Credit River, MN

Final Report - Fluvial Geomorphic Assessment

March 5, 2008

Prepared for:

Scott County Community Development
Natural Resources Department
Government Center 14
200 Fourth Avenue West
Shakopee, MN 55379-1220

inter·fluve

3602 Atwood Avenue
Suite 3
Madison, WI 53714

TABLE OF CONTENTS

1. Introduction

In the spring of 2007, the Scott County Natural Resources Department contracted with Inter-Fluve to conduct a fluvial geomorphic assessment of the Credit River Watershed. The project is an attempt to locate channel stability problems, assess overall stream condition and address the concerns of landowners regarding erosion, flooding and threats to infrastructure. Through several meetings, Inter-Fluve and County officials identified the following objectives:

1) *Conduct a reconnaissance level geomorphic assessment that collects information regarding channel stability, infrastructure, fish habitat, and general stream health*

2) *Identify potential restoration or reclamation projects in the watershed*

3) *Create a system of prioritization for identified projects*

4) *Integrate the results of the study with the existing Scott County Geographic Information System (GIS) platform*

Scott County staff assisted with collection of existing data (aerial photographs, maps etc.) and created field maps. Inter-Fluve scientists identified distinct study reaches within the Credit River watershed. Fieldwork commenced in June and July 2007, and Inter-Fluve met with interested landowners on site and with officials from the City of Savage.

The report that follows is a brief summary of the data collected, and outlines general stream conditions by reach for the main stem and tributaries. This report is supplemented by completed project forms which the County will integrate into the Scott County GIS platform.

This fluvial geomorphic assessment was geared toward project identification so that Scott County can eventually develop a long term restoration and watershed management strategy. This type of assessment typically results in a large number of total projects; in this case 48 significant projects were identified on the Credit River mainstem. In order to prioritize these projects for funding allocation, a ranking system for potential restoration projects was developed for the watershed. This ranking system scores potential 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 that priority can be a result of any combination of metrics chosen by Scott County staff.

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 project did not include any formal structural engineering survey or risk assessment. If infrastructure is determined in this survey to be at

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 1/4 to 1/2 of watershed	1/2 to upper 3/4 of watershed	Upper 3/4 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

some risk, we advise local officials to conduct their own formal structural engineering assessment. This scoring does not reflect any risk from flooding. Other metrics gauge the potential project's effect 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.

Inter-Fluve has introduced this method of prioritization for other communities, and the system can be a very valuable planning tool. All of the metrics have been developed by Inter-Fluve in conjunction with Scott County staff. To some degree, these metrics have been tailored to fit the size of the watershed, the landuse and the goals of the County managers.

1.1. Review of fluvial geomorphology principles

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 effect the timing of runoff can effect 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 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 1). 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).

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.

Figure 1: 2003 aerial photograph showing the sinuous nature of the Minnesota River in the western part of Scott County. Flow is from the south to the north.

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 straightening of streams and thus decreasing channel length or by direct changes in the bed

Figure 2: A headcut and incised channel on Tributary 1 of the Credit River.

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 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 2). 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 3).

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

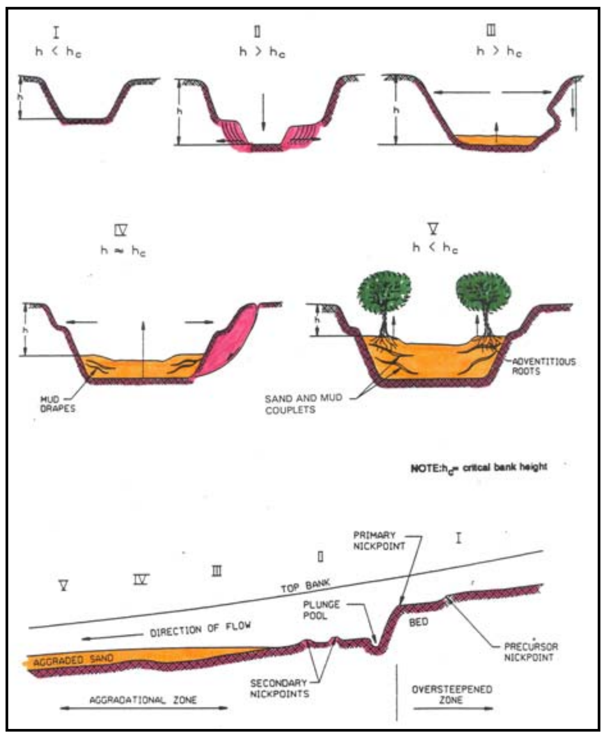


Figure 3: The Schumm channel evolution model (from Schumm, 1984).

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 Credit River watershed. U.S. Geological Survey topographic maps from 1985 and Flood Insurance Study (FIS) maps were analyzed for changes in gradient throughout the watershed. Aerial photographs from 2003 were analyzed in a GIS to determine reach breaks based on land use and changes in valley form, soils, profile, and planform. These photographs were compared with aerial photographs taken in 1937, 1947, and 1957, and plat maps from early surveys completed in 1855 to identify temporal changes in land use as well as changes to the planform of the Credit River channel. Information was also gathered from existing soil, erosion, and water quality studies and incorporated into this report.

2.2. Fluvial Geomorphology

Two Inter-Fluve fluvial geomorphologists walked most of the length of the Credit River, collecting information on soils, streamflow, stream bed grain size, observed aquatic biota, fish passage barriers, infrastructure, landuse, and vegetation. This information was compiled on two forms for each reach, a customized reconnaissance form and a Stream Visual Assessment Protocol (SVAP) form. 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. The time of floodplain formation was estimated based on the ages of the oldest trees growing on the floodplain, which was determined by extracting tree cores and counting the tree rings. The SVAP form was developed by the U.S. Department of Agriculture (USDA) in 1989 and includes information regarding channel condition, hydrologic alteration, the riparian zone, bank stability, water appearance, nutrient enrichment, barriers to fish movement, instream fish cover, pools, invertebrate habitat, canopy cover, riffle embeddedness, and observed macroinvertebrates.

2.3. Hydrology

Inter-Fluve hydrologists completed flood frequency analyses for the Credit River based on mean daily discharge gage data collected within 1 mile of the confluence with the Minnesota River from 1989 to 2006. The greatest mean daily discharge in each year that data was collected was used for the analysis as instantaneous peak flow data were unavailable. The magnitude of floods calculated from this analysis will therefore be slightly lower than if instantaneous peak flow data were used.

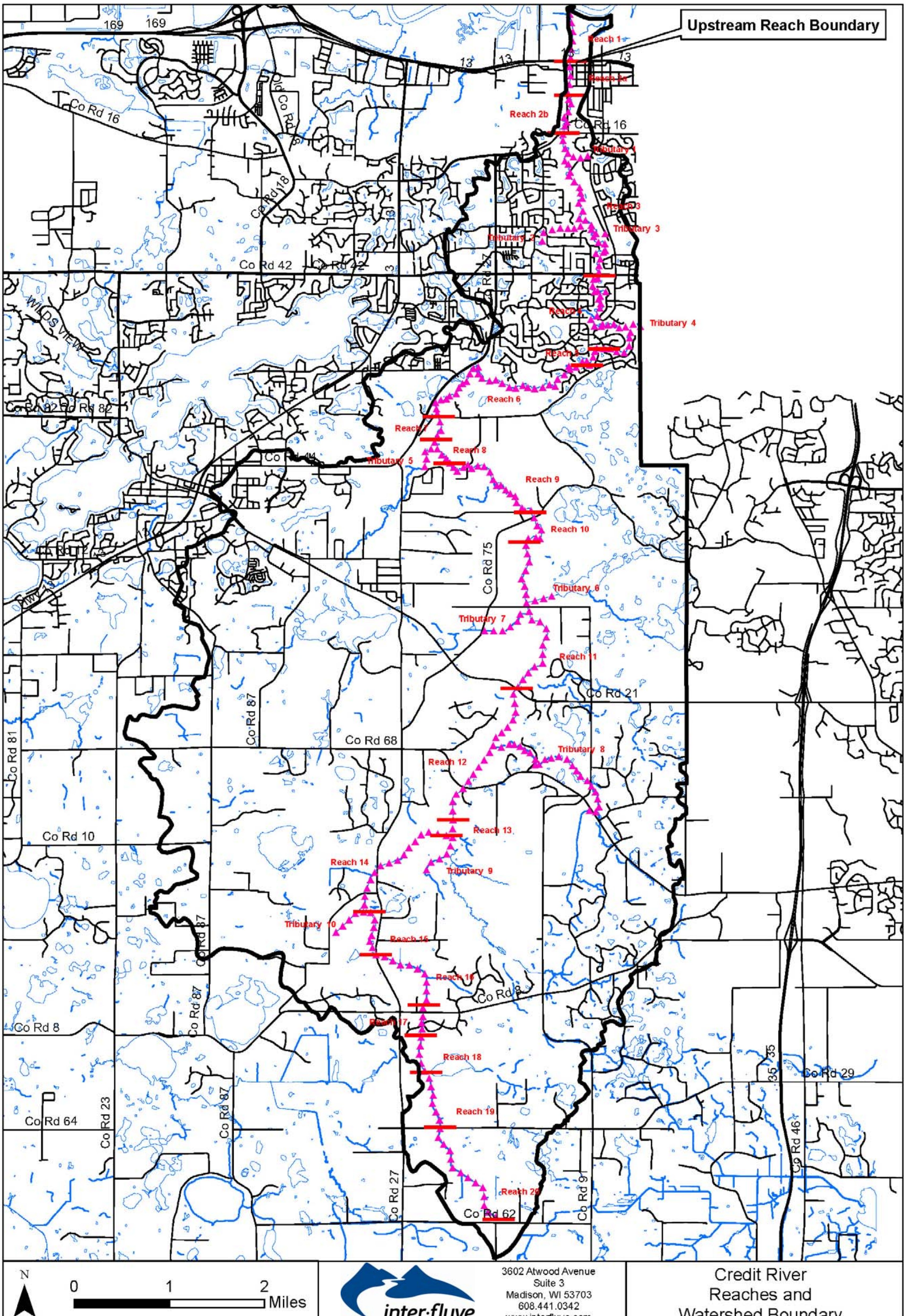


Figure 4: Credit River watershed (black polygon) and reach boundaries (red horizontal lines). Pink triangles indicate 500-ft increments along the channel centerline. Scott County provided the channel, road, and watershed layers; some of the smaller tributaries were not included in these layers.

3. Results

3.1. Geology, topography and soils

The Credit River is a post glacial stream originating near New Market, MN and draining south through farmland and developed land in the city of Savage (Figure 4). The Credit River drains an area of 59 square miles (15,360 hectares), emptying into the Minnesota River just north of State Highway 13 in Savage. Scott County is underlain by early to middle Paleozoic rock. The western half of Scott County is comprised primarily of Upper Cambrian sandstone and siltstone of the St. Lawrence Formation, whereas the eastern half is made up of Lower Ordovician crystalline dolostone, sandstone, and shale of the Prairie du Chien Group (Runkel and Mossler, 2006, Figure 5A). Surficially, Scott County is dominated by glacial till, except along the Minnesota River, which is composed of alluvium and terrace deposits (Lusardi, 2006, Figure 5B). The abundance of glacial till, a material with low permeability because of the silts and clays that fill in the spaces between the larger grains, provides a layer of protection for the county's aquifers that lie in the sedimentary rock below.

