Watonwan River Watershed Hydrology, Connectivity, and Geomorphology Assessment Report

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MINNESOTA DEPARTMENT OF NATURAL RESOURCES
DIVISION OF ECOLOGICAL AND WATER RESOURCES

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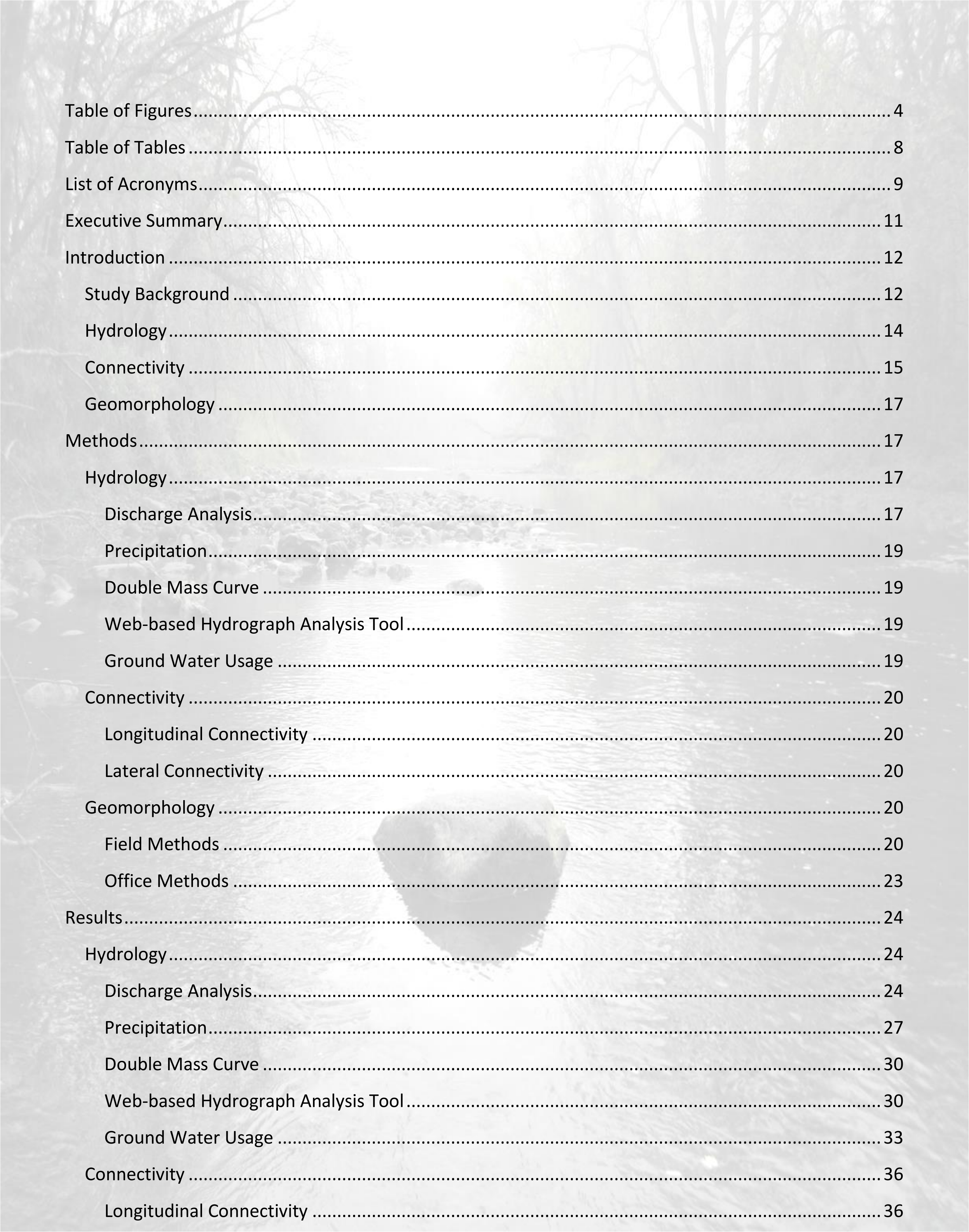

