation of the earth, and the friction of water on soil all combine to cause flowing water to assume a sinuous planform. Steeper streams in rockier terrain tend to be straighter and dissipate energy readily through cascading riffles or waterfalls. Lower down in the watershed, or in flatter areas like the Midwest, streams erode slowly through sand, silt and loam to form lazy, winding rivers and streams. Minnesota has several million acres of drained land, with over 80% of that drainage achieved through ditches and channelized stream segments. It is very likely that all ditches with perennial flow were at one time meandering streams, and many of our dry summer ditches were at one time intermittent stream channels or wetlands. Restoring the geomorphic function of these ditches through natural channel restoration can lead to dramatic improvements in habitat and water quality (Figure 37). Ditches are generally deeper and more incised than their sinuous predecessors. Incised streams move flood water quickly, and they do so by concentrating more of the flood flow in a large channel rather than across the floodplain. By adding sinuosity, we can decrease the slope of the channel and in some cases raise the bed of the stream, thereby reconnecting the stream with its former floodplain. Restoring floodplain connectivity slows the exit of water off of the land and allows for greater infiltration, higher baseflows, lower stream temperatures and lower peak flood flows. Restoring incised ditches can be accomplished in three main ways. The first and most inexpensive way is to introduce roughness elements that encourage the formation of a sinuous channel inside the ditch cross-section, essentially using natural forces to carve out a floodplain over a long period of time. The other methods involve either lowering the floodplain

Figure 37. This segment of Trout Creek on the Oneida Reservation was channelized in the early 1900s (top). The restored segment (bottom) involved floodplain excavation, woody debris habitat installation and native plantings (photo Inter-Fluve).

through excavation, or raising the channel bed. Clearly, restoring meanders to a stream requires that the stream occupy a wider swath of land than did the straightened ditch. In areas where little or no buffer currently exists, restoration would need to include expansion of the buffer. The meander limit, or belt width of a stream, is generally a function of the watershed area and the discharge of the stream. For small headwater channels, a reasonable belt width might be in the range of 50 to 100 feet (assuming a channel top width of 15 to 30 feet).

Hydraulic modeling and hydrologic analysis are important components of stream restoration in regulatory drainages. Flood peaks spreading out on downstream farmland can actually be reduced by attenuating the flashy floods upstream through floodplain reconnection and stream restoration. Ditch construction in the Midwest typically occurs without any hydraulic modeling of flood flows to see if ditching actually accomplishes the intended goal. Computer modeling of flood elevations can now be used to determine the practical value of ditches and determine the impact of channel restoration.

Natural channel restoration involves several steps, the first of which is dewatering. Given enough floodplain width, this can be accomplished with little or no effort by simply building the new channel completely off line from the existing ditch. The new channel is constructed "in the dry" adjacent to the existing ditch. Rough channel excavation is completed, with the spoils either removed off site or stockpiled near the existing stream for later filling. Fine grading involves bank stabilization, riffle and pool construction where appropriate, and incorporation of habitat elements. Once the channel has been stabilized, either using fabric methods or by allowing vegetation to grow for a period of time, then water is diverted permanently into the new

Figure 38: Stream restoration in agricultural areas can sometimes involve reconstructing a new valley form or incipient floodplain (photograph: Inter-Fluve).

sinuous channel and the old one is filled in to the floodplain level (Figure 38).

Natural channel restoration in farmed headwater systems can be complicated by the elevation of road crossing inverts. Many modern culvert crossings were installed flush with the bottom of the ditch at the time of construction. The elevation of the channel bottom at the time of culvert installation was more than likely much lower than the elevation of the channel bed prior to ditching, when the stream was a smaller, sinuous channel with good floodplain access. Restoration projects in agricultural areas don't typically involve raising the channel bed at road crossings, which would require replacement of the culvert to minimize or eliminate any upstream rise in flood elevation. The cost of creating an incipient floodplain on a restored stream, or raising the channel and possibly replacing crossings can limit the amount of restoration that a local group can reasonably accomplish.

New stream channel construction can vary greatly in cost between $50 and $200 per foot, depending on constraints and floodplain restoration strategies. A large project might restore a mile of stream channel, placing the cost between $200,000 and $1 million. Granting programs in the Midwest are fairly limited in their ability to fund many large projects of this type, and many coastal and Great Lakes programs are currently focused on fish passage. Hopefully, future granting programs, farm bills and state restoration programs will recognize the importance of headwater stream restoration in our agricultural watersheds.

5.1.1. Restoration and Ditch Law

A major obstacle in restoring headwater streams is current drainage law, governed in Minnesota by Minnesota Statutes, Chapter 103. The ideal option for restoring a farm ditch would be abandonment of the public drainage easement, which is a very difficult process in Minnesota. The State Water Resources Board (later BWSR) originally authorized the creation of watershed districts, who in turn could govern drainage systems within their geographic boundaries. County boards were required by law to assess the potential environmental and natural resources impacts of drainage projects, but much of this was done before watershed issues were deemed important to the general public. Since the 1960s, more watershed residents have raised questions about drainage and water quality, and whether the current drainage law protects the public good in the best possible way. The Clean Water Act and subsequent farm bills have placed more of an emphasis on wetland protection, but because the existing laws are designed to increase drainage, not reduce it, abandonment is still challenging. A ditch is owned by the landowners, and therefore the costs for maintenance of ditches is typically borne by the landowners. Restoration in regulatory ditches typically involves either full abandonment, partial abandonment, and impoundment. Full abandonment requires initiation by landowners, a signed petition by 51% of the landowners assessed for the system, and final approval by the authority. This is usually done in urban areas where the ditch is no longer in existence or in areas with few landowners. Abandonment through the RIM program is possible but often requires an engineering study and some drainage modifications to prevent downstream flooding from worsening. Partial abandonment is not usually done because the drainage authority can be lost if some portion of the system is abandoned. Installation of water control structures to restore wetland conditions is also a possibility, but those structures must be maintained by the landowner.

Two alternative ways of restoring floodplains and streams within existing ditch law have been demonstrated by the Minnesota DNR and others. The first involves *ditch improvement*, whereby a channelized ditch can be confined within parallel berms running along both sides of the channel dozens or hundreds of feet from the channel center (Figure 39). Within these berms, a lower floodplain can be excavated or the channel raised and a meandering stream restored. The second involves *diversion for public benefit*, whereby both ends of a segment are blocked and the ditch is then no longer maintained. A meandering channel can then be built off line from the existing ditch.