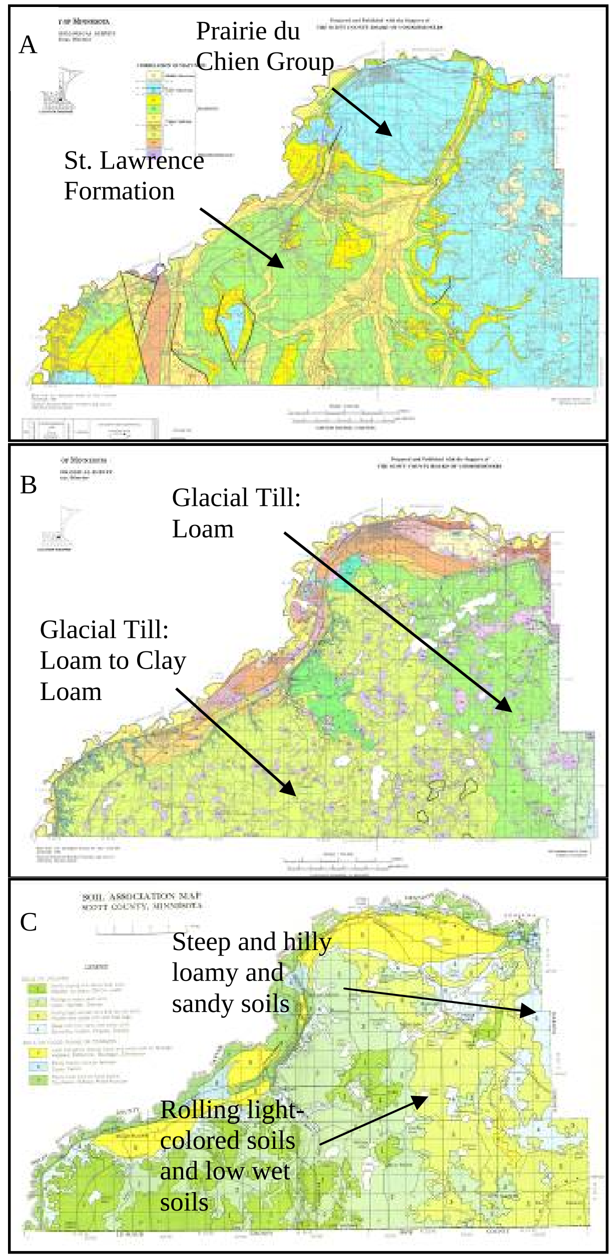


Figure 5: (A) Bedrock (Runkel and Mossler, 2006) and (B) surficial (Lusardi, 2006)) geology for Scott County. (C) Soil map for Scott County (USDA, 1959).

The valley form of the Credit River is rooted in its post-glacial history. The Credit River drains through steep slopes at the edges of the Minnesota River valley, but the steep slopes defining the edges of Bloomington and Eden Prairie to the north and Savage and Shakopee to the south, were not formed by the erosion of the Minnesota River. As the Des Moines lobe of glacial ice retreated around 10,000 years ago, it left behind moraine and till deposits many feet thick across Minnesota. Behind the southernmost terminal moraine, Glacial Lake Agassiz covered a large region from the Brownsville area north to central Manitoba. As the lake overtopped the southern moraine, flowing water (Glacial River Warren) cut down into the deposited glacial sediments and carved out the valley now occupied by the Minnesota River. Smaller drainages began to develop after River Warren subsided, and those tributaries to the Minnesota River began to erode the valley walls left behind by the glacial river. The Credit River is one of these drainages, and steep valley walls are typical in the middle section of the Credit, where the channel has cut down into the old glacial river terrace.

The soils along the Credit River are composed primarily of silt, with some sand, clay and loam intermixed (Figure 5C). The predominance of silt is due to the glacial activity during the Pleistocene Epoch that ended approximately 10,000 years ago. Glacial lobes from the northeast and northwest carried sand and clay-based drift from Lake Superior, northwestern Minnesota, northeastern North Dakota, and Manitoba, and deposited it in southern Minnesota, including throughout Scott County.

There is little variation in topography through much of the Credit River watershed. The topographic features that are present are primarily glacial in origin, such as moraines, eskers, kames, and kettle ponds. Kettle ponds are the main feature that has resulted in the occurrence of land-locked bodies of water. There are many small ponds in the Credit River watershed that have no overland outlet and are dependant on precipitation to maintain their form and function. These land-locked ponds are particularly susceptible to polluted runoff as it takes the water much longer to cycle out of the system than in ponds with inlets and outlets.

From the headwaters to approximately 18 miles downstream, the elevation of the channel decreases 250 feet. In the final 4 miles to the Minnesota River, the channel elevation drops an additional 175 feet. Most of the decrease in elevation in the first 18 miles occurs within three, 1 to 2-mile steeper sections, surrounded by a cumulative 12 miles of relatively low-gradient channel (Figure 6). The low-gradient sections of channel are located in wide, flat alluvial valleys; if these channels have not been straightened and ditched into agricultural channels, they are often in the form of wetland channels. The Credit River has eroded a narrow alluvial valley through the bluff near the Minnesota River with steep valley walls that rise more than 75 feet in some areas (Figure 7).

3.2. Historic Conditions

Most of the arable land within Scott County was converted to farmland starting approximately 150 years ago; to create this farmland many of the smaller rivers and streams were straightened and ditched and most of the wetlands were drained. Settlement began after two treaties were signed with the Dakota Indians in 1851 and 1853. As settlers arrived, the hardwood forests that dominated the region were removed to make room for crops.

The earliest survey of the region was conducted in the early 1850s and published in

Figure 6: Longitudinal profile of the Credit River based on 1:100,000 scale topographic maps.

1855. These platmaps indicate that the Credit River channel maintained a high degree of sinuosity from the headwaters to the mouth (Figure 8); additionally, the map indicates that low-gradient wetland channels were likely the predominant channel form from the present-day County Road 68 crossing upstream to the 230th St. E. crossing (the river does not continue upstream of this location on the 1855 maps). The straightened ditches that characterize many of the reaches higher in the watershed were created between 1855 and 1937. The 1937 series of aerial photographs indicate that the channel planform looks much the same in 1937 as it does today (Figure 9).

3.2.1. Wetlands

The 1855 platmaps indicate that the Credit River channel is sinuous through some of the wetland regions and non-existent in others, indicating that water flowed diffusely through some wetland areas rather than along a distinct channel. Though it can be assumed that these maps do not precisely indicate the planform of the channel, it is likely that sinuous channels were present in some wetlands and not in others. One difference that was observed in the 1937 photographs was the absence of wetlands that appeared to be present on the 1855 platmaps and that are currently present along the Credit River (Figure 10). The drought that occurred during the 1930s caused many of these wetlands to diminish or disappear and created more potential farmland.

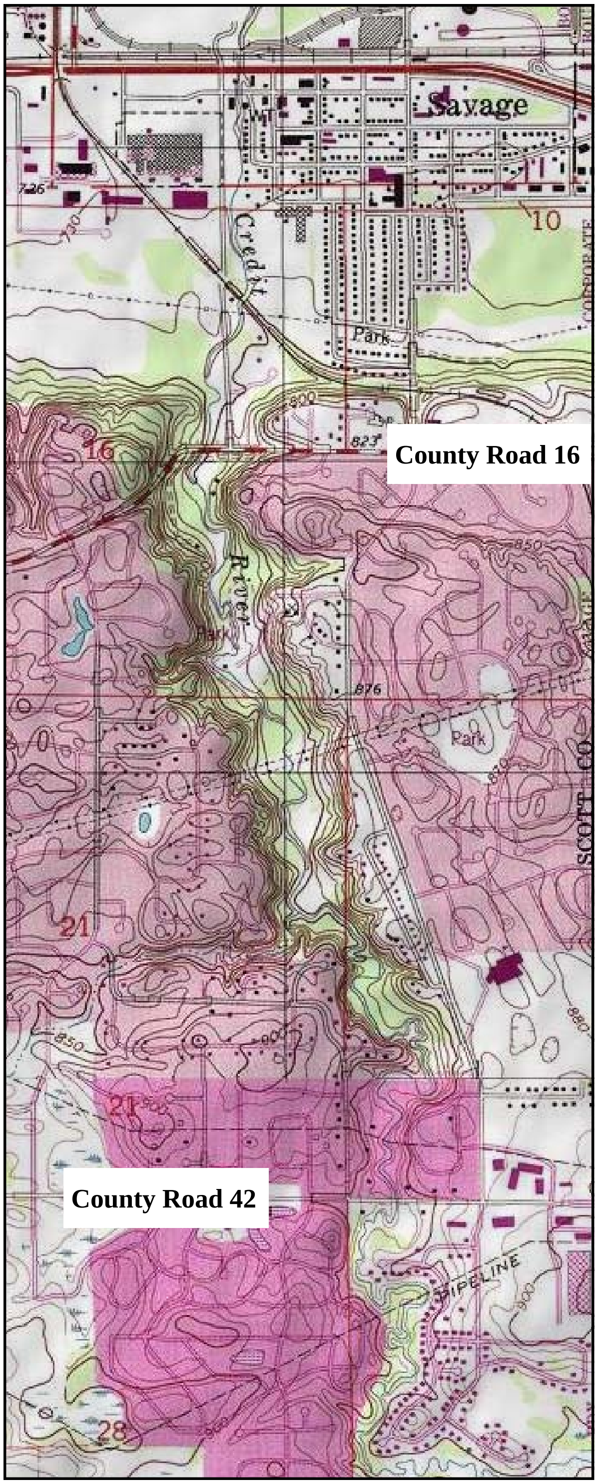


Figure 7: Shaded topographic image of the Credit River and the steep bluff between County Roads 42 and 16. Contour lines are 10 feet.

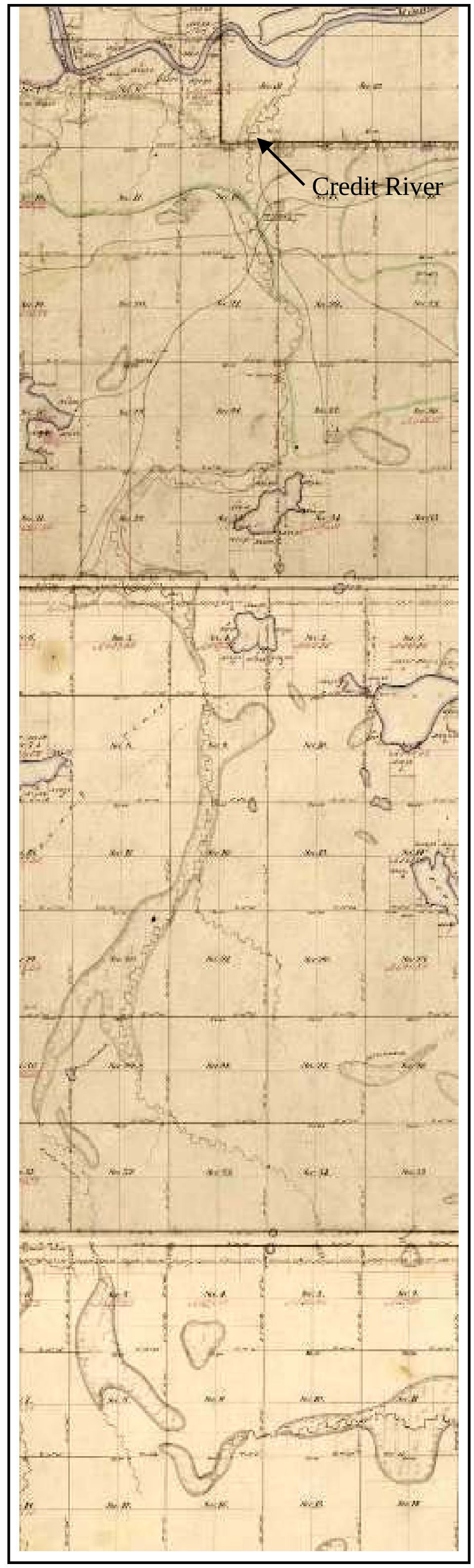


Figure 8: 1855 plat map from first survey completed in the area. The Minnesota River is the large river into which the Credit River flows.

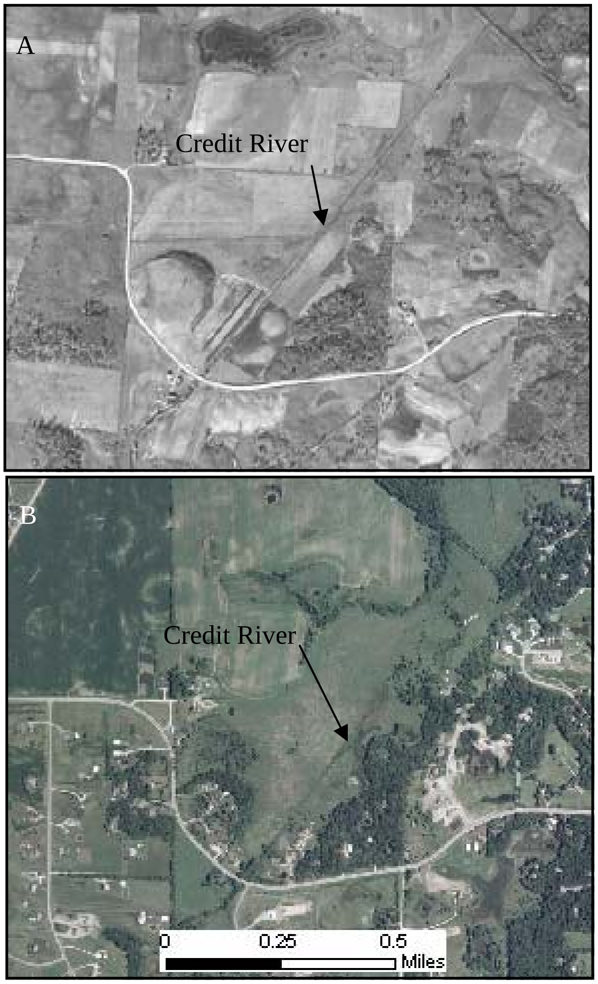


Figure 9: The planform of the Credit River has remained largely unchanged between 1937 (A) and 2003 (B).