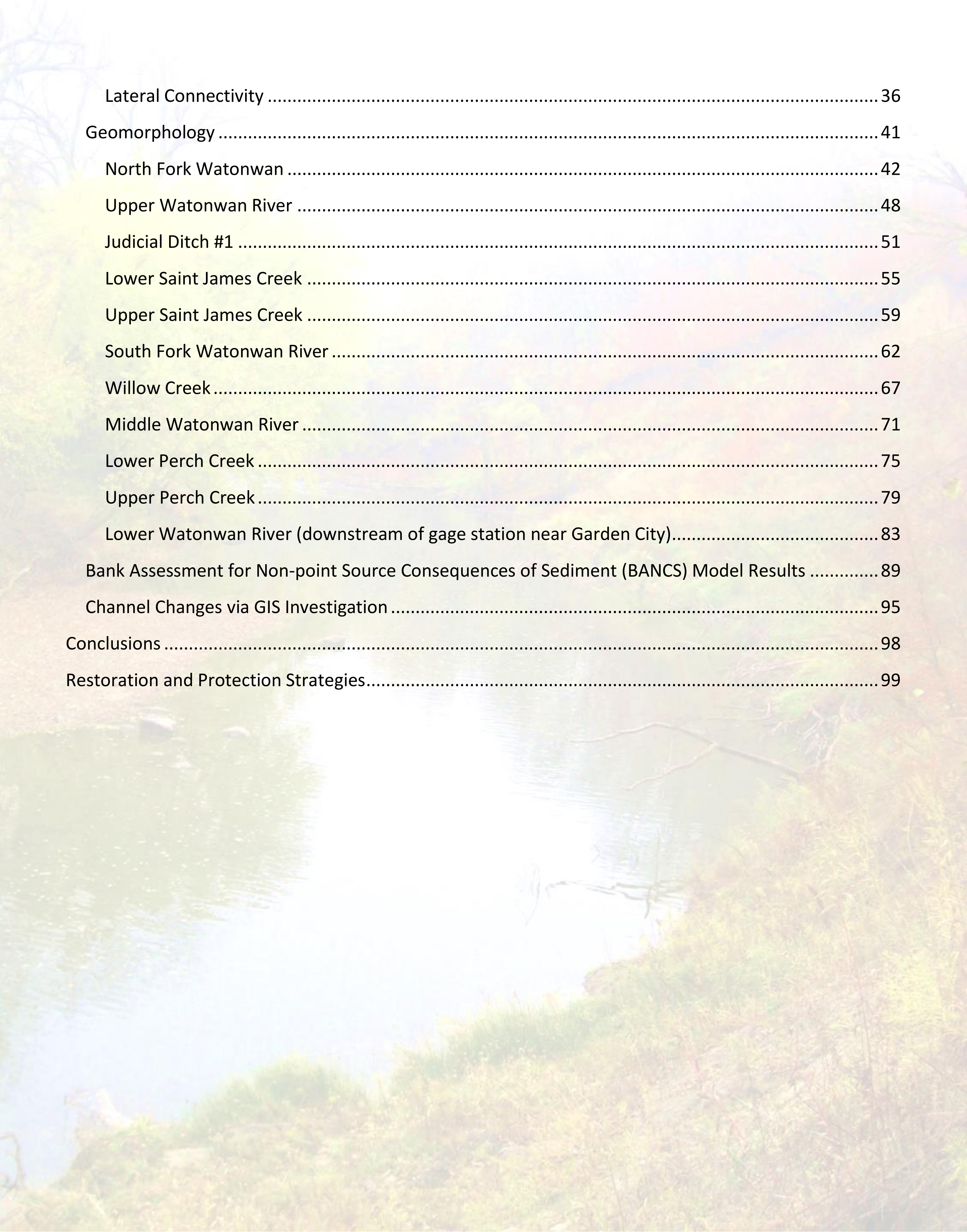

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List of Acronyms

AUID – Assessment Unit Identification

BANCS – Bank Assessment for Non-point source Consequences of Sediment

BEHI – Bank Erosion Hazard Index

BHR – Bank Height Ratio

DEMs – Digital Elevation Models

DMC – Double Mass Curve

FFC – Flood Flow Confinement

GBERB – Greater Blue Earth River Basin

GIS – Geographic Information System

GNIS – Geographic Names Information System

HUC – Hydrologic Unit Code

IWM – Intensive Watershed Monitoring

JD – Judicial Ditch

LiDAR – Light Detection and Ranging

LGU – Local Government Unit

MGIO – Minnesota Geospatial Informational Office

MNDNR – Minnesota Department of Natural Resources

MNDOT – Minnesota Department of Transportation

MPCA – Minnesota Pollution Control Agency

NBS – Near-Bank Sheer Stress

NID – National Inventory of Dams

PHDI – Palmer Hydrologic Drought Index

QBAA – Quaternary Buried Artesian Aquifers

QWTA – Quaternary Water Table Aquifers

SID – Stressor Identification

SWCD – Soil and Water Conservation District

SWMA – State Wildlife Management Area

SWUDS - State Water Use Data System

USDA – United States Department of Agriculture

USGS – United States Geologic Survey

w/d – Width-to-Depth Ratio

WHAF – Watershed Health Assessment Framework

WMA – Wildlife Management Area

WRAPS – Watershed Restoration and Protection Strategies

Executive Summary

The Watonwan River watershed is an eight-digit Hydrologic Unit Code (HUC) watershed draining approximately 878 mi^2 of predominantly agricultural land in south-central Minnesota. The following report analyzes the hydrology, connectivity, and geomorphology components of the Watonwan River watershed. Historical gage data on the Watonwan River, stream crossing data, and applied fluvial geomorphology assessments were analyzed to characterize conditions of the watershed and find relationships to help understand water quality and biological impairments throughout the watershed.

Evidence of past channelization at or near geomorphology field sites was apparent at 10 of 11 reaches surveyed. According to the Minnesota Pollution Control Agency (MPCA), 70% of the Watonwan watershed has altered watercourses (*e.g.,* channelized or impounded). Channelized systems have limited floodplain connectivity and are often incorrectly sized (*e.g.,* cross sectional area to drainage area, width/depth ratios), not allowing the channel to effectively transport the sediments of its watershed. Rivers and streams in the Watonwan watershed that are maintaining deep-rooted perennial vegetated riparian corridors, and