Wetland restoration as floodplain management ties directly into the discussion of ditch management and natural channel restoration. Although there are a few samll wetlands in the watershed, a central ditch and its associated tile lines still drain the landscape. Wetland restoration is a good method of improving water storage in reaches with only ephemeral flows. Wetland restoration and/or wetland stream restoration would need to include managing tile drainage and minimizing or eliminating ditch drainage so that water stays on the wetland longer. In recent projects completed with the Oneida Tribe in Green Bay, Wisconsin, Inter-Fluve has combined wetland and stream restoration

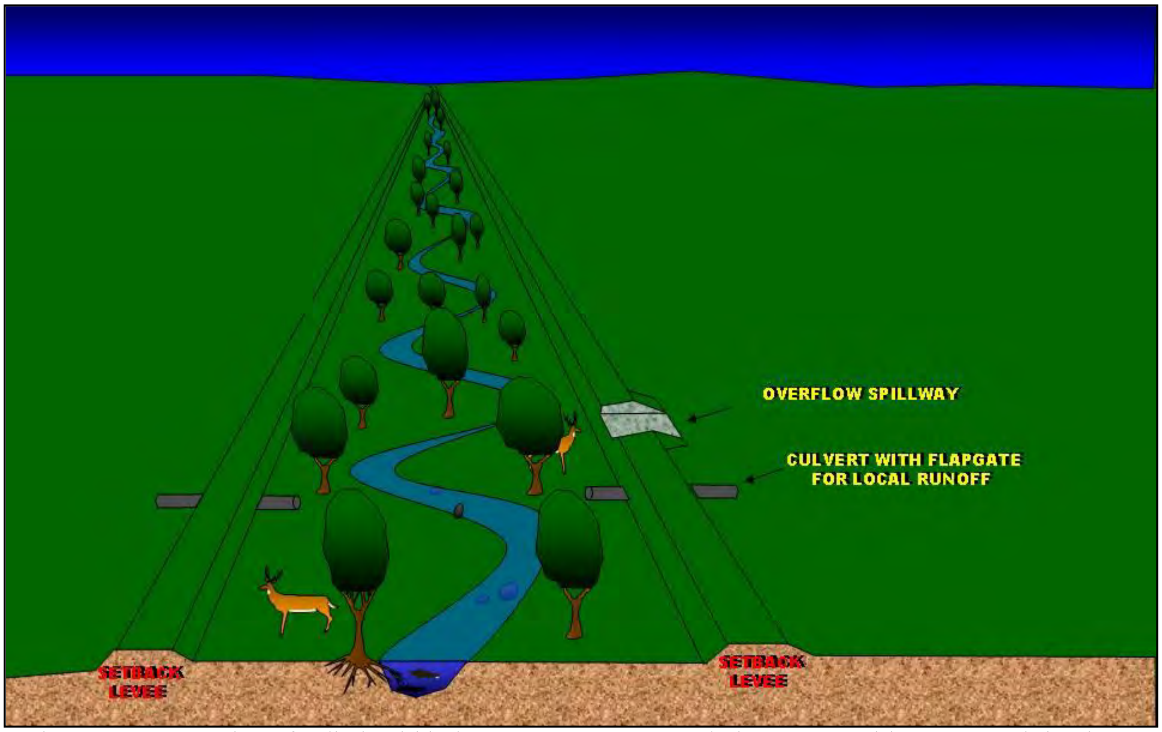

Figure 39: Restoration of a ditch within levees to create a meandering stream with a vegetated riparian buffer (courtesy of L. Aadland, MN DNR).

with buffer management in headwater tributaries to a small agricultural stream. In just four years, the water quality of the system has improved to the point where trout will be re-introduced (Snitgen and Melchior 2007). Many such examples of a headwater restoration approach can be found around the Midwest. The flow of water during wet times of the year, natural ground water flow, hyporheic flow and abundant wetland vegetation combine to eliminate any increase in water temperature before the water flows downstream. The ability to reintroduce trout into a system with newly restored wetlands and stream is evidence that water temperatures remained low.

A major obstacle to native plant wetland restoration is the ubiquitous presence of reed canary grass (*Phalaris arudinacea*), giant reed grass (*Phragmites australis*) and cattail (*Typha angustifolia*). These invasive species have taken over most of the wetlands in the Midwest, with reed canary grass often colonizing disturbed sites to become monoculture. The fecundity of these plants, their ease of seed spreading, and their proximity to moving water make wetland restoration with native plants extremely difficult. However, the hydrologic benefits of invaded wetlands still remain. Eventually, better methods will be discovered that will help improve the diversity of restored wetlands and minimize invasion by exotic species.

5.2. Project type – Grade Control

In reaches with extreme incision or active downcutting, grade control is often prudent. Grade control involves the installation of an armored riffle or drop structure placed to prevent any further incision from traveling upstream. Grade controls can be discrete weirs, concrete structures or armored riffles (Figure 40). Inter-Fluve recommends the latter in natural stream systems to avoid blocking fish passage and to maintain natural geomorphic function. There is no obvious active incision and the headcut that resulted in historic incision appears to have stopped at some tree roots in the upper reaches of South Creek.

Figure 40. The above photos show a riffle-pool channel (A) just after and (B) 2 years after construction. Grade controlling riffles can be built either in conjunction with armored banks to prevent channel migration, or with sediment input in mind, so that as the stream moves laterally, new riffle lobes will form (photos Inter-Fluve).

5.3. Project type – Floodplain Management

Floodplain management projects vary considerably, but include expansion of riparian buffers, removal of infrastructure, and stormwater management. The South Creek watershed has some residential and commercial development throughout; new development must capture stormwater and encourage as much infiltration as possible or the stream will experience a sharp decline in water quality. Retrofitting of existing stormwater systems will help improve water quality and prevent incision and erosion problems.

5.4. Project type – Riparian Management

One way of improving filtration of nutrients, reducing stream temperature and restoring the connectivity of green corridors is to revegetate streambanks and riparian areas where row cropping and urban development have encroached on the channel. Revegetation projects are relatively simple to institute, and can be inexpensive. Plants can be purchased through local NRCS or nurseries, and can be planted using volunteer labor. Much of the South Creek watershed is composed of straightened ditches with minimal riparian vegetation and canopy cover. Removal of the forest canopy exposes the channel to more direct sunlight and removal of soil binding tree roots can result in major bank erosion. Organisms dependent on forest leaf litter for energy can be impacted, and fertilizer from expanding lawns would likely drain directly and quickly into the channel, resulting in increased algal growth and decreased oxygen levels. The streamside natural area is critical to the connectivity of watersheds. Migratory birds and other animals use these green corridors through their range or to migrate seasonally. Removal of these buffers fragments habitat for already stressed organisms. This pattern can be reversed however, by increasing natural buffers of both native grasses and forested riparian areas.