Figure 10: A section of the Credit River was first characterized as a wetland channel in 1855 (A); this section was later turned into farmland and was essentially dry by 1937 (B), but it has since returned to a wetland that is dominated by reed canarygrass (C). Each grid in *A* are equal to 1 mile.

The active crop rows visible in the 1937 photographs are still visible within the wetland on the 2003 aerial photographs, but these areas are no longer actively farmed and are generally dominated by reed canarygrass (Figure 11).

3.2.2. Forestry

Hardwood forests dominated Scott County prior to the logging that began shortly after settlement in the 1850s. Today, only scattered remnants remain of what was the Big Woods

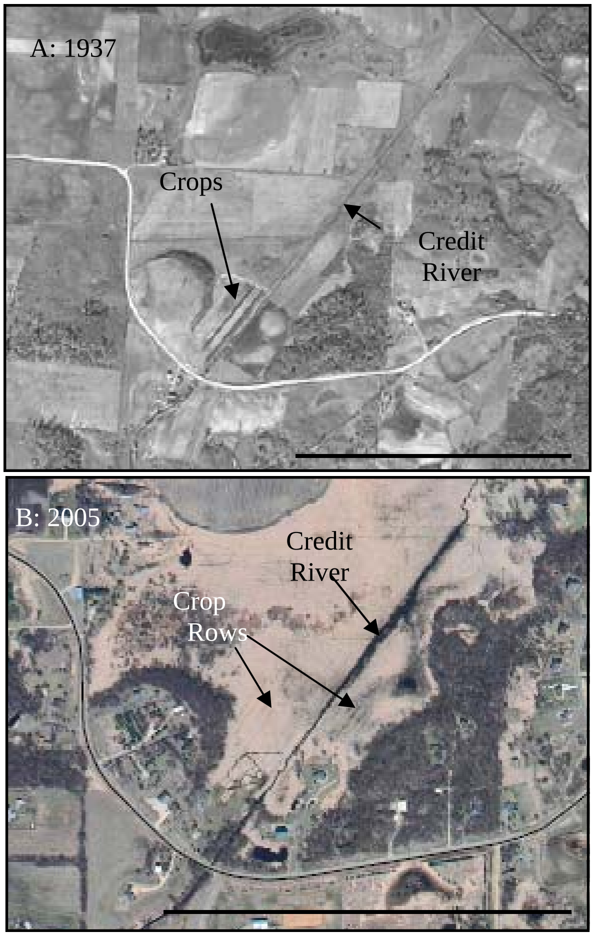


Figure 11: Some land adjacent to the Credit River that was farmland in 1937 (A) has since been converted to wetland with the crop rows parallel to the Credit River still visible from the air during spring or fall (B). Scale bar is approximately equal to 0.5 miles.

ecosystem, an expansive maple-basswood forest that covered 3,400 square miles east of central Minnesota and stretching to Southern Illinois. The largest remaining tracts of Big Woods are the Cannon River Wilderness Park (1,100 acres), Seven Mile Woods (700 acres), and Nerstrand Big Woods (1,300 acres) in Rice County. These hardwood forests provided abundant aquatic habitat with shade cover and woody debris in the form of trunks, large branches and root masses. Large woody debris, as it is commonly known, provides channel complexity as log jams develop, which cause sediment deposition within, and upstream of, the log jam and also cause scouring downstream of the log jam. Log jams can cause the channel to change its course by eroding cut banks or directing flow onto the floodplains, which causes new channels to form. This channel complexity creates habitat complexity that allows a high diversity of macroinvertebrate and fish species to survive. Since most of the forests were eliminated in the late 1800s, many channels have become more stable and less complex, resulting in decreased habitat complexity and decreased biotic diversity. Additionally, the shade provided by the hardwood forests is no longer available, likely increasing water temperatures and reducing the amount of protection from aerial predators. In some reaches of the Credit River, particularly in the steep reaches near the confluence with the Minnesota River where building could not occur because of the steep valley walls, there are still trees covering the hillsides and floodplains that provide shade and woody debris. However, this is a relatively short reach with no upstream woody debris source. Wood that does reach the channel is typically too small to remain in place for very long, and is washed downstream during floods.

3.2.3. Agriculture

Agriculture began with initial settlement in the 1850s. Currently, corn and soybeans are the primary crops with more than 38,000 acres of corn and 34,000 acres of soybeans harvested in

2005 (Scott County data available on website: http://www.city-data.com/county/Scott_County-MN.html). In addition, there was less than 1000 acres of wheat and vegetables harvested. Crops occupied approximately 75% of all farmland, with cattle likely occupying much of the remaining 25%.

3.2.4. Development

Although the major road systems around the Credit River valley have been in place since prior to the 1880s, development was limited prior to World War II. In the early 1980s, the first subdivisions were being constructed (based on 1984 county landuse map – Appendix A), and by the late 1990s, most of the existing developments were in place (based on 1997 county landuse map – Appendix B). In 2005, over 20% of the land in Scott County was residential, 1.4% was non-residential (commercial, industrial, extraction, or utilities), 0.3% was public or institutional, 5% was parks and open space, 54% was agricultural or undeveloped, and 19% was municipal or tribal land (Scott County Community Development, 2007). There is likely a similar distribution of land use in the Credit River watershed as most of the watershed is farmland, with residential development increasing with increased proximity to the Minnesota River. Though data for the Credit River watershed is unavailable, more than one third of the residents in Scott County use a septic system (http://www.co.scott.mn.us/wps/portal/ShowPage?CSF=876&CSI=35146192801002ps). A map developed by the University of Minnesota indicates that impervious cover accounts for approximately 5% of the Credit River watershed (http://land.umn.edu/quickview_data/index.html). Studies have shown that development of watersheds beyond 10% impervious cover results in the extirpation of most coldwater species, including salmonids from coldwater streams (Schueler, 1994). Minnesota DNR fisheries studies from 1985 and 1991 show only warmwater species such as black bullhead, green sunfish, carp, and fathead minnows (Ebbers 1985).

Subdivisions continue to be built as more people move into the suburbs of Minneapolis/St. Paul. There were multiple subdivisions encountered while conducting fieldwork that were not on the 2003 aerial photographs. This expansion will likely continue as farmland is sold to developers to accommodate the influx of residents. Amidst all of this development, there are two parks encompassing 3445 acres within the Credit River watershed that are managed by the Three Rivers Park District. Murphy-Hanrehan Regional Park Reserve (2400 acres) is undeveloped except for trails and provides high quality native plant and animal habitat. Cleary Lake Regional Park (1045 acres) provides many recreational opportunities including boating on Cleary Lake and golf at the Cleary Lake Golf Course.

3.3. Existing Geomorphology

Inter-Fluve geomorphologists conducted

Table 2: Length of each reach along the mainstem of the Credit River and the river station for the upstream and downstream extents of each reach.

Reach Number	Length of Reach (miles)	Distance from Mouth of Credit River (miles)	Beginning Station (ft)	End Station (ft)
1	0.61	0.61	0	3200
2a	0.38	0.99	3200	5200
2b	0.61	1.60	5200	8400
3	2.61	4.21	8400	22200
4	2.42	6.63	22200	35000
5	0.44	7.07	35000	37300
6	3.11	10.18	37300	53700
7	0.30	10.48	53700	55300
8	0.42	10.90	55300	57500
9	1.72	12.62	57500	66600
10	0.61	13.23	66600	69800
11	1.86	15.09	69800	79600
12	1.69	16.78	79600	88500
13	0.19	16.97	88500	89500
14	1.50	18.47	89500	97400
15	0.59	19.06	97400	100500
16	0.91	19.97	100500	105300
17	0.40	20.37	105300	107400
18	0.42	20.79	107400	109600
19	0.63	21.42	109600	112900
20	1.29	22.71	112900	119700
Total	22.71			

detailed investigations of the Credit River watershed in an effort to identify areas of bank instability, excessive incision or deposition, channel change due to human engineering, and fish-passage barriers. More than 22 miles of the Credit River were divided into 20 distinct reaches based primarily on channel planform and adjacent land use. The average reach length was 1 mile, though reaches ranged from less than 0.5 miles to more than 3 miles in length (Table 2). In addition to the mainstem of the Credit River, we also assessed the geomorphology and habitat quality of 10 tributaries (Table 3).

3.3.1. Reach 1

Reach 1 of the Credit River is a single-thread channel that extends 0.61 miles from the Minnesota River upstream to the state Rt. 13 bridge crossing. The channel is trapezoidal in cross-section and is 15 to 25 feet wide with 3 to 4-foot steeply sloping banks (Figure 12). The floodplains are 5 to 15 feet wide benches inset into a high terrace on the left bank (horse race track in the early 1900s) and an engineered levee

Table 3: Location of tributaries to the Credit River.

Tributary Number	Distance of confluence from mouth of Credit River (miles)	Mainstem Station at Confluence (ft)
1	1.9	10100
2	3.0	15700
3	3.3	17400
4	6.0	31600
5	10.6	55900
6	13.9	73400
7	14.0	74100
8	15.8	83600
9	16.9	89000
10	18.3	96600

Figure 12: Reach 1 of the Credit River; station 1750 looking upstream. Notice the high berm on the left side of the photograph (river right).

on the right bank that is 15 to 20 feet higher than the channel bed. Large cottonwoods growing on this narrow floodplain are 40 to 50 years old, a finding supported by aerial photograph comparison. In the 1957 aerial photographs, the Credit River channel meandered northeast to the Minnesota River; by 2003, the main channel flowed north in a straight channel with no sinuosity and little channel complexity. The meandering channel of 1957 is visible on the 2003 aerial photographs, and was apparent during the field investigations in 2007 (Figure 13). The bed of this relict meandering channel is currently buried under approximately 8 to 10 inches of organic material and silt. The current, engineered channel was likely completed in the 1960s for flood control as the high levees extend along the Minnesota River as well. The channel alterations have resulted in a channel with few riffles or bars and no interaction with the original floodplain; there is little bank erosion and few pieces of large woody debris that might result in some channel and habitat complexity.

Upstream from the reconstructed portion of Reach 1 the gradient is higher and the channel is in sediment deficit resulting in the emergence of bedrock in a number of locations. Near the mouth of the Credit River, there is a backwater effect from the higher water surface elevation of the Minnesota River (one cause of this is likely the altered location of the mouth of the Credit River). This backwater effect has resulted in a lower water velocity and subsequent increased sediment deposition. The channel in the lower 0.2 miles of Reach 1, therefore, is in sediment surplus and the bed has aggraded multiple feet with sand and silt and has resulted in increased overbank floodplain deposition.

3.3.2. *Reach 2*

Reach 2 extends nearly a mile from State Highway 13 upstream to County Road 16. We divided Reach 2 into two subreaches, with Subreach 1 extending 0.38 miles upstream from State Highway 13. Subreach 1 is a relatively straight, urban channel with limestone bedrock outcropping in the bed of the channel in a few locations. Though it may have been straightened historically, the channel in Subreach 1 might be naturally straight due to the steep gradient in this area. There are few gravel/sand bars but pools are common. The riparian corridor is narrow with active floodplains that extend about 20 feet on either side of the channel and provide the only buffer from the heavy development to the east and the industrial zone to the west. Culverts

Figure 11: The location of the lower Credit River changed between (A) 1957 and (B) 2003.

under the road crossings of State Highway 13 and 123rd St. may be fish barriers at low flows. However, minnows, chub, and crayfish were observed, indicating that there is some reasonable habitat with protected undercut areas caused by bedrock or shade from some overhanging vegetation.

Subreach 2 is a stable, meandering reach with fairly good habitat (Figure 14). There is channel complexity with gravel bars, sandy pools, cut banks, and meanders. Though there are dense residential neighborhoods nearby and multiple road crossings, the actual riparian corridor is wooded and mostly free of development, likely due to the steep bluffs on either side of the channel. The floodplains are wide and contain recent (1 to 2 years) deposition of sand and silt as well as 1 to 2-year old reed canarygrass and other forbs. The channel complexity combined with an active floodplain has resulted in good habitat conditions with abundant fish and invertebrate species present.