those able to access their floodplains to dissipate energy during high flows, are showing greater sign of stream stability. However, altered hydrology is currently a substantial driver for geomorphic response. Discharge and precipitation data collected from the Watonwan River indicate the amount and timing of water delivered per inch of precipitation has increased over time. This increased volume and rate of water delivery can further destabilize the river system, and is a contributing factor to the geomorphic response within the watershed.

Investigation of the longitudinal connectivity of the Watonwan watershed indicated a bridge density of 0.20/mi^2, and a culvert density of 0.17/mi^2. Bridges and culverts can have drastic impacts on rivers and streams, especially when improperly sized. Improperly sized bridges and culverts can create flood flow confinement (FFC), which in return can cause channel widening, alter sediment transport capacity, and sediment deposition (Zytkovicz and Murtada 2013). Furthermore, 11 dams are located in the Watonwan watershed; 2 of the dams are potential barriers to fish passage at most water levels. Fluvial geomorphology survey results indicated 7 of 11 survey reaches have lateral floodplain connectivity.

Overall, the objective is to improve the health of the watershed, to enhance agricultural sustainability, groundwater conservation, fish and wildlife habitat, biodiversity, recreation, and water quality throughout the watershed. As important as the restoration of disturbed areas is, focus must also be set to protect undisturbed areas generating multiple ecosystem services that appear to be near “reference” condition. Instability was documented at several of the survey sites, instability that culminates from systemic issues. Restoration efforts should thus focus on addressing system wide issues.

Introduction

Study Background

The Watonwan River watershed is a Hydrologic Unit Code (HUC) 8 watershed [07020010] of the Minnesota River basin. Draining approximately 878 mi^2 of south-central Minnesota, the Watonwan River watershed is the western most drainage of a larger sub basin within the Minnesota River basin; the Greater Blue Earth River Basin (GBERB). The Watonwan, Blue Earth, and Le Sueur River watersheds comprise the GBERB and converge prior to confluence with the main channel of the Minnesota River in Mankato. The Algona Moraine borders the three HUC 8 watersheds to the west, south, and east respectively. Moraines are landscape features created during glaciation, and the Algona Moraine was left after the retreat of the Des Moines lobe of the last glacial period.