Although the small ditches throughout the South Creek watershed may seem insignificant, it is extremely important to buffer these channels. Water pollution in rivers is cumulative. Once you have poor water quality, it does not generally improve with distance downstream. Any attempts at reforestation should consider the impact of exotic species such as reed canary grass and buckthorn. Special measures such as removal and herbicide treatment must be taken before establishing native species.

5.5. Project type – Crossing

There are very few fish passage barriers in the South Creek watershed. Where continuous water flow is available for fish passage, most of the culverts are well-placed and are partially buried to provide in-stream habitat and limit perching.

Figure 41: Bottomless arch that is partially buried for better habitat and fish passage conditions.

Perching is caused by either incorrect placement of the culvert above the downstream channel bed or by incision traveling upstream and causing the channel bed below the culvert to downcut. Most warmwater fish have poor leaping ability, so even a six inch perch can present problems. Perched culverts can be made passable by raising the channel bed downstream, backwatering through the culvert or by replacing the culvert. Culvert replacement should consider bottomless arch options or culverts that are partially buried to mimic a natural channel bottom (Figure 41).

Low flows can present a passage barrier at any culvert, and this is not only a function of the culvert design, but also the hydrology of the system. During midsummer, when flows are very low, all culverts may be impassible. However, low flow can be concentrated or backwatered through a culvert to minimize passage problems. For instance, flow up to a certain elevation can be easily diverted (eg. low concrete weir) into one box of a double box culvert, essentially doubling the amount of water in the culvert at low flow. Most crossings in the South Creek watershed with multiple boxes or pipes have high, medium and low flow pipes in order to maintain continuous flow.

5.6. Bank Stabilization

Bank stabilization projects in urban and agricultural areas seek to minimize soil loss and prevent stream channel migration and property loss. Urban and agricultural streams are often in a state of flux, that is the streams are trying to adjust their cross-section (get bigger) to accommodate the increase in flows. South Creek and its tributaries have made some adjustments over time, but appear to be reaching an equilibrium with the existing hydrology. There are very few locations with excessive bank erosion, and these are only spot locations near an inflow. The banks are stable throughout.

In general, bank stabilization should consider infrastructure constraints, future channel migration patterns, and riparian buffer protection. A simple bank restoration project is to plant trees away from the eroding bank and allow those trees to grow to maturity before the channel has a chance to erode to their base. By the time the channel has moved, the trees will be large enough to provide deep rooted bank stabilization. The most successful trees for this purpose would be cottonwood, black willow and silver maple, all common riparian or "wet feet" trees capable of withstanding frequent inundation. Another approach is to provide some toe protection in the form of rock or encapsulated gravel combined with planting. Rock is sized or protected such that it remains stable long enough for vegetation to grow. Bioengineering fabrics can be used to provide structural stabilization and to prevent the piping of soils during high flow. These materials biodegrade once the vegetation is established (Figure 42).

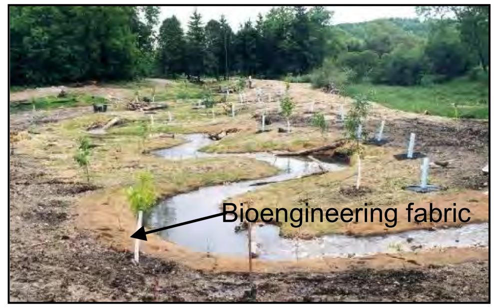

Figure 42: Grasses are beginning to grow through biodegradable bioengineering fabric along this restored stream (photograph: Inter-Fluve).

The least expensive bank stabilization is simply for landowners to leave the stream alone. New and existing landowners in forested reaches should be encouraged to remove exotics such as buckthorn and garlic mustard, but to otherwise leave the streamside vegetation to manage itself (Figure 43). This encourages natural stabilization and habitat formation. In most cases, our best intentions are actually detrimental to the stream environment. Erosion and deposition of streambank sediment are the essential physical forces behind stream and floodplain formation. Some degree of bank erosion is natural. However, when watershed changes or riparian landuse practices cause the stream to be out of equilibrium, abnormal erosion rates can result. What constitutes abnormal erosion is somewhat subjective, and depends on sediment pollution concerns, habitat degradation and on concerns over nearby infrastructure such as roads, houses and underground conduits. Prior to undertaking a project, it is therefore important to obtain professional opinions from land managers, geomorphologists, and engineers. If the erosion appears dramatic, but the erosion rate is extremely low, there may be no real basis for a stabilization project. Conversely, erosion may not appear dramatic, but the rate may be high, requiring

Figure 43: The root structure of trees hold the bank material together to stabilize the banks against rapid erosion.

some immediate stabilization. Determining the risk of no action is extremely important.

Often times, people see a downed tree, or a scour area around a rootwad or tree base, and associate bank erosion with trees. In fact, had the tree not been there until it fell, the bank would have probably eroded at a much greater rate. Boxelder trees are primary colonizers, and are very quick to establish in areas where trees have fallen and clearings result. This association of boxelder with unstable banks also leads to the misconception that boxelders, and thus all trees cause erosion. Common riparian trees have evolved over time to do just the opposite. Eastern cottonwood, black willow and silver maple, our three most common streamside trees, have evolved deep, water searching root systems to provide for added stability in the dynamic streamside environment. Black willow roots can travel dozens of feet up and downstream, creating an extremely well armored bank.

Native grasses provide adequate streambank root protection down to approximately 3 to 4 feet, and are useful in smaller streams or areas where prairie restoration makes sense. Larger streams or incised channels with banks taller than 3 feet need deeper and stronger root protection. No vegetation can provide long term stability beyond five feet of streambank height, and the root protection is then limited to trees and grasses in the upper banks. The Minnesota River is a good example of this dynamic.

6. General Recommendations/Conclusions

The South Creek watershed is primarily composed of straightened ditches with minimal channel or habitat complexity and minimal riparian vegetation. A few short sections have been restored with increased sinuosity and riparian plantings, but portions of these sections are being aggressively invaded by reed canary grass. Storm water detention basins and wetlands have been created in areas with new development, especially along Tributary 4. There is not continuous flow through all of the South Creek watershed, leaving the lower few miles of South Creek as the only viable fish habitat for species migrating from the Vermillion River.