3.3.3. Reach 3

The Credit River through Reach 3 maintains a high-gradient, sinuous channel for 2.61 miles from County Road 16 to County Road 42.

Figure 14: Reach 2, Subreach 2, station 6600 looking upstream.

Though the riparian corridor is surrounded by densely populated residential developments, the channel and floodplains have remained free from substantial alterations because of the steep valley walls that allow little development from occurring within a few hundred feet of the channel (Figure 15). Therefore, this is a relatively natural, meandering reach with active cut banks and developing point bars, floodplains that are inundated on a 1 to 5 year recurrence interval, a channel with a steep gradient that results in regularly spaced riffle-pool sequences, and

Figure 15: Reach 3, station 9000 looking upstream.

riparian vegetation of varying maturity that provides large woody debris as well as fine and coarse organic matter to the channel. This channel complexity provides habitat variability important to aquatic life.

Despite the relatively healthy state of this reach, there are a number of concerns. Of the few landowners residing adjacent to the channel, we observed evidence of one that had excavated gravel from the channel and deposited material elsewhere in the channel. Another landowner had built a small stone dam across the channel providing a fish-passage barrier at low flows and had also cleared all of the riparian vegetation from the channel banks with mowed turfgrass being managed to the edge of the channel. In the vicinity of Hidden Valley Park (Station 10700 to 12300) a poorly constructed footbridge has modified local hydraulics and caused excessive bank erosion, and the bridge footing area with poured concrete. This concrete is already being undercut and should be viewed as a temporary solution. At one corner of the Hidden Valley Park parking lot, there is an asphalt drainage chute that concentrates all parking lot runoff during rainstorms directly into the channel. There is no riparian buffer and no opportunity for excess water to drain more slowly through floodplain soils. Hidden Valley Park is well used and this has caused many of the banks to experience excessive bank erosion and loss of riparian vegetation. This reduces canopy cover, increases sediment delivery to the channel, and reduces the

Figure 16: Tributary 1 looking downstream; confluence with Credit River is at station 10100.

effectiveness of any remaining riparian corridor.

Tributary 1 is a small tributary that enters Reach 3 approximately 1.9 miles from the mouth of the Credit River (Station 10100). This tributary originates in the residential developments built on the bluff above the Credit River and has eroded an incised channel with steep banks. The channel is 2 to 4 feet wide and there are no well-defined floodplains (Figure 16). There is an active knick-point about 200 feet from the Credit River that is progressing slowly upstream as a result of abnormally high concentrated flows originating from the upstream residential development and possibly a base-level drop in the main channel. The knick-point has created a 6-foot headcut in the channel.

Tributary 2 extends about 2000 feet from its confluence with the Credit River (Station 15700) to a pond between Vernon Avenue and Utica Avenue (Figure 17). The tributary flows through a 5-foot concrete pipe underneath Utica Avenue 500 feet downstream from the pond. The pipe is perched 2.5 feet on the downstream side, and much of the riprap that was placed to stabilize the banks has been washed downstream. Active progression of successive headcuts has caused the channel to down cut roughly 5 to 6 feet. This incision has, for the time being, been slowed at Utica Avenue, but the crossing is in danger of failure due to future incision and subsequent erosion around the outlet. Previous reconstruction of the channel has occurred near the Princeton Court development. Riprap was placed within the channel and along the banks, but does not appear to have accounted for incision, and does not include any visible gravel or fabric filter component. Riparian vegetation was removed and the right bank is managed for turfgrass, although the degree of incision is independent of vegetation treatment in this case. Much of this riprap has been moved by high flows and downcutting, and is no longer providing the designed stability. The lack of riparian vegetation has reduced bank stability and canopy cover.

Figure 17: Tributary 2 looking upstream; confluence with Credit River is at station 15700.

Tributary 3 is a short tributary that originates in the residential developments on top of the bluff and empties into the east side of the Credit River at Station 17500. Similar to Tributary 1, this is a steep, narrow channel with some scouring and incision (Figure 18). There are no headcuts, but the channel is deeply incised with steep hillsides for banks. This may be the natural form of the tributary, or it may be exacerbated by the channeling of rainwater off of the streets and driveways directly into the channel.

Figure 18: Tributary 3 looking upstream; confluence with the Credit River is at station 17500.

3.3.4. Reach 4

Reach 4 extends 2.42 miles from County Road 42 to River Crossing Road. This is a sinuous reach with wide, undeveloped floodplains similar to Reach 3 (Figure 19). The gravel and sand bed is mobile and there are riffles and pools regularly spaced; active cut banks are prevalent as are point and bank-attached gravel bars. There is floodplain deposition and the riparian vegetation is of varied maturity, providing a mix of large and small woody debris and organic matter to the channel.

Figure 19: Reach 4, station 30500 looking upstream.

Residential development, though dense, has been limited, with a few exceptions, to the relatively flat land on top of the bluff, high above the channel and separated from the channel by steep valley walls. Of the residences near the channel, eight landowners have replaced the riparian vegetation adjacent to the channel with mowed turfgrass, gardens, or stone walls. Riprap has been installed in a few locations, with some treatments failing and increasing bank degradation. Additionally, two small stone dams crossing the channel are fish passage barriers at low flows.

Tributary 4 is a low-gradient tributary that joins the Credit River 6 miles from its mouth. Two branches of the tributary that originate in residential developments come together in a wetland that extends to the Credit River. The wetland channels are in good condition; the only restoration needed would be native wetland plant restoration to combat the exotic reed canarygrass (*Phalaris arudinacea*) that currently dominates the reach.

3.3.5. Reach 5

Reach 5 is a short reach that extends 0.44 miles from River Crossing Road upstream to the beginning of a low-gradient, wetland channel. This reach has most of the same fluvial geomorphic and ecological characteristics as Reach 4, but landowners have not negatively impacted the floodplains or channel to the same degree. There is little development within the vegetated riparian corridor that is up to 200 feet wide and there are few occurrences of attempts at restricting channel migration with riprap or concrete bank stabilization methods. The channel is meandering with active cutbanks and gravel bars and there is some large woody debris within the channel (Figure 20). The channel bed alternates between riffles and pools with the riffles composed primarily of cobbles and the pools composed primarily of sand and cobbles. This channel diversity creates high quality habitat for the fish and macroinvertebrates observed. There is evidence of overbank sandy deposition and previous channels found on the floodplains indicate active channel migration.

Figure 20: Reach 5, station 35400 looking upstream.

The canopy cover is diverse and includes green ash, black willow, cottonwood, elm, maple, and oak; these trees range in age from saplings a few years old to approximately 50 years old. One landowner is managing mowed turfgrass in the riparian area, but there is a narrow buffer of riparian vegetation between the lawn and the channel. Another landowner has cleared much of the undergrowth on the floodplain but has retained the overstory.

3.3.6. Reach 6

Reach 6 is a wetland reach extending over 3 miles from the upstream extent of Reach 5 to County Road 74 (Station 37300 to 53700). The channel geometry is primarily rectangular with sporadic narrow sand bars (Figure 21). The channel planform is extremely sinuous and there are many secondary channels and abandoned channels, indicators that this wetland channel is actively migrating within the alluvial valley. The bed of the channel consists primarily of sand, whereas the banks are silt with some peat; there are a few short riffles created by large woody debris or large embedded clasts and many pools of varying depths. Though there is no canopy cover from riparian vegetation, there are overhanging banks in some locations that provide protection from predators and heat. The wetland is dominated by exotic invasive reed canarygrass. There are three wooden box culverts under County Road 74 that are fish passage barriers at low flows.

The form of the channel in this reach is somewhat dependant on the regional climate. The boundaries of the current wetland are similar to those made by the first surveyors on the 1855 plat maps. The construction of County Road 27, and the berm associated with the road, appears to have forced the Credit River to the east of the road and eliminated the possibility of any westward channel migration. However, analysis of the 1855 maps indicates that there was a trail in the same location as County Road 27, and this trail does not pass through the wetland. Therefore, the Credit River has likely remained in its current location since early settlement except for local migration within the meander beltwidth of the channel, and the highway may have had little impact on the Credit River within Reach 6. In 1937, Reach 6 was entirely farmland. The historic Credit River was still a meandering channel, but the land was cultivated to the channel banks, except in some areas where there were a few trees separating the crops from the channel. A long period of drought or dewatering must have occurred for the wetlands to disappear and riparian trees to flourish.

3.3.7. Reaches 7-8

Reaches 7 and 8 are grouped together in this discussion due to similarity of character (Figure 22). Reach 7 extends 0.3 miles upstream from County Road 74 through a narrow (100 to 300 feet) wetland with adjacent farmland. Reach 8 extends another 0.42 miles upstream through a much wider (more than 1500 feet wide) wetland that is adjacent to both farmland and newly developed residential neighborhoods. The channel through Reach 7 is single-thread, whereas the Reach 8 channel has multiple active

Figure 21: Reach 6, station 52300 looking upstream.

Figure 22: Reach 7, station 53300 looking upstream.

side channels as well as some abandoned channels. The channel through Reach 8 is able to migrate laterally to a much greater extent than through Reach 7 because of its greater belt width (wide undeveloped floodplain). There is only one short section of Reach 7 through which the landowner has removed any wetland or riparian vegetation and has mowed turfgrass to the edge of the channel. Invasive reed canarygrass dominates the riparian vegetation in these reaches.

Although marked as wetland on the 1855 platmaps, reaches 7 and 8 were meandering channels through farmland with narrow riparian buffers in the 1937 aerial photographs (Figure 23). Crops were grown to within 100 feet of the channel, and channel migration was restricted to within this narrow riparian corridor. Since this period of drought and intense farming, the area has reverted back to a wetland; many invasive

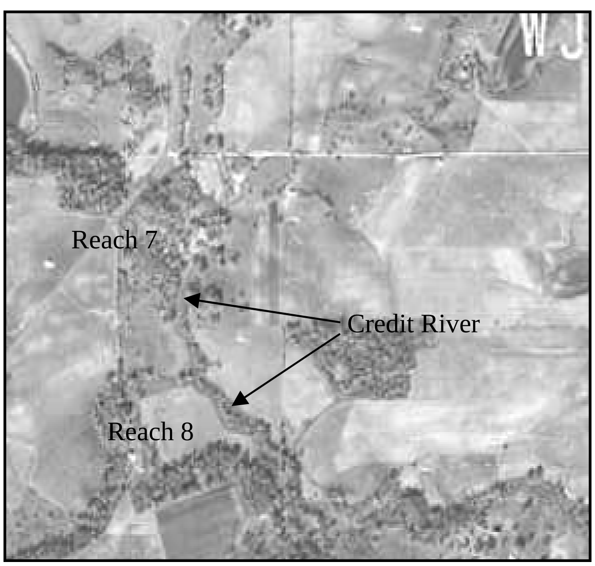


Figure 23: In 1937, the channel in Reach 7 and 8 had a narrow riparian buffer separating it from adjacent agriculture fields.

plant species thrive in disturbed areas, and the reed canarygrass likely spread throughout the farmland soon after it was abandoned.

Tributary 5 joins the Credit River from the west side of the wide wetland of Reach 8. It is a meandering channel with active, wooded floodplains before it reaches the wetland through which it meanders before joining the Credit River. Though a dirt driveway does cross over this tributary, there are no major areas of concern apart from reed canarygrass monoculture in the riparian wetland areas.