The advance and recession of the Des Moines Lobe shaped the landscape of south central Minnesota, leaving a general west to east slope to the Watonwan River watershed. The Algona Moraine constitutes the westernmost boundary of the Watonwan watershed while separating the Minnesota River basin from the Des Moines River watershed. Near the moraine landscape feature, the Watonwan River originates approximately three miles southwest of Jeffers, MN. Flowing in a west to easterly orientation, the Watonwan River travels from central Cottonwood County, into northern Watonwan County, and proceeds to its confluence with the Blue Earth River in central Blue Earth County. The watershed is drained by three primary branches of the Watonwan River; North Fork Watonwan, South Fork Watonwan, and Watonwan rivers, and four minor tributaries to these branches; Butterfield, Saint James, Willow, and Perch creeks (Figure 1).

The Minnesota Pollution Control Agency (MPCA) initiated the Intensive Watershed Monitoring (IWM) process for the Watonwan watershed in 2013 to assess the overall health of the watershed and identify areas for restoration and protection efforts. The MPCA and Minnesota Department of Natural Resources (MNDNR) use a five component "healthy watershed" framework to understand and describe how complex ecological systems are functioning. The five components of a healthy watershed consist of hydrology, geomorphology, connectivity, water quality, and biology (Figure 2). Within this five-component framework, the MPCA is charged with assessing the biology and water quality components. The MNDNR thus analyzes the current and historical hydrology trends of the watershed, assesses the fluvial geomorphology and stability of rivers and streams within the system, and investigates connectivity (*i.e.,* longitudinal, lateral, and riparian). All of the components are interrelated, and the disruption of any of them can result in undesirable results deeming the stream impaired for one or more condition.

Once all of the components have been assessed, the MPCA completes a stressor identification (SID) document to show what stressors are causing listed impairments within each Assessment Unit ID (AUID). The SID document is one component to help develop Watershed Restoration and Protection Strategies (WRAPS); a report summarizing the water quality monitoring and assessment, pollutant and stressor source identification, civic engagement and public participation, and restoration and protection strategy development. Ultimately, WRAPS can be used to inform local plans to guide conservation work within the watershed.

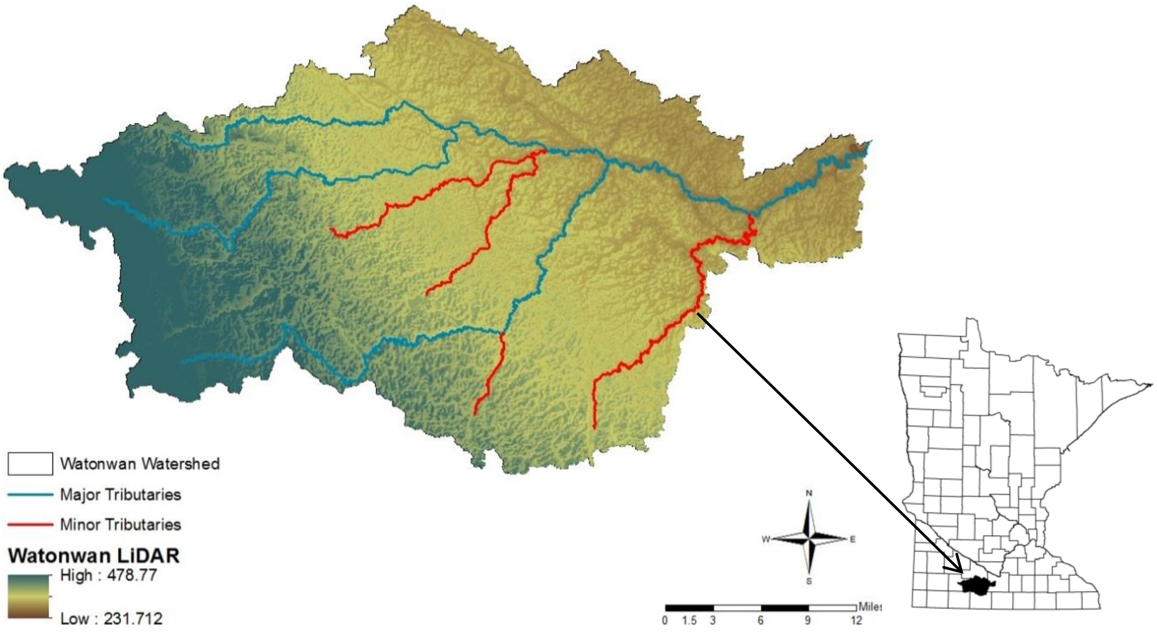


Figure 1. Light Detection and Ranging (LiDAR) imagery depicting the west-to-east slope of the watershed's landscape with the major and minor tributaries of the watershed.