We have identified and described 46 potential restoration projects throughout the South Creek watershed (Appendix B). We have ranked these projects and grouped them by project type (Appendix C). The primary problem throughout the watershed is a lack of channel and habitat complexity and a lack of native riparian habitat. There are very few erosion problems in the watershed because the low-gradient system results in very low energy in the channel. Large flows will move fine sediment and some sand but is not capable of creating excessive erosion. The channels through the watershed are generally stable because of this low energy and there are very few fish passage problems.

The first land survey and plat maps from 1855 indicate that there may not have been any tributaries and that South Creek may have only had a few miles of continuous flow before it flowed into the Vermillion River. There are no extensive wetlands indicated on the plat maps. However, the extensive tiling throughout the watershed to drain farm fields of excessive water likely resulted in increased water flow and the need for ditches. Straightened ditches were built and the water delivered to them from the fields was moved rapidly downstream. Because the ditches were built to move water out of the area quickly, there is no ability to store water for habitat.

A combination of natural channel and wetland restoration will help to fully restore the channels in the South Creek watershed. Restoration efforts should focus on the areas of the watershed that receive sufficient rainfall and runoff to support a wetland, continuous flow in a channel, or residual pools. Wetlands should be built near developments and industrial areas to retain stormwater. Narrow wetlands can be built elsewhere through farm fields where there is minimal width in which to work. Excessively high water temperatures should not be a problem in these wetlands if constructed properly. Continuous flow during wet portions of the year will keep cool water moving through and the ground water, hyporheic flow and abundant native wetland vegetation will keep temperatures low. Where wetlands are not feasible due to width constraints or otherwise, the sinuosity of the channel should be increased and the riparian vegetation should be restored. Sinuous channel should be built in reaches 1, 2, and 4 of South Creek, portions of reach 1 of Tributary 1 and reach 1 of tributaries 2-4.

Increasing the width of riparian buffers with native riparian vegetation will improve aquatic and riparian habitat as well as channel complexity. Vegetation diversity is very important to attracting diverse macroinvertebrates, birds and other aquatic and riparian animal species. Historically, the South Creek watershed likely contained a combination of prairie streams and stream bounded by old growth riparian forest. The current channels can be restored to either habitat, but it is likely that a mix would be most beneficial to the system. Woody debris from forested floodplains would create channel and habitat complexity and would begin to stabilize banks. The shade provided by these forested floodplains would keep water temperatures down and prevent reed canary grass from establishing.

The key to river restoration in this watershed is diversity and complexity: increased channel types with meanders, scour pools and riffles, increased variability in channel bed substrate with gravels and cobbles and increased variety in native riparian vegetation will attract a wide variety of aquatic and riparian animal species.