3.3.8. Reach 9

Reach 9 extends 1.72 miles from just downstream of Hampshire Road to just downstream of Murphy Lake Boulevard. The channel through the entire reach is sinuous with no evidence of historic straightening, ditching, or other channel reconstruction. However, we divided this reach into three subreaches based on channel type (Figure 24). Subreach 1 is primarily a single-thread meandering reach with forested floodplains and surrounding hillsides. The valley width is approximately 0.6 miles (3100 feet) and there is farmland to the north and some residential development to the south. However, the floodplains are active with riparian vegetation of varying maturity and relatively minimal human disturbance. Historic channels through the floodplains likely become activated during floods, increasing habitat potential. The channel maintains regularly spaced gravel-dominated riffles and sand-dominated pools;

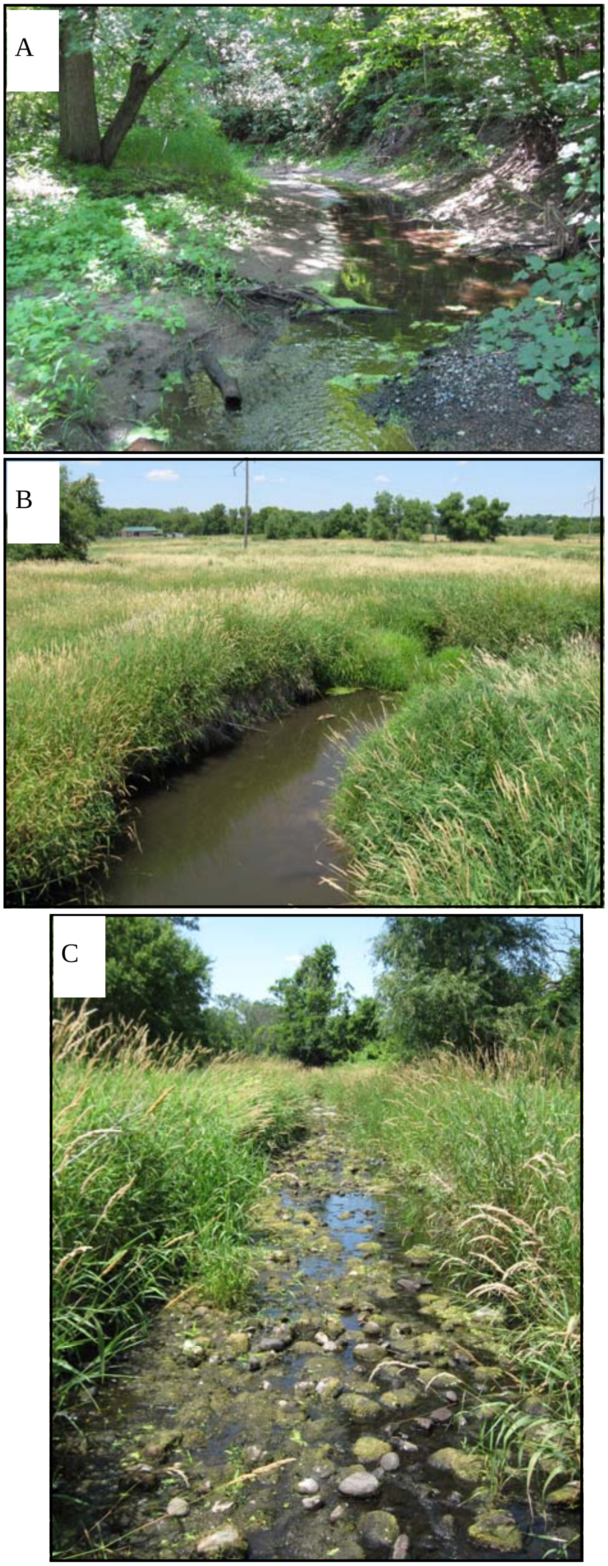


Figure 24: Reach 9, (A) Subreach 1 at station 58900 looking upstream, (B) Subreach 2 at station 63450 looking downstream, (C) Subreach 3 at station 65900 looking downstream.

undercut banks and canopy cover provide good protection from predators.

Subreach 2 is a wetland reach and the channel is sinuous with multiple active and abandoned side channels. Though there is farmland on the adjacent hillsides, the wetland is up to 800 feet wide and the valley crests are over a mile apart. This wetland appears to have remained intact through the drought of the 1930s, though it is difficult to determine with the low quality of the aerial photographs. However, cultivated row crops are not apparent near the channel and there appears to be open land with sporadic mature trees, indicating that it could have been a wetland in 1937 with similar characteristics as today. In the 1957 aerial photographs, the wetland is present with a few trees growing throughout the wetland. There is no distinct channel through the wetland indicating that flows were diffuse and then came together as a single channel at the upstream and downstream extents of the subreach. Channel migration is common in this subreach, as evidenced by the frequent active or abandoned side channels. The bed consists mainly of sand and the channel is dominated by runs with many pools of varying depths. A few riffles with small gravel on the bed are also apparent. A covered bridge about 1000 feet upstream from Hampshire Road crosses the Credit River and the structure that was built below it to provide water flow is a complete barrier to fish passage. Below the covered bridge is a solid concrete foundation with four, 2.5-foot pipes for water flow. On the downstream end of this foundation is a 7.5-foot by 18-foot concrete apron that is perched 1 foot above the channel. At low flows, fish are completely blocked from upstream or downstream travel.

Subreach 3 has a steeper gradient than Subreaches 1 and 2 and the channel has a cobble bed. The alluvial valley is narrower and there are steep hillsides to the west and south. There is less canopy cover in this subreach than in Subreach 1 as much of the riparian and surrounding vegetation has been removed.

3.3.9. Reaches 10-14

We grouped Reaches 10 through 14 in this discussion because these reaches have been heavily impacted by human engineering since agriculture began in the region. Reaches 10 through 14 span 5.85 miles of the Credit River and are primarily straightened agriculture ditches with little or no riparian buffer between the crops and channel. The water flow is not continuous through these reaches during periods of low flow, which is likely due to dewatering. Reach 10 has a slightly meandering channel with wide, active floodplains that are heavily vegetated. An abandoned railroad berm restricts channel migration 100 feet downstream from Murphy Lake Boulevard and the concrete box culvert under Murphy Lake Boulevard is perched 1 foot on the downstream side, acting as a fish passage barrier at low flows.

The remaining four reaches have ditched channels with no sinuosity (Figure 25). In Reach 11, levees up to 15 feet above the channel bed separate farmland from the channel and prevent any overbank flooding. Reaches 12 through 14 are primarily wetland reaches, but the channels are straightened ditches with few curves. A railroad berm divides the wetland about 0.4 miles upstream from Cleary Lake Road in Reach 12 (Station 81500). This berm and the accompanying bridge over the channel were active in the 1937 and 1957 aerial photographs, but today the bridge is gone, and only the berm and wooden piers remain. The berm continues to restrict channel migration within the wetland.

Many of the areas that are currently wetland

Figure 25: Reach 11 at station 71500 looking upstream. Beaver have constructed a small dam creating the pool covered with duckweed.

were row crops in the 1937 aerial photographs, and those crop rows are still visible in the 2003 aerial photographs. Some of these crops were already abandoned and were reverting back to wetland ecosystems when the 1957 aerial photographs were taken. Reach 13, which is currently open water within a wetland, was dry land with a single channel flowing through it in 1937 and was a pond about half its current size by 1957. Complete wetland and channel restoration, coupled with the return of the natural hydrology, are required for these reaches to return to fully functioning riparian and wetland ecosystems.

Tributary 6 flows into the Credit River 200 feet downstream from 175th St. in Reach 11 (Station 73500). This is a straightened ditch emanating from an earthen dam and reservoir within a nature preserve about 1500 feet to the east of the Credit River (Figure 26). The dam is less than 50 years old as it is not present in the 1957 aerial photographs. In 1937 and 1957, this tributary was a straightened ditch that originated further east amongst farmland and wetland.

Figure 26: Tributary 6 looking upstream from dirt road that is approximately 100 feet from the confluence with the Credit River at station 73500. The former wetland is visible in the background.

Tributary 7 flows into the Credit River 300 feet upstream from 175th St. in Reach 11. This tributary has been a straightened ditch between row crops since 1937, though the location of its confluence with the Credit River has changed over the years. This tributary provides no habitat as it is dry for parts of the year, maintains no channel or habitat complexity, and receives all of the runoff from the surrounding farms.

Tributary 8 flows into the Credit River about 0.5 miles downstream from County Road 68. It originates in farmland to the southeast and flows through straightened ditches before it flows under County Road 68. The 4-foot culvert under County Road 68 is perched 4 inches and is a fish passage barrier at low flows due to inadequate depth and perching. Downstream of this culvert, the tributary meanders through a narrow forested riparian corridor between developments before entering The Legends Golf Club. After flowing through the golf course, the tributary flows through a culvert under Brookwood Road and meanders into the wetland before joining the Credit River.

Tributary 9 joins the Credit River in Reach 13, the reach that is currently a small pond within a wetland. This tributary originates in a small pond to the south and has been straightened and ditched since 1937. This tributary provides little aquatic habitat with no channel or habitat complexity and little canopy cover.

Tributary 10 joins the Credit River near the upstream end of Reach 14. It is a short tributary that has been straightened and ditched since 1937. The channel is about 10 feet wide and lies predominantly within a wetland. The bed of the channel consists of 1 to 2 feet of fine silt and sand that has aggraded since the channel was constructed. As with the other ditches in the watershed, this tributary provides little high quality aquatic habitat.

3.3.10. Reaches 15-20

We grouped these six reaches for similar reasons as Reaches 10 through 14: these reaches represent a long section of river, 4.24 miles, that has been substantially altered by human activities (Figure 27). Reach 15 contains a meandering channel with active, wooded floodplains, but there are multiple culverts under private driveways that are fish passage barriers. Reaches 16 through 19 are straightened agricultural ditches with little or no riparian buffer between crops and the channel. There is essentially no sinuosity, canopy cover, or channel or habitat complexity in these reaches. Two fish passage barriers in Reach 16 include a 1.5-foot concrete dam and a 7-foot culvert under County Road 8 that is perched 6 inches on the downstream end. The amount of water in these ditches is variable with dewatering likely the main cause. The channel through Reach 20 is a straightened ditch through wetland. The crop rows of the early 20th century are still visible, but the wetland is now dominated by reed canarygrass. Farming is still active adjacent to the wetland and new residential developments are currently being constructed. The channels through these straightened reaches generally have sand/silt beds with occasional cobble riffles.

Figure 27: Reach 20 at station 116650 looking up-stream.

Though the 1937 aerial photographs only extend the upstream extent of Reach 16, the form of the channel through Reaches 15 and 20 has remained the same since 1937 and 1957. Reach 16 is the only reach that contains sections of channel that were slightly more sinuous in 1957 than they are currently. Portions of these six reaches that are currently wetland were likely farmland in 1937, but were beginning to be converted into wetland by 1957. The channels through these wetlands, however, have remained straightened and ditched.

3.4. Surface Water Hydrology

Seventeen years of mean daily discharge data have been recorded on the Credit River 0.6 and

0.9 miles upstream from the confluence with the Minnesota River between 1989 and 2006 (data for 2002 was not available). The annual hydrograph indicates that the Credit River peak flow generally coincides with the spring snowmelt, but that flows are flashy through the rest of the year and driven by rainstorm events (Figure 28). Winter flows were generally

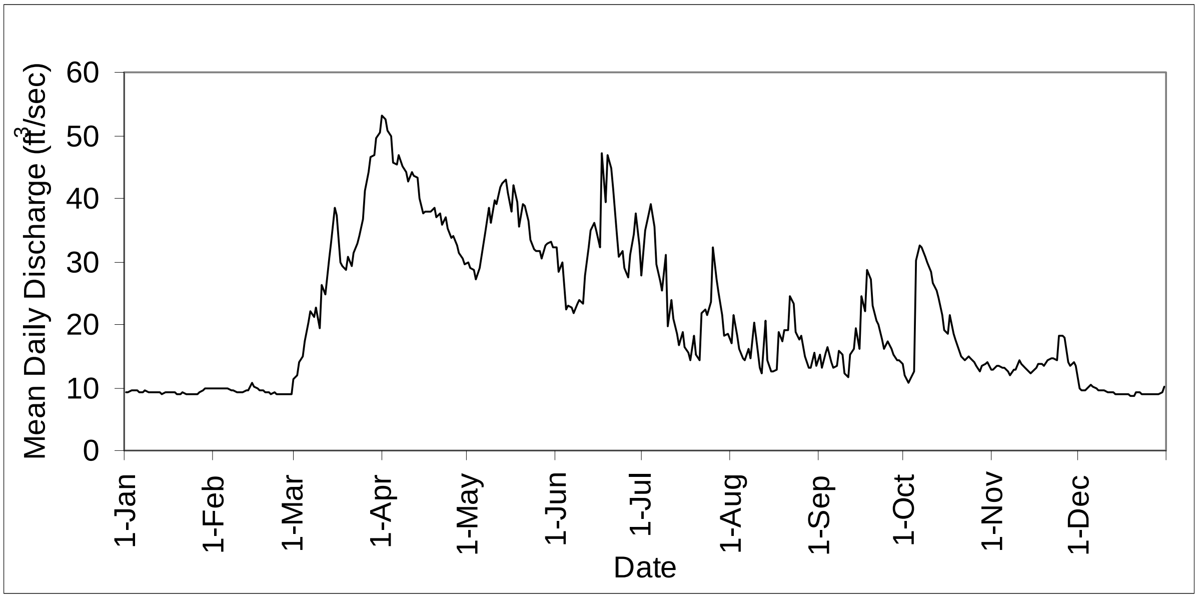


Figure 28: Hydrograph of the Credit River based on average mean daily discharge values from 1989 to 2006 (data for 2002 were not available.