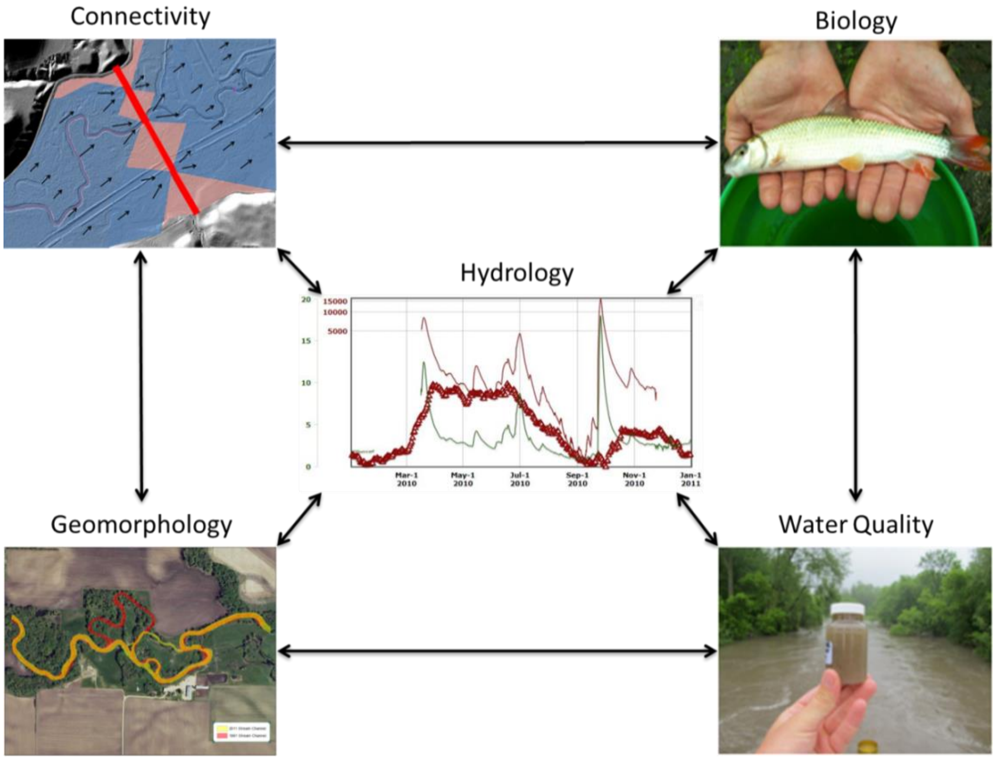


Figure 2. Five components of a healthy watershed. All components are interrelated; a disruption of any one of the components can have an effect on the rest of the components.

Hydrology

Hydrologic conditions (*e.g.,* precipitation, runoff, storage, and annual water yield) and the disturbance of natural pathways (*e.g.,* tiling, ditching, land use changes, and loss of water storage) has become the driver of many impairments in other Minnesota watersheds (MPCA 2012). These disturbances coupled with an increase in precipitation (*i.e.,* total, frequency, and magnitude) have resulted in issues with: increased bank erosion, excess sediment, habitat degradation, and disturbance of natural flow regime.

Hydrologic modification is the alteration or addition of water pathways and associated changes in volume by human activity. Those modifications can dramatically alter discharge due to changes in volume, timing, connectivity, or flow rates, particularly if the area was not a flow pathway in the past. The types of hydrologic modifications are vast, including the draining and filling of wetlands and lakes, ditching or draining formerly hydrologically disconnected basins, adding impervious surfaces across the basin, increasing drainage for increased transport of water (*i.e.,* in urban and agricultural areas), straightening or constricting a natural flow path or river, and changing the timing and rate of delivery within the hydrologic system. Any increase in stream power (*e.g.,* due to change in peak flows or increased frequency of bankfull flows) will generate an increase in water yield (Lane 1955). Reduced surface storage, increased conveyance, increased effective drainage area along with altered crop rotations supporting soybeans over perennial grasses and small grains have all altered the dynamics of, and generally increased the annual water discharged from, these watersheds while also dramatically altering the return interval for various flow stages (Schottler 2014).