7. References

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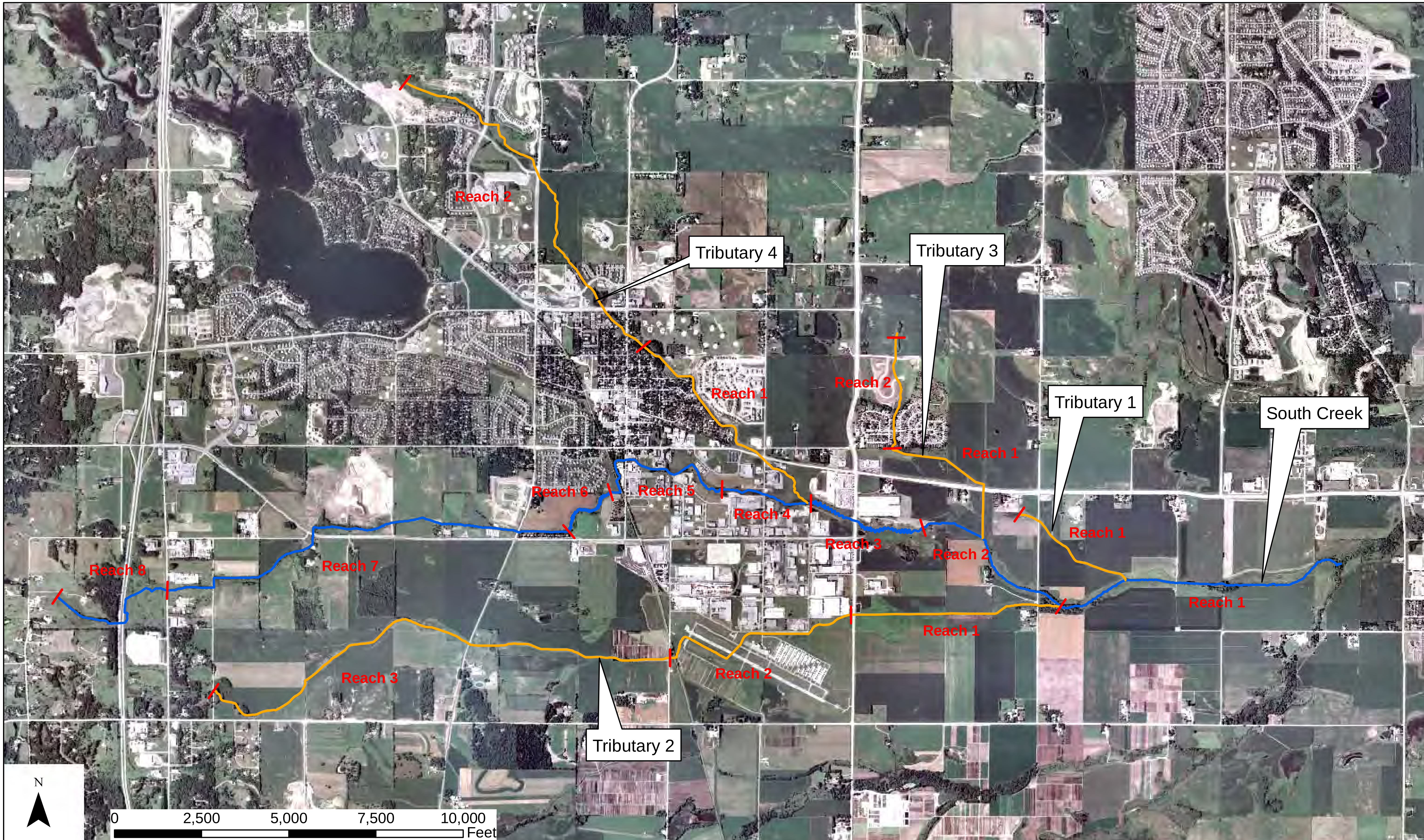
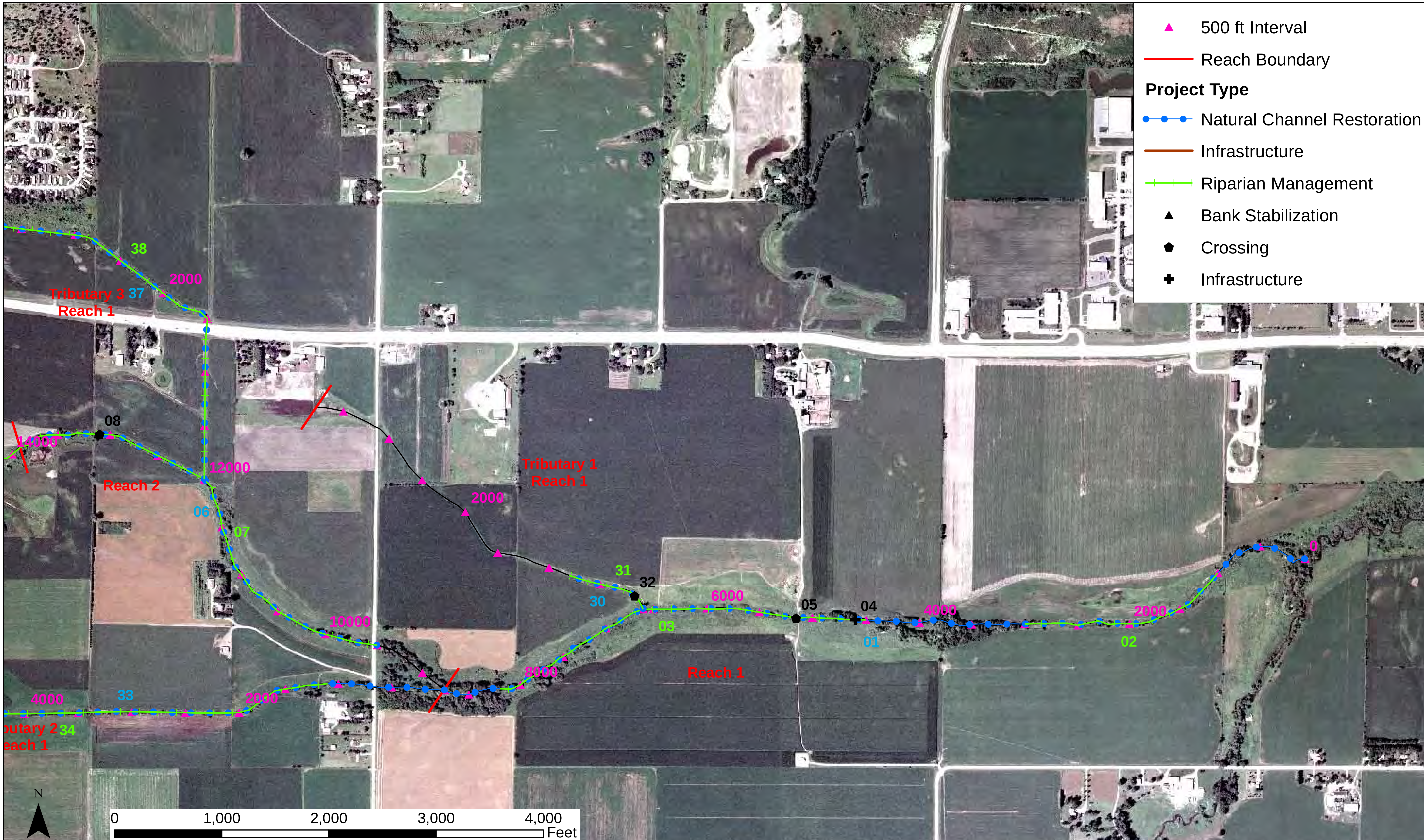
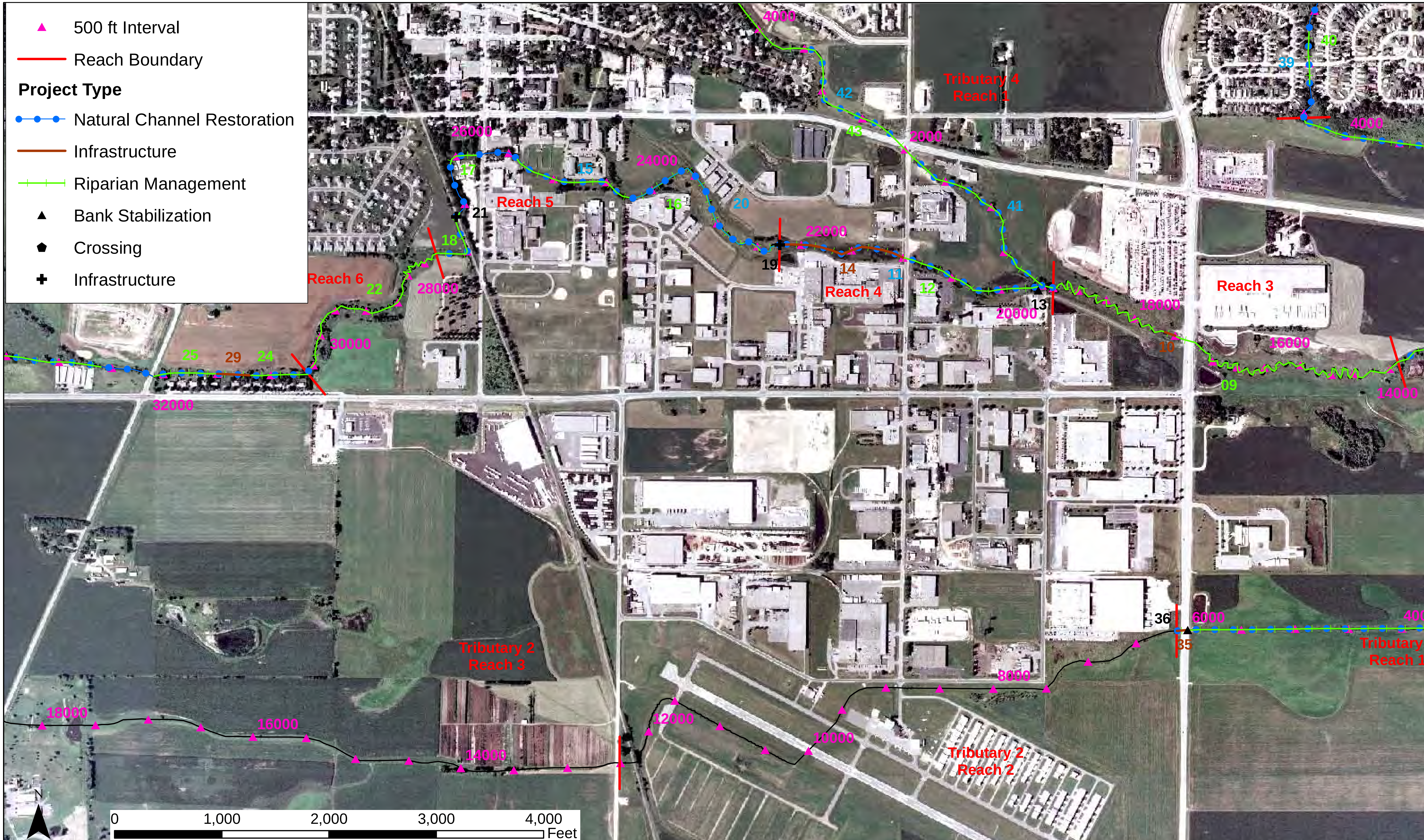