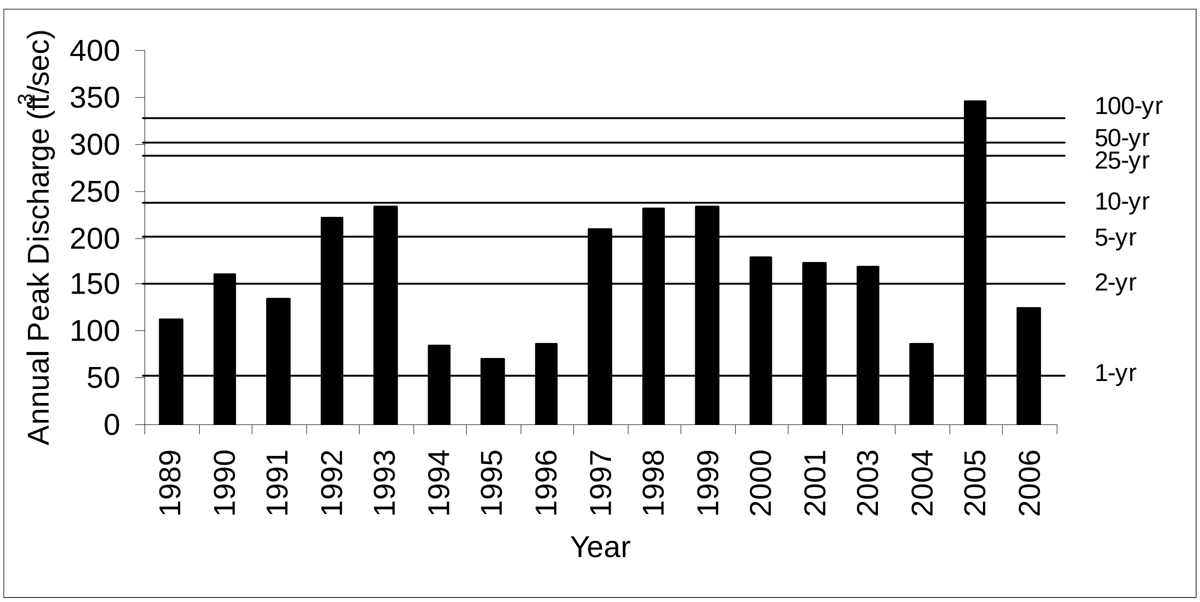


Figure 29: Annual peak discharge for the Credit River based on the greatest mean daily discharge value for each year. Flow data for 2002 was not available. Horizontal lines indicate the magnitude of discharges for the recurrence intervals noted on the right side of the figure.

estimated as a result of ice cover; therefore, base flows of 10 ft^3/sec between early December and early March do not represent actual flow magnitudes.

Though data for only a short period of time were available, analysis of peak flows indicates that periods of wet and dry years occur in cycles of roughly 10 years (Figure 29). Between 1989 and 1993, floods in two of the five years exceeded the magnitude of the 5-year recurrence interval; between 1997 and 2003, floods in three of the six exceeded the magnitude of the 5-year recurrence interval and all exceeded the magnitude of the 2-year recurrence interval. These periods of high flows were separated by floods that did not exceed 100 ft^3/sec. The flood of record occurred in 2005, between two years of flows that did not exceed the magnitude of the 2-year recurrence interval. The flood in 2005 was 346 ft^3/sec and exceeded the magnitude of the 100-year recurrence interval.

The peak flow data indicate that the Credit River floods with a high degree of variability in its magnitude. Through field investigations, we found that the reaches that had not been straightened and ditched had retained functional floodplains. We found recent overbank deposition and piles of woody debris on the floodplains indicating recent overbank flooding. This flooding is important for floodplain plant regeneration and the flux of nutrients between the channel and the floodplains. Floodplains are constructed in response to current hydrologic conditions and available sediment (Wolman and Miller, 1960; Andrews, 1980; Leopold, 1994); the active floodplains adjacent to the Credit River are likely built by relatively common floods similar in magnitude to floods with a 2-year recurrence interval.

These hydrologic analyses only apply to the downstream reaches of the Credit River that are below substantial tributaries. The upstream reaches, particularly those that have been straightened into agricultural ditches, likely operate differently as there are no active floodplains, rainwater drains quickly off of the farmland in to the channel, and there is much less water in the system.

4. 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 simply that some infrastructure (building, road, bridge etc.) would be affected by the project. No specific description is given below.

4.1. 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.

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. 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 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 the upper Credit River, many of these headwater

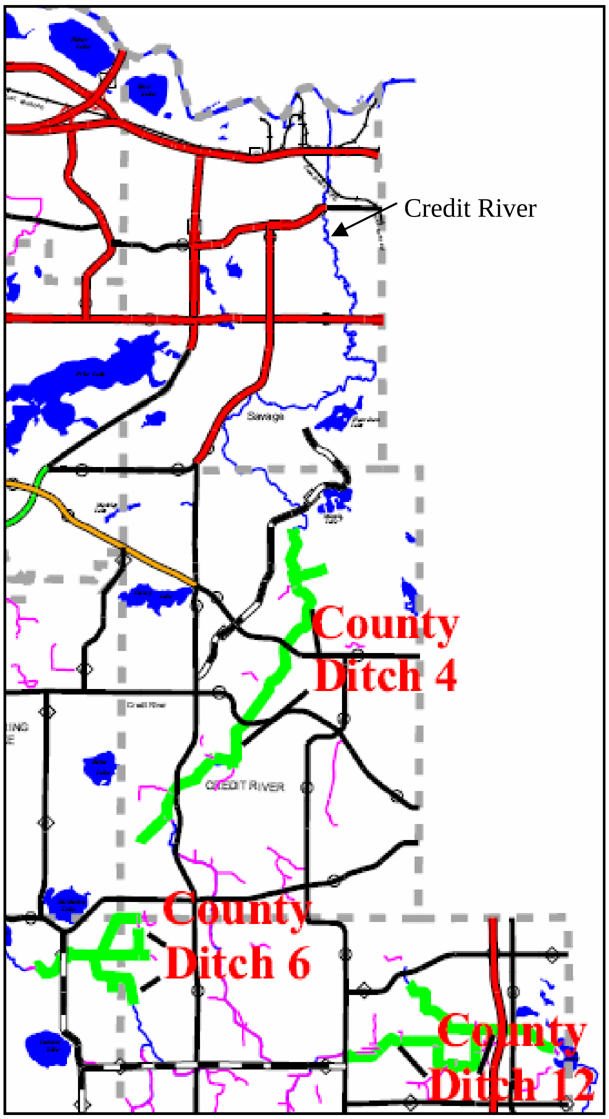


Figure 30: The Credit River is considered a county ditch (#4) between Reaches 11 and 14 and a private ditch (pink line) from Reach 15 to the headwaters at Reach 20. All tributaries upstream from Reach 11 are private ditches. (Modified from map produced by Scott County.)

areas are bordered by wide uncultivated wetlands, and thus restoration would not encroach upon existing agricultural land. 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, upper watershed channels on the Credit River, a reasonable belt width might be in the range of 50 to 100 feet (assuming a channel top width of 15 to 30 feet).

Scott County has identified 42% (9.5 miles) of the Credit River as either public or private ditch (Figure 30). Public ditches make up 23% (5.2 miles) of the Credit River extending from Station 69800 to Station 97400 and including Reaches 11-14. Private ditches make up 19% (4.2 miles) of the Credit River extending from Station 97400 to the headwaters at Station 119700, which includes Reaches 15-20. In addition to the upper 42% of the Credit River being designated as public or private ditch, Tributaries 6 through 10 are also ditches. This means that a substantial proportion of the Credit River watershed could be restored through natural channel restoration or relocation.

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 sinuous channel and the old one is filled in to the floodplain level (Figure 31).

Figure 31: Stream restoration in agricultural areas can sometimes involve reconstructing a new valley form or incipient floodplain (photograph: Inter-Fluve).

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.

4.1.1. Restoration and Ditch Law

A major obstacle in restoring headwater streams is current drainage law, governed in Minnesota by Minnesota Statutes, Chapter 103. The best 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. In Scott County, the County is the drainage authority responsible for operation, inspection and maintenance of drainage ditches. A ditch is owned by the landowners, and therefore the costs for maintenance of ditches is typically borne by the landowners. The three main ways of achieving some restoration in regulatory ditches are 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. The third option involves installation of water control structures to restore wetland conditions, but those structures must be maintained by the landowner.

Wetland restoration as floodplain management ties directly into the discussion of ditch management and natural channel restoration. Although the upper watershed has many reaches with wide wetland buffers, there is still a central ditch and its associated tile lines draining the landscape. 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 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.

A major obstacle to native plant wetland restoration is the ubiquitous presence of reed canarygrass (*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 canarygrass 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.

4.2. 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. Inter-Fluve recommends the latter in natural stream systems to avoid blocking fish passage. Grade control is only warranted at two culvert crossings on the Credit River, where the channel bed could be raised downstream to prevent perching and further undermining of the crossing. In the lower section downstream of County Highway 13, grade control would be incorporated into any natural channel restoration.

4.3. Project type – Floodplain Management

Floodplain management projects vary considerably, but include expansion of riparian buffers, removal of infrastructure, and stormwater management. The Credit River has some development in the lower watershed, and this is expanding rapidly into the upper reaches. 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. One example of retrofitting would be the detention and infiltration of parking lot runoff at Hidden Valley Park, where parking lot runoff currently runs directly into the stream.

4.4. 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 by volunteer labor. Currently the Credit River system has only a few scattered urban lots that have been cleared down to the edge of the stream. However, were more landowners to repeat this pattern, the water quality of the system could sharply decline. 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 typically drains 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 small ditches in the headwater areas of New Market, Credit River Township and Prior Lake may seem insignificant, it is extremely important to buffer these channels. Water pollution in rivers is cumulative. Once you have poor water quality, it doesn’t generally improve as you travel downstream. The headwaters of the Credit River are fairly well protected by wide buffers of grass and forest, but improvements can always be made. Any attempts at reforestation should consider the impact of exotic species such as reed canarygrass and buckthorn. Special measures such as removal and herbicide treatment must be taken before establishing native species.

4.5. Project type – Crossing

Fish passage barriers on the Credit River are of two types, perched culverts and small dams. The dams in question are essentially rock piles placed in the stream, and are not permanent structures by any means. However, during low flow periods, these small rock dams may act as fish passage barriers. The former barrier type, a perched culvert, is found throughout the lower Credit River, particularly at box culvert crossings. 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

Figure 32: Bottomless arch that is partially buried for better habitat and fish passage conditions.

bottom (Figure32). Future road design in Scott County should include training of Public Works officials on the design and installation of fish-friendly culverts.

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.

4.6. 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. The Credit River has made some adjustments over time, but appears to be reaching an equilibrium with the existing hydrology. The only areas of major bank erosion noted were those induced by human activity, generally the clearing of trees and other vegetation from the banks. For the most part, the Credit River is remarkably stable given its watershed landuse. This is mainly due to the presence of wetlands throughout the corridor.

Bank stabilization along the Credit River 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 33)

The least expensive bank stabilization is simply for landowners to leave the stream alone.

Figure 33: Grasses are beginning to grow through biodegradable bioengineering fabric along this restored stream (photograph: Inter-Fluve).

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 34). 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.

Figure 34: The root structure of trees hold the bank material together to stabilize the banks against rapid erosion.

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 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.

4.7. General Recommendations

The Credit River is in remarkably good geomorphic condition for a stream near a major urban center with expanding development and a headwater area dominated by row crop agriculture. However, the stream still suffers from high nutrient inputs, warming and inadequate stormwater management. The Credit River could undergo major landuse changes in the next few years, and preventative measures should be taken to ensure long term stability and stream health. We recommend a top down or headwaters approach to restoration. Installing the most up to date best management practices and innovative stormwater management solutions can improve the health of the Credit River. By focusing on the headwaters and moving downstream, you can isolate problem areas and prioritize overall stream recovery in a systematic way.