In extensively drained landscapes, such as the agricultural Midwest of the United States, the connection of isolated basins has inflated total surface water discharge and increased the density of linear drainage networks (Ter Haar & Herricks 1989, Haitjema 1995, Magner et al. 2004). Many streams in the region are in disequilibrium due to past and current land-use change with corresponding hydrologic responses, as well as direct channel modifications (Lenhart 2007).

These modifications have not occurred at a constant rate, but in episodes or events, such as construction of the public drainage system from 1912-1920 (Lenhart 2007, 2008) and continue today through repair, upgrade, and increased amount of impervious surfaces and subsurface drainage. Construction of subsurface tile and surface ditch drainage systems in the early 1900s increased contributing drainage areas, resulting in greater amounts of water delivered to rivers (Leach and Magner 1992, Kuehner 2004, Lenhart 2008). The effects of these suites of changes are cumulative, interrelated, and tend to compound across different spatial and temporal scales (Spaling & Smit 1995, Aadland et al. 2005, Blann et al. 2009). The contribution of subsurface drainage to aquatic ecosystem affects may be difficult to isolate relative to other agricultural impacts (Blann et al. 2009). Cumulatively, these changes in hydrology, geomorphology, nutrient cycling, and sediment dynamics have had profound implications for aquatic ecosystems and biodiversity (Blann et al. 2009).

The hydrologic analysis found in this report focuses on surface-water components of the hydrologic cycle, rainfall-runoff relationships, open-channel flow, flood hydrology, and statistical and probabilistic methods in hydrology.

Connectivity

Connectivity is defined as the maintenance of lateral, longitudinal, and vertical pathways for biological, hydrological, and physical processes within a river system (Annear 2004). Connectivity is thus the water-mediated transfer of energy, materials, and organisms across the hydrological landscape (Pringle 2003). The transport of these integral components within a river travel in four dimensions: longitudinal, upstream and downstream; lateral, channel to floodplain; vertical, hyporheic to groundwater zones; and temporal, continuity of transport over time (Annear 2004; Figure 3). Due to the objectives of this study, vertical connectivity was not directly assessed.

Longitudinal connectivity of flowing surface waters is of the utmost importance to fish species. Many fish species' life histories employ seasonal migrations for reproduction or overwintering. Physical barriers such as dams, waterfalls, perched culverts and other instream structures disrupt longitudinal connectivity and often impede seasonal fish migrations. Disrupted migration not only holds the capacity to alter reproduction of fish, it also impacts mussel species that utilize fish movement to disperse their offspring. Structures, such as dams, have been shown to reduce species richness of systems, while also increasing abundance of tolerant or undesirable species (Winston et al. 1991, Santucci et al. 2005, Slawski et al. 2008, Lore 2011).

Longitudinal connectivity of a system's immediate riparian corridor is an integral component within a healthy watershed that promotes the free movement of aquatic terrestrial species both up and down stream within a hydrologic system. Continuous corridors of high quality riparian vegetation work to sustain stream stability and play an important role in energy input and light penetration to surface waters. Lateral riparian connectivity provides habitat for terrestrial species as well as spawning and refuge habitat for fish during periods of flooding and represents one of the most significant attributes for maintaining stream stability. Improperly sized bridges and culverts hinder the role of longitudinal riparian connectivity as they reduce localized floodplain access, disrupt streambank vegetation, create impassable flow velocities, stand as tunnel lengths that restrict species movement, reduce or eliminate natural migration pathways for terrestrial and aquatic organisms, and cause streambed and floodplain aggradation upstream and streambed degradation or aggradation downstream.

Lateral connectivity represents the connection between a river and its floodplain. The dynamic relationship amongst terrestrial and aquatic components of a river's floodplain ecosystem comprises a spatially complex and interconnected environment (Ickes et al. 2005). The degree to which lateral connectivity exists is both a time-dependent phenomenon (Tockner et al. 1999) and dependent upon the physical structure of the channel. Stable river systems are hydrologically dynamic systems where their floodplain inundation relates to prevailing hydrologic conditions throughout the seasons. Riverine species have evolved life history characteristics that exploit flood pulses for migration and reproduction based on those seasonally predictable hydrologic conditions that allow systems to access their floodplains (Weclomme 1979, McKeown 1984, Scheimer 2000). When a river system degrades to a point where it can no longer access its floodplain, the system's capacity to dissipate hydrologic energy is lost. Without adequate dissipation of hydrologic energy through floodplain access, the hydrologic sheer stress on streambanks and streambed increase. Increasing sheer stress within the channel causes the channel to widen or streambed to scour, depending upon which feature has the lowest sheer strength based upon the materials the feature is comprised of. Channel widening or channel incision driven by this hydrologic sheer reduces channel stability and decreases effective bedload transport capacity. Reduced bedload transport causes aggradation or degradation of the streambed, leads to the loss of important aquatic habitat, increases water temperature, lowers oxygen levels, and leaves smaller and less diverse bed materials that in turn reduce biotic integrity of the aquatic and terrestrial communities in the system.