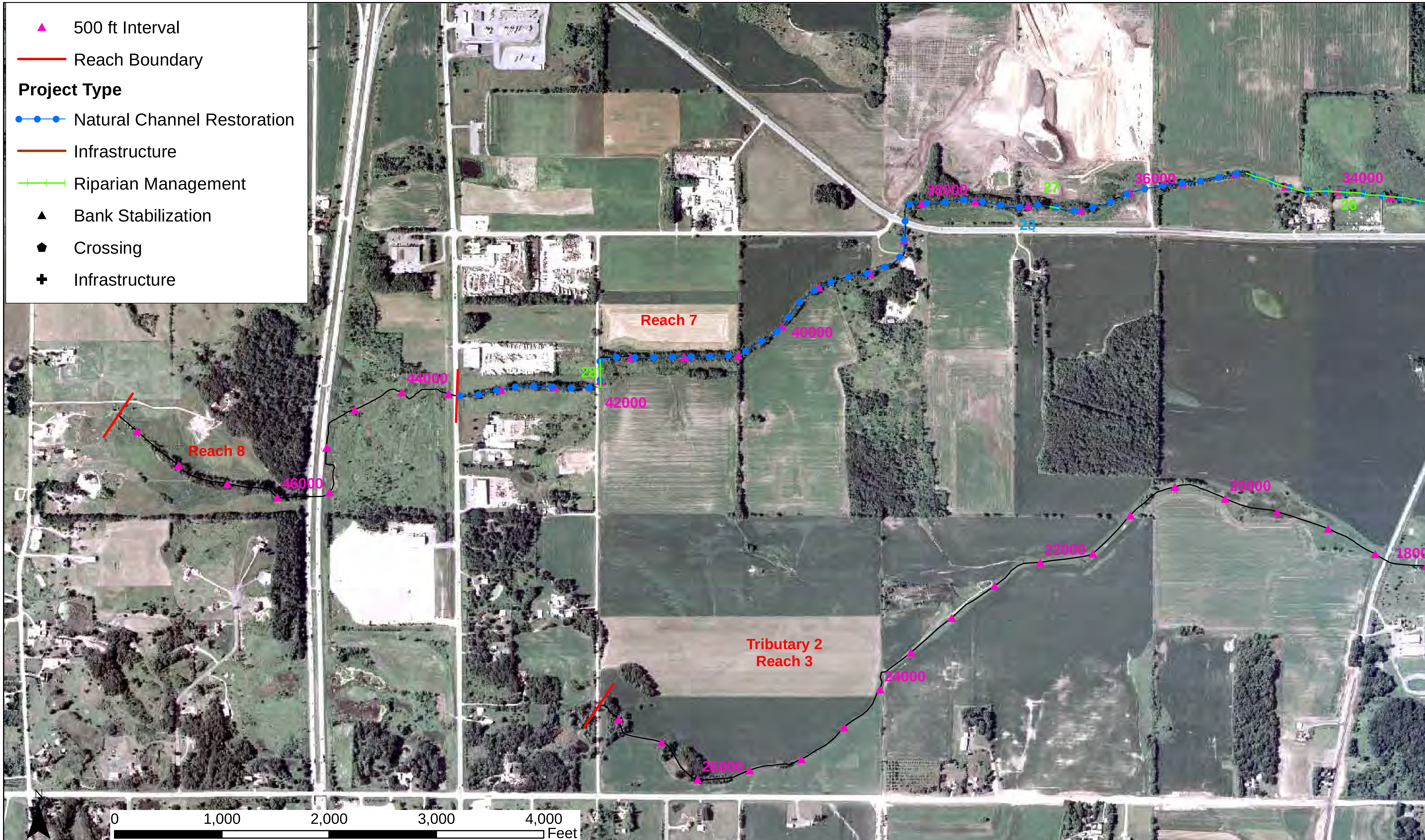
Appendix A: South Creek and its tributaries with the reach boundaries indicated.