4.8. Specific Potential Projects

Inter-Fluve identified 48 potential projects along the main stem of the Credit River as well as seven potential projects along the tributaries (Appendix D). Each of these potential projects were ranked (Appendix E) and described in details. We have provided few specific details regarding the solutions for the problems discussed as the purpose of this study was the completion of a geomorphic assessment, which does not include detailed restoration designs. Once specific problem areas are designated for restoration, more detailed studies and designs must be completed.

In an erosion inventory study completed by the Scott County Watershed Management Organization in 2006, no areas of moderate or severe erosion were identified. The cause of the majority of areas with slight erosion was channel migration and erosion of the outside banks. Recommended solutions were generally a combination of riprap and bioengineering. We did not identify many of these areas as potential project areas as slight erosion on the outside of bends is part of the natural channel migration. However, we did have a few potential projects where bank stabilization was necessary; our solutions focused on bioengineering rather than the placement of riprap.

5. References

Andrews, E.D., 1980. Effective and bankfull discharges in the Yampa River basin, Colorado and Wyoming. Journal of Hydrology 46: 311-330.

Ebbers, M. and Sundmark, L., 1985. Stream survey of the Credit River. Minnesota Dept. Nat. Res. Report, July 1985. St. Paul.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964. Fluvial Processes in Geomorphology. Dover Publications, Inc. New York, NY. 522 pp.

Leopold, L.B., 1994. A View of the River. Harvard University Press, Cambridge, MA. 298 pp.

Lusardi, B.A., 2006. Geologic Atlas of Scott County, MN – Plate 3: Surficial Geology.

Runkel, A.C., Mossler, J.H., 2006. Geologic Atlas of Scott County, MN – Plate 2: Bedrock Geology.

Schueler, T., 1994. The Importance of Imperviousness. Watershed Protection Techniques 1(3), 100-111.

Scott County Community Development, 2007. Scott County 2030 Comprehensive Plan Update. Draft, Scott County, MN.

Schumm, S.A., Harvey, M.D., and Watson, C.C., 1994. Incised Channels: Morphology Dynamics and Control. Water Resources Publication., Littleton, CO. 200 pp.

Snitgen, J. and Melchior, M.J., 2007. A top-down approach to watershed restoration. Poster and presentation, Midwest Fish and Wildlife Conference, Madison, WI.

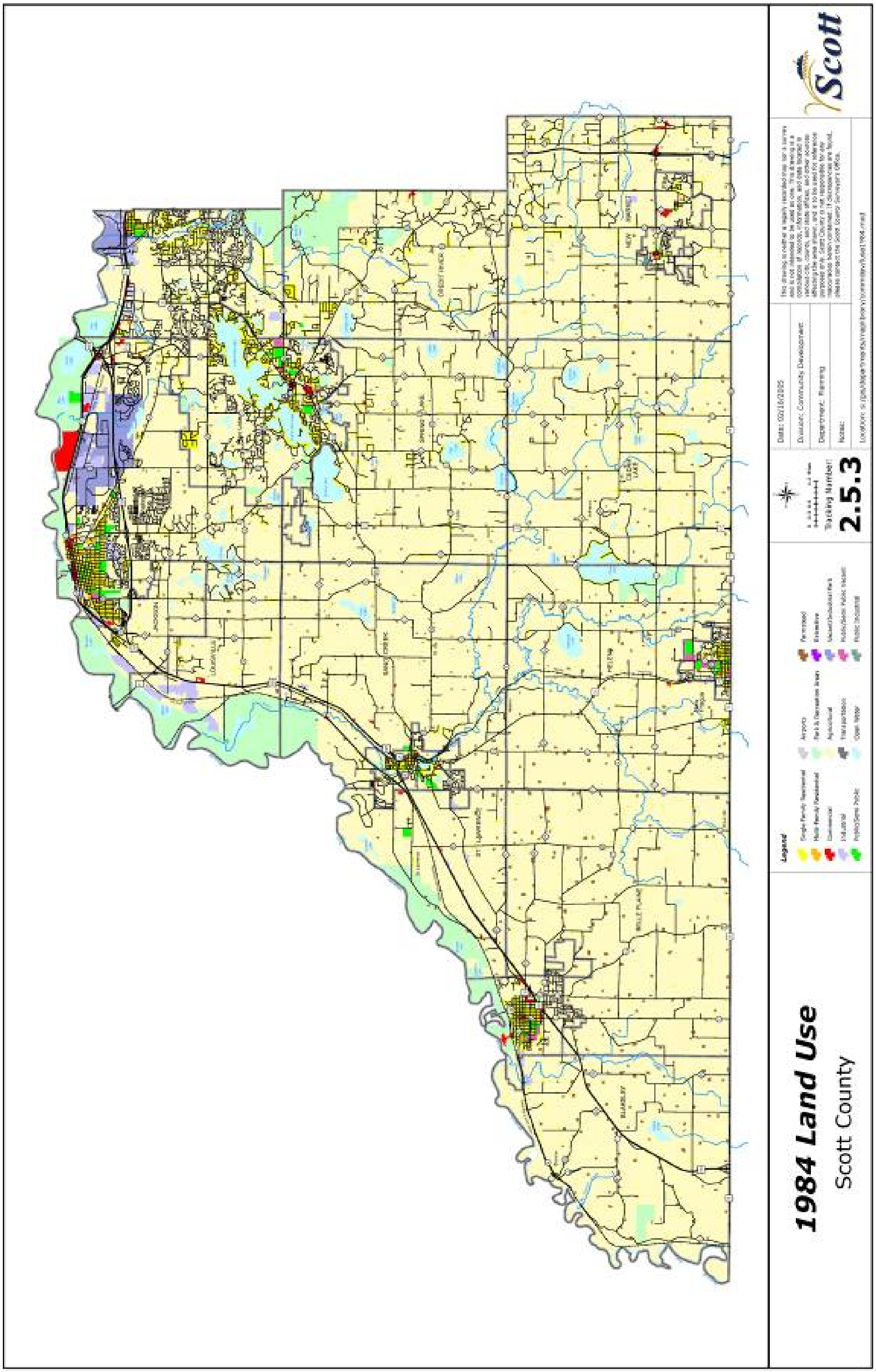
US Department of Agriculture, 1959. Soil Survey: Scott County, MN. Soil Conservation Service in cooperation with Minnesota Agriculture Experiment Station. Series 1533, number 4.

Wolman, M.G., Miller, J.P., 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology 68 (1), 54-74.

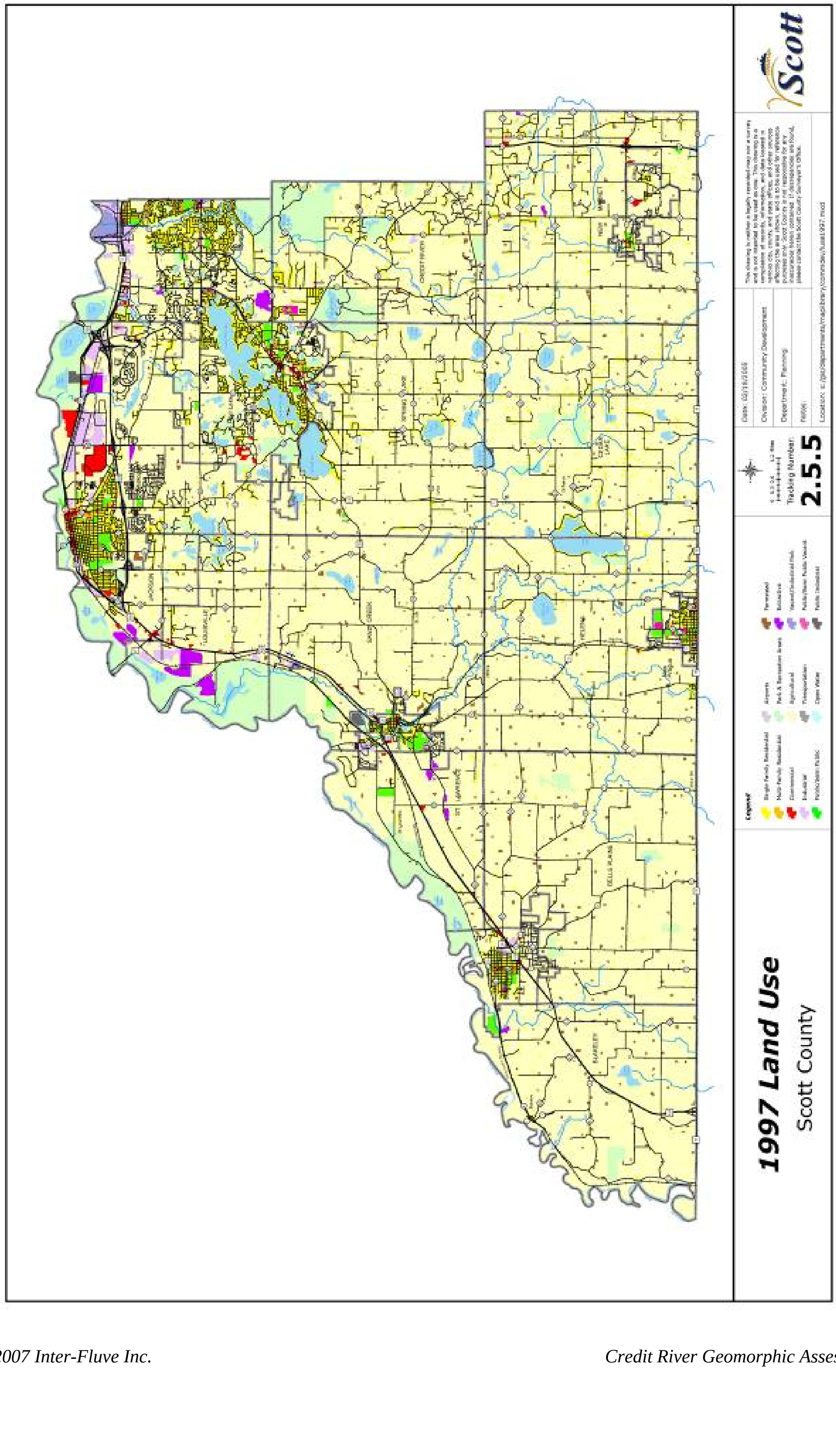
http://www.city-data.com/county/Scott_County-MN.html

http://www.co.scott.mn.us/wps/portal/ShowPage?CSF=876&CSI=35146192801002ps

http://land.umn.edu/quickview_data/index.html



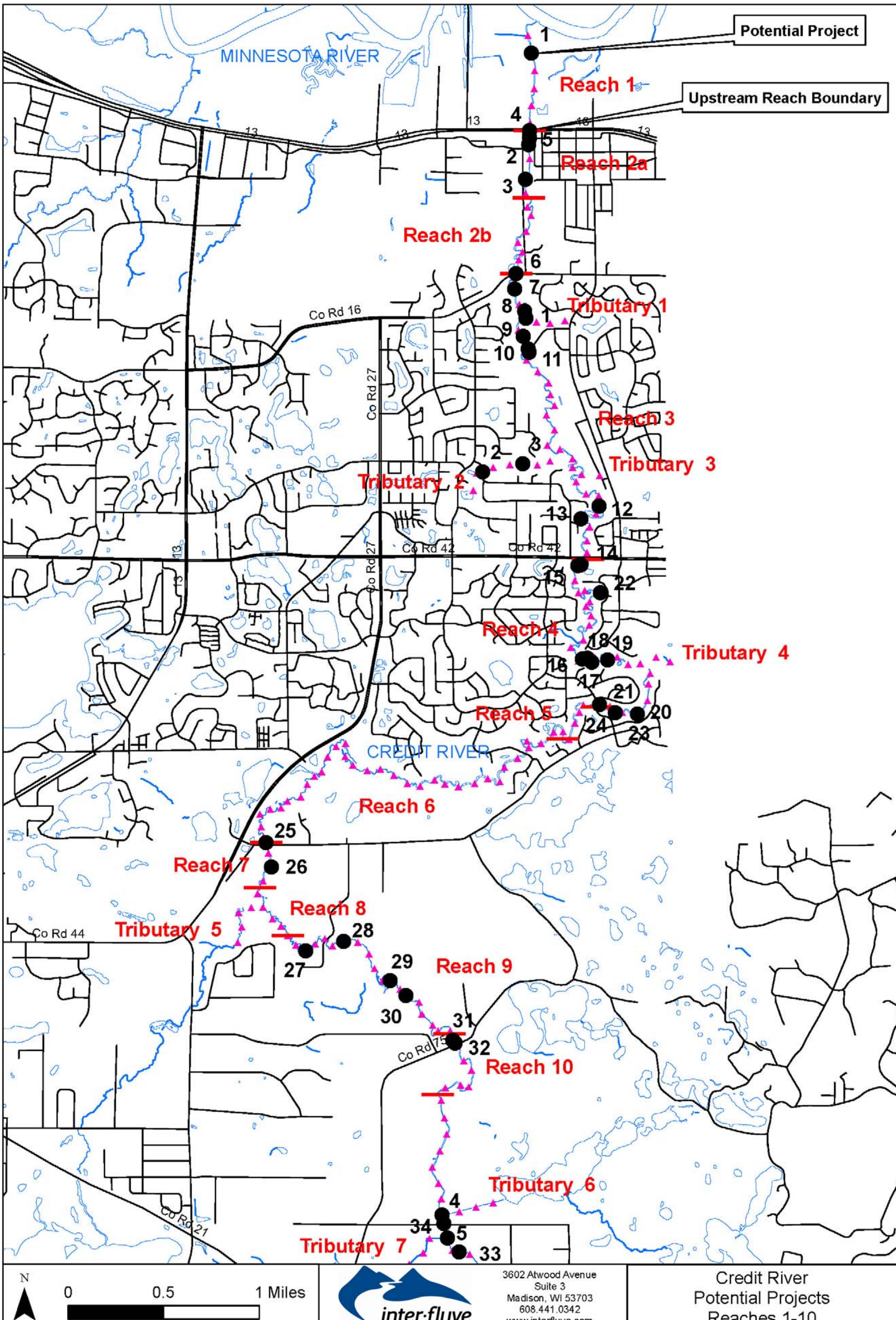
Appendix A: 1984 land use for Scott County (courtesy of Scott County).