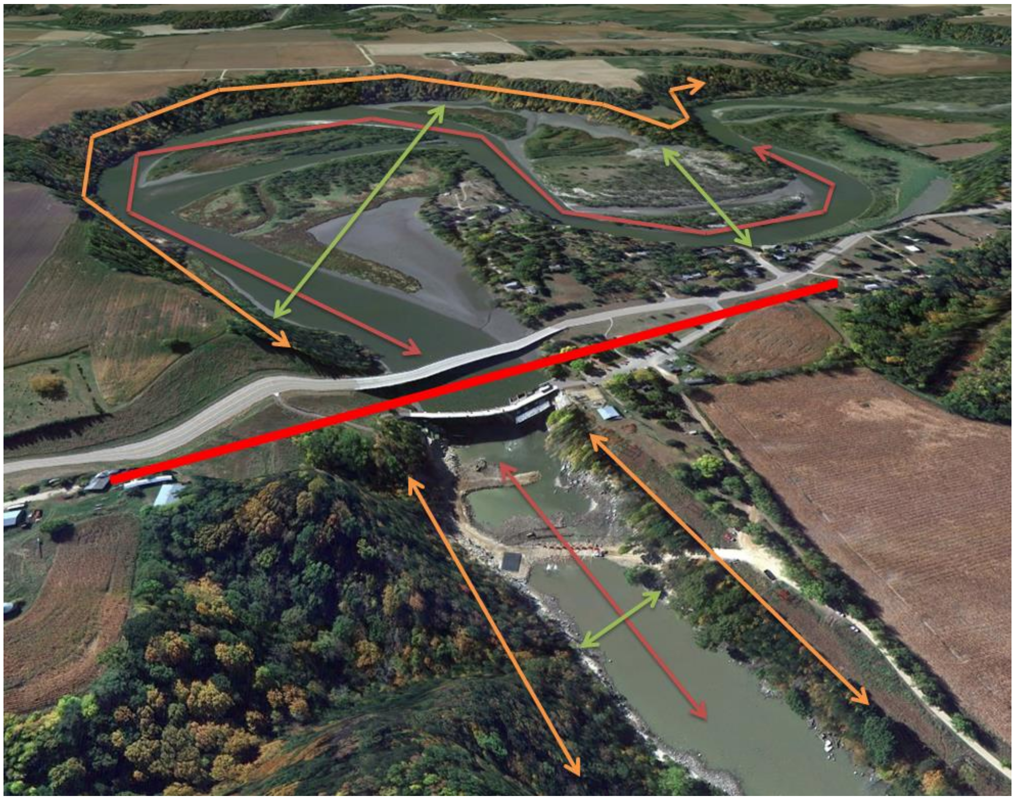


Figure 3. Three spatial dimensions of connectivity: longitudinal (red), lateral (green), and riparian (orange). Dams and bridges are two of several structures that disrupt each of these three dimensions of connectivity. Rapidan Dam, Blue Earth River image courtesy of Google Earth, 2014.

Geomorphology

Fluvial geomorphology pertains to the way land has formed and continues to form by flowing water (Leopold et al. 1964). The principal methods utilized in this study to describe the geomorphology of the watershed follow the Rosgen (1994) classification system (Figure 4). Within the Rosgen classification system, the dimension, pattern, and profile of a stream are measured through the use of dimensionless ratios in order to classify the stream regardless of its size (Table 1). Subsequently, measurements such as bank height ratio, erosion rate, and sediment competence are used to assess whether the channel is in a stable or transitional state (*i.e.* evolving to or from a disturbed channel type).

Equilibrium and river stability are terms that are often used interchangeably within the context of geomorphology. River stability is defined as a river's ability, in the present climate, to transport the flows and sediment of its watershed, over time, in such a manner that the channel maintains its dimension, pattern, and profile without either aggrading or degrading (Rosgen 1996, 2001a, 2006). When components of a healthy watershed are disturbed, successional changes in rivers occur in order to adjust to the new conditions. Typically, these adjustments impact habitat and water quality due to an imbalance of sediment and bedload supply and transport that results in biotic and turbidity impairments.