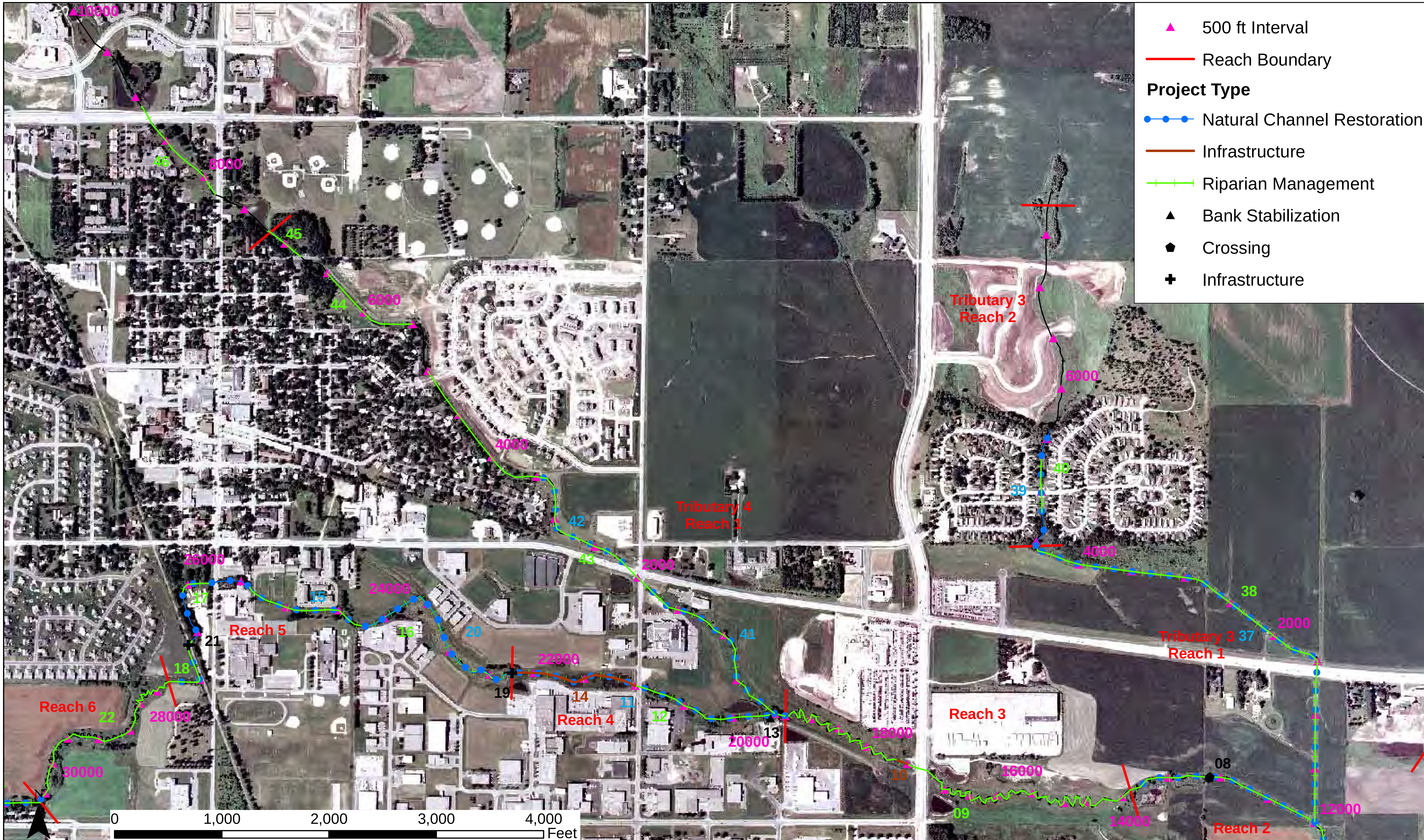
Appendix B: South Creek and its tributarties with the potential restoration projects indicated. Pink numbers are channel centerline station numbers; other numbers reference potential restoration projects.



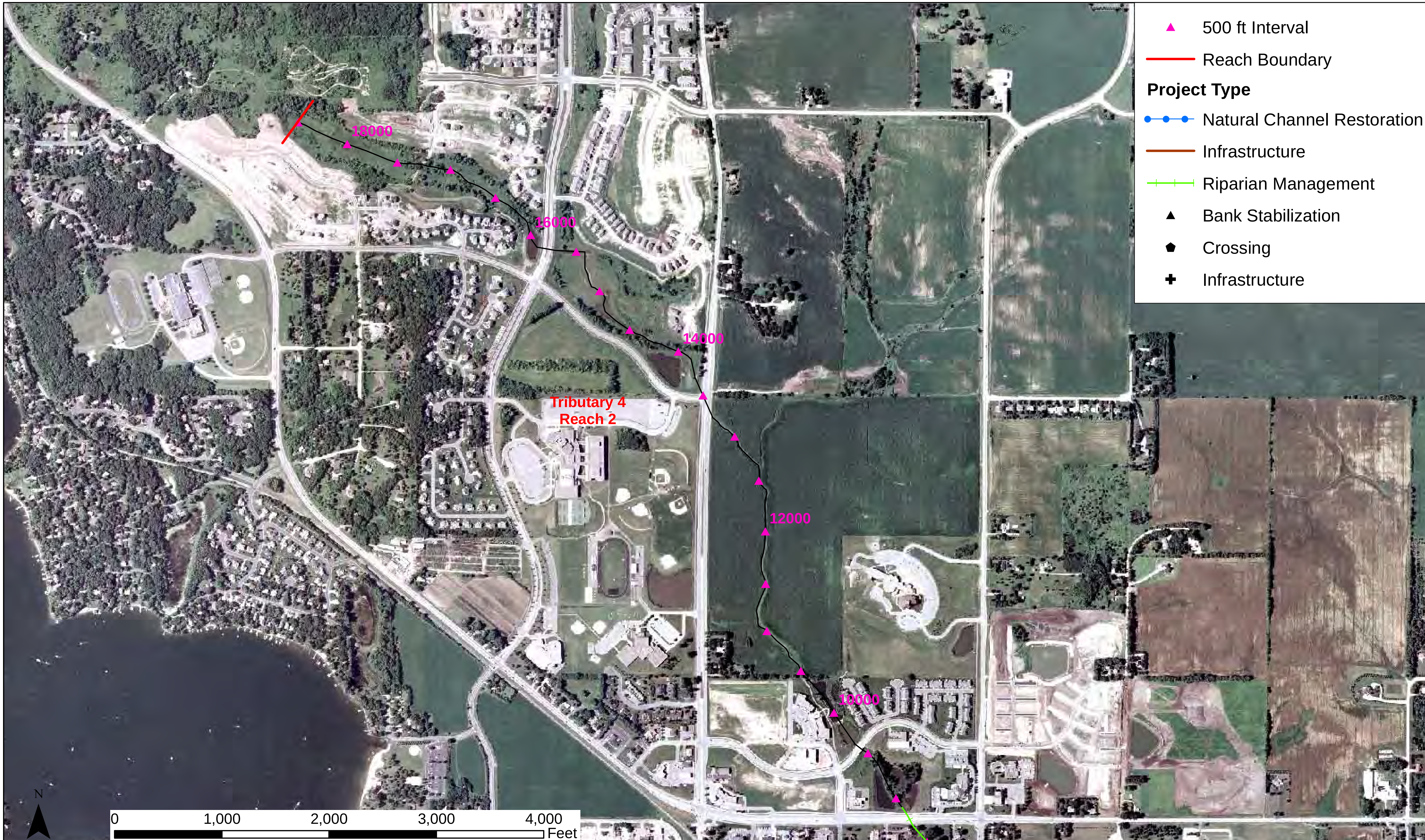
Appendix B continued: South Creek and its tributarties with the potential restoration projects indicated. Pink numbers are channel centerline station numbers; other numbers reference potential restoration projects.



Appendix B continued: South Creek and its tributarties with the potential restoration projects indicated. Pink numbers are channel centerline station numbers; other numbers reference potential restoration projects.



Appendix B continued: South Creek and its tributarties with the potential restoration projects indicated. Pink numbers are channel centerline station numbers; other numbers reference potential restoration projects.