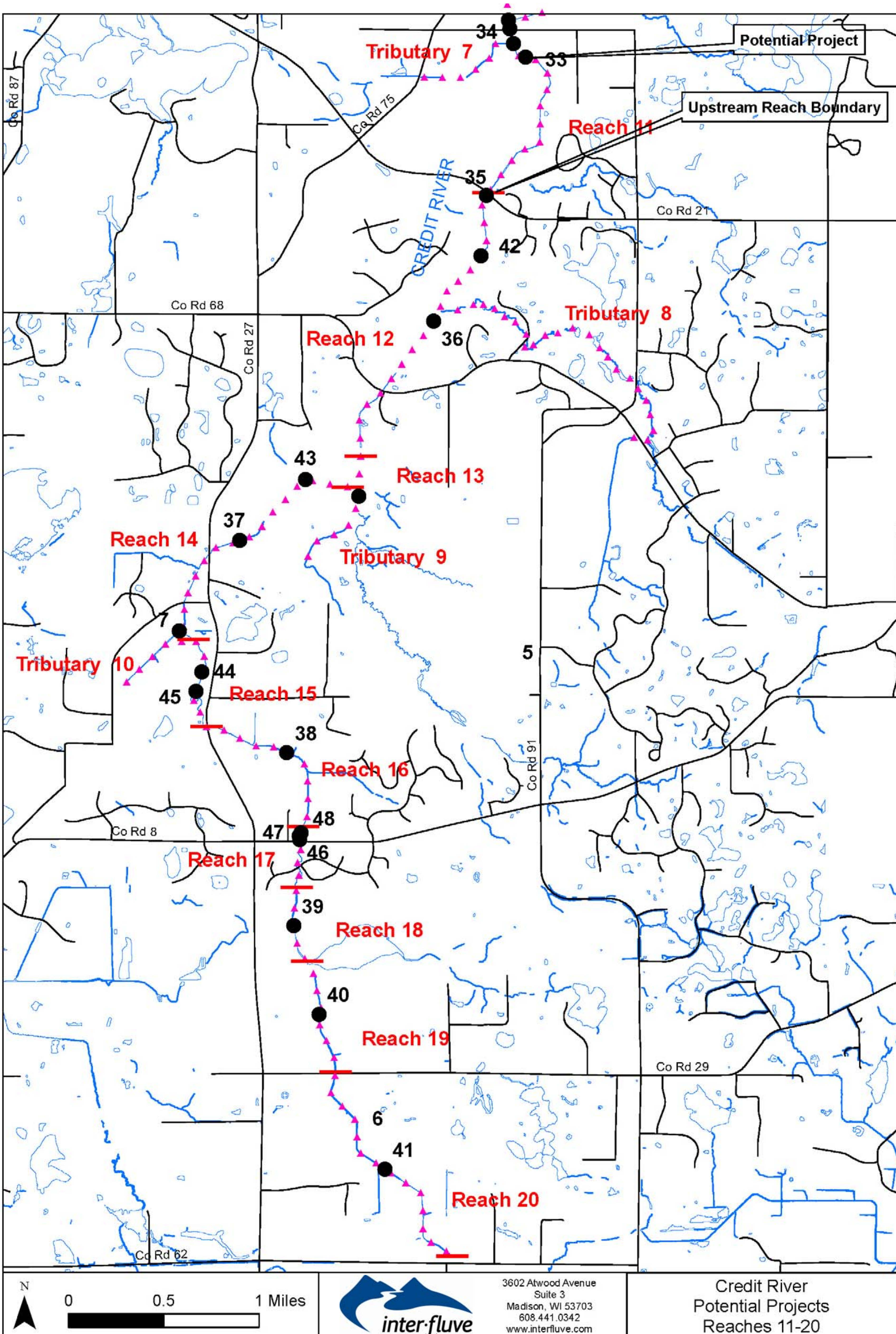
Appendix B: 1997 land use for Scott County (courtesy of Scott County).

Scott County website	http://www.co.scott.mn.us/wps/portal/Home?CSF=742
Scott County GIS website	http://www.co.scott.mn.us/wps/portal/ShowPage?CSF=1382
Scott County Historical Society	http://www.scottcountyhistory.org/index.html
History of Scott County	http://www.scottcountyhistory.org/scotthistory.html
Geology—maps	http://www.co.scott.mn.us/wps/portal/ShowPage?CSF=873
Geology—text	http://www.co.scott.mn.us/wps/portal/ShowPage?
Soils data—tabular and spatial for GIS	http://soildatamart.nrcs.usda.gov/Survey.aspx?State=MN
Water data from stream monitoring stations	http://www.metrocouncil.org/environment/RiversLakes/Streams/ StreamResults.htm
GIS layers—topos, air photos, historic air photos, soil maps, etc.	http://deli.dnr.state.mn.us/ http://deli.dnr.state.mn.us/data_search.html http://www.datafinder.org/index.asp http://seamless.usgs.gov/ http://www.lmic.state.mn.us/chouse/northstarmapper.html
PDFs of county data in map form	http://gis.co.scott.mn.us/maps/countymaps.html

Appendix C: Online resources for Scott County.



Appendix D: Potential projects on the Credit River (black circles). Pink triangles indicate 500-ft increments along the channel centerline. Scott County provided the channel, road, and watershed layers; some of the smaller tributaries were not included in these layers.



Appendix D continued: Potential projects on the Credit River (black circles). Pink triangles indicate 500-ft increments along the channel centerline. Scott County provided the channel, road, and watershed layers; some of the smaller tributaries were not included in these layers.

A

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*
PP01	0-2000	N	1	5	3	1	3	5	2	1	3	7	7	**38**
PP02	3450-3700	R	2	3	7	1	3	7	5	1	4	2	7	**42**
PP03	4000-5200	R	2	3	7	1	3	7	5	1	4	2	7	**42**
PP04	3200	C	1	1	7	1	1	7	1	5	3	4	1	**32**
PP05	3450	C	1	1	7	1	1	7	1	5	3	4	1	**32**
PP06	8400	C	1	1	7	3	1	7	1	4	3	4	1	**33**
PP07	9000-9100	B,F,R	1	1	7	1	3	7	5	1	3	1	3	**33**
PP08	9850-9900	R	1	3	7	1	3	7	5	1	3	2	3	**36**
PP09	10800	I,B,F	3	3	4	1	3	7	5	1	5	1	1	**34**
PP10	11400	I,B,R,F	2	1	5	1	5	6	5	1	7	3	3	**39**
PP11	11450-11500	B,R	1	1	7	1	3	7	5	1	7	2	2	**37**
PP12	19400-19500	R,F,B	1	1	7	1	3	7	5	1	3	1	3	**33**
PP13	20600	I,R	1	1	7	1	3	7	3	5	1	3	3	**35**
PP14	22700-22900	R	1	2	7	1	3	7	5	1	4	2	3	**36**
PP15	22900-23000	R	1	2	7	1	3	7	5	1	4	2	3	**36**
PP16	28700-28750	R	1	1	7	2	3	7	5	1	4	2	3	**36**
PP17	28800-29100	R	1	2	7	2	3	7	5	1	4	2	3	**37**
PP18	29200	R	1	1	7	2	3	7	5	1	4	2	3	**36**
PP19	30100-30200	R	1	1	7	2	3	7	5	1	4	2	3	**36**
PP20	33500	R	1	1	7	2	3	7	5	1	4	2	3	**36**
PP21	34200-34300	R	1	1	7	2	3	7	5	1	4	2	3	**36**
PP22	25000-25100	B,F,I	2	1	6	1	2	7	3	1	1	1	1	**26**
PP23	33500	I	1	3	7	3	3	7	1	5	2	4	1	**37**
PP24	34900	B,R,F	4	3	5	3	1	7	5	1	4	2	3	**38**
PP25	53700	C	1	1	7	3	1	7	1	3	3	3	1	**31**
PP26	54200-54650	R	1	3	7	3	3	7	6	1	4	3	5	**43**
PP27	58600-58700	R	1	1	7	3	1	7	3	1	2	1	3	**30**
PP28	60500	C,I,F	3	3	3	5	3	3	3	5	2	3	1	**34**
PP29	63000	I,R	3	1	7	5	1	7	4	1	1	1	3	**34**
PP30	63900	I,R	3	1	7	5	1	7	4	1	1	1	3	**34**
PP31	66800	I,F,R	1	3	5	5	1	5	3	1	4	3	5	**36**
PP32	66950	C,G	1	1	7	5	1	7	1	3	3	3	1	**33**
PP33	69800-79600	N,R	1	7	3	5	3	1	7	3	7	7	7	**51**
PP34	73700	C	1	1	7	5	3	7	1	4	3	3	1	**36**
PP35	79700	C	1	1	7	5	3	7	1	4	3	3	1	**36**
PP36	79600-88500	N,R	1	7	3	5	3	1	7	3	7	7	7	**51**
PP37	89500-97400	N,R	1	7	3	6	3	1	7	3	7	7	7	**52**
PP38	100500-105300	N,R	1	7	3	7	3	1	7	3	7	7	7	**53**
PP39	107400-109600	N,R	1	7	3	7	3	1	7	3	7	7	7	**53**
PP40	109600-112900	N,R	1	7	3	7	3	1	7	3	7	7	7	**53**
PP41	112900-119700	N,R	1	7	3	7	3	1	7	3	7	7	7	**53**
PP42	81500	F,I,R	1	1	7	5	1	5	5	1	3	1	4	**34**
PP43	90700	I,R	3	3	5	6	3	7	2	1	1	1	3	**35**
PP44	98500	F,R	1	3	7	6	1	7	3	1	1	1	3	**34**
PP45	99000-99200	B,R	1	3	7	7	3	7	5	1	3	3	3	**43**
PP46	105700	C,G	3	3	5	7	3	5	1	4	1	3	1	**36**
PP47	105600	I,N,F	1	4	5	7	3	5	2	5	5	3	3	**43**
PP48	105550	I	3	3	7	7	1	7	4	1	1	1	1	**36**

B

Project Number	Credit River Station	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*
PP01	10100	G	3	5	5	1	5	5	1	1	3	3	1	**33**
PP02	15700	G,C,I,N	5	5	3	1	7	1	3	1	5	3	3	**37**
PP03	15700	G,R	1	3	7	1	3	7	4	1	1	7	7	**42**
PP04	73400	N,R	1	3	3	6	5	2	5	5	7	7	7	**51**
PP05	74100	N,R	1	7	3	5	3	1	7	3	7	7	7	**51**
PP06	89000	N,R	1	3	5	6	3	3	3	1	5	3	5	**38**
PP07	96600	N,R	1	3	5	6	3	5	3	1	5	1	5	**38**

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 E: Scoring of potential projects for (A) the mainstem and (B) the tributaries of the Credit River .