Appendix B continued: South Creek and its tributarties with the potential restoration projects indicated. Pink numbers are channel centerline station numbers; other numbers reference potential restoration projects.

Appendix C: Potential project priority ranking by project type for South Creek.

Stream: South Creek Mainstem
Location: Dakota County, MN
Client: Vermillion River Watershed Joint Powers Organization

Potential Project - Priority Ranking List

Project Number	Station Number	Project type	*Inf. Risk*	*Channel stability*	*Project Complexity*	*Location*	*Sed/Nutrient Loading*	*Cost*	*Aesthetic impact*	*Fish passage*	*Public Education*	*In-stream Ecological*	*Riparian Ecological*	*Total Score*
BankStabilization														
PP13	19650	B	3	3	7	3	3	7	1	1	1	3	3	**35**
Culvert or Other Crossing														
PP05	5150	C	3	3	5	1	1	5	3	5	3	3	1	**33**
PP08	13100	C	1	1	5	3	3	7	3	1	3	3	1	**31**
Infrastructure														
PP19	22200	I	1	3	5	5	1	5	5	7	7	7	7	**53**
PP29	31200-31500	I	1	1	7	7	1	7	1	5	3	3	1	**37**
PP04	4600	I	3	1	5	1	3	5	3	1	3	3	1	**29**
PP14	21000-22200	I	1	1		3	7		5	1	5	5	1	**29**
PP10	17500-17600	I	5	1	3	3	1	5	1	1	1	3	1	**25**
PP21	26650	I/B	3	3	7	5	3	7	1	1	1	1	1	**33**
Natural Channel Restoration/Relocation														
PP23	30600-43400	N	1	7	1	6	1	1	7	1	7	7	7	**46**
PP15	22200-27300	N	1	7	1	5	1	1	7	1	7	7	7	**45**
PP01	0-8750	N	1	7	1	1	3	1	7	1	7	7	7	**43**
PP11	19500-22200	N	1	7	1	3	1	1	7	1	7	7	7	**43**
PP06	9500-13900	N	1	7	1	2	1	1	7	1	7	7	7	**42**
PP20	22200-24200	N/F	1	1		5	1		5	7	7	7	7	**41**
Riparian Management														
PP16	22200-25400	R	1	7	7	5	5	5	7	1	7	7	7	**59**
PP12	19500-22200	R	1	7	7	3	5	5	7	1	7	7	7	**57**
PP26	32600-34900	R	1	5	7	5	5	5	7	1	7	7	7	**57**
PP07	9500-13900	R	1	7	7	2	5	5	7	1	7	7	7	**56**
PP02	1000-3000	R	1	7	7	1	5	5	7	1	7	7	7	**55**
PP03	4500-8300	R	1	7	7	1	5	5	7	1	7	7	7	**55**
PP09	13900-19500	R	1	5	7	3	3	7	5	1	5	5	7	**49**
PP18	26600-27300	R	1	3	7	5	3	7	5	1	5	5	5	**47**
PP22	27300-30600	R	1	3	7	5	3	7	5	1	5	5	5	**47**
PP24	30700-31500	R	1	3	7	5	3	7	5	1	5	5	5	**47**
PP25	31500-32100	R	1	3	7	5	3	7	5	1	5	5	5	**47**
PP28	41800-42100	R	1	3	7	7	3	7	3	1	3	3	3	**41**
PP17	25800-26100	R	1	3	7	5	3	7	3	1	3	3	3	**39**
PP27	36700-36800	R	1	1	7	7	3	7	3	1	3	3	3	**39**

Project type

B	Bank stabilization
G	Grade control
C	Culvert or other crossing
N	Natural channel restoration/relocation
F	Floodplain management
I	Infrastructure (outfalls, buildings etc.)
R	Riparian management

Appendix C continued: Potential project priority ranking by project type for the tributaries of South Creek.

Stream: South Creek Tributaries 1-4
Location: Dakota County, MN
Client: Vermillion River Watershed Joint Powers Organization

Potential Project - Priority Ranking List

Project Number	Station Number	Project type	*Inf. Risk*	*Channel stability*	*Project Complexity*	*Location*	*Sed/Nutrient Loading*	*Cost*	*Aesthetic impact*	*Fish passage*	*Public Education*	*In-stream Ecological*	*Riparian Ecological*	*Total Score*
Bank Stabilization														
PP36-Trib 2	6000	B/C	5	1		3	1		1	1	1	1	1	**15**
Culvert or Other Crossing														
PP32-Trib 1	150	C	3	1	7	1	1	7	1	3	3	3	1	**31**
Infrastructure														
PP35-Trib 2	6000-6100	I	1	1	5	3	1	5	3	7	5	7	5	**43**
Natural Channel Restoration/Relocation														
PP37-Trib 3	0-4400	N	1	7	1	3	1	1	7	1	7	7	7	**43**
PP33-Trib 2	0-6100	N	1	7	1	2	1	1	7	1	7	7	7	**42**
PP39-Trib 3	4400-5600	N	1	5	1	3	1	1	5	1	7	7	7	**39**
PP41-Trib 4	0-1900	N	1	5	1	3	1	1	5	1	7	7	7	**39**
PP42-Trib 4	2200-3500	N	1	3	1	3	1	1	5	1	7	7	7	**37**
PP30-Trib 1	0-800	N	1	3	3	1	1	5	5	1	5	5	5	**35**
Riparian Management														
PP38-Trib 3	0-4400	R	1	7	7	3	5	5	7	1	7	7	7	**57**
PP43-Trib 4	0-5000	R	1	7	7	3	5	5	7	1	7	7	7	**57**
PP34-Trib 2	1100-6100	R	1	7	7	2	5	5	7	1	7	7	7	**56**
PP44-Trib 4	5500-6500	R	1	3	7	5	3	7	5	1	7	7	7	**53**
PP46-Trib 4	7800-8900	R	1	5	7	5	3	7	5	1	5	5	5	**49**
PP40-Trib 3	4800-5300	R	1	3	7	3	3	7	5	1	5	5	5	**45**
PP31-Trib 1	0-800	R	1	3	7	1	3	7	5	1	5	5	5	**43**
PP45-Trib 4	6800-7200	R	1	3	7	5	3	7	5	1	3	3	3	**41**

Project type

B	Bank stabilization
G	Grade control
C	Culvert or other crossing
N	Natural channel restoration/relocation
F	Floodplain management
I	Infrastructure (outfalls, buildings etc.)
R	Riparian management