Methods

Hydrology

In order to understand and evaluate the hydrologic processes within a watershed, several types of analysis are used to examine the relationships between flow (*i.e.* discharge) and precipitation. Ground water levels and usage over time is also reviewed. Analysis methods can evaluate and measure changes within a system by reviewing statistical variations and trends over time.

Discharge Analysis

Flow/discharge data sets are collected by the USGS and MPCA/DNR stream gage network for the various watersheds. Site-specific stream flow data are calculated using continuous stream stage measurements and periodic stream flow measurements. These data are plotted and charted to allow for statistical analysis and is used to create hydrographs, flow duration curves, and other visual representations of the period of record.

Watershed discharge data can be used to review daily, monthly, seasonal, annual, and long term trends within a watershed, and examine changes in the discharge characteristics such as periods of low or zero flow, flood frequency, base flow volume, and seasonal variability. Discharge data from the Watonwan River has been collected near Garden City (USGS site # 05329500) since 1940.

Discharge data are also used to create a duration curve. Duration curves are used to examine discharge and determine when a specific flow volume was exceeded or equaled in a given period, such as how often the flow volume exceeds high (10th percentile) and low (90th percentile) flow conditions for the watershed. Data can also be used to calculate relative frequency if the data set is large enough.

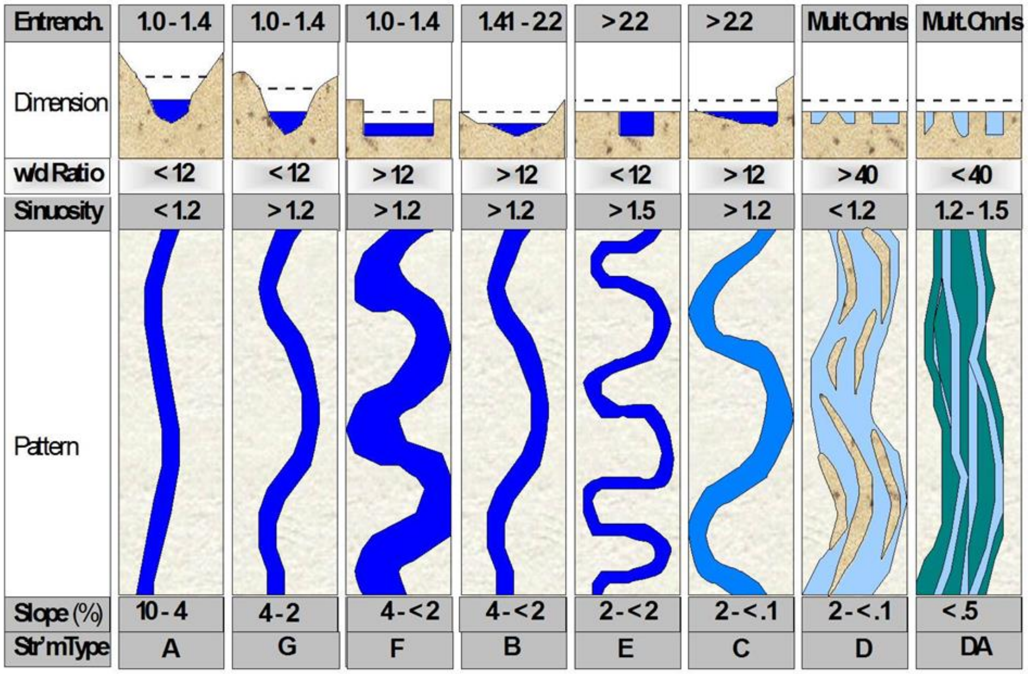


Figure 4. Measurements used to classify a representative stream reach. Once measurements of entrenchment, bankfull width to depth ratio, sinuosity, and slope at a riffle cross section have been established, a conclusion on stream type can be made. Additional measurements are taken to determine whether the stream is stable within its current state or if it is in a successional state to adapt to its current climate, hydrology, and land use (Rosgen 1997).

Table 1. Dimension, pattern, and profile measurements used within the Rosgen methodology for channel classification.

$$\text{Entrenchment Ratio} = \frac{\text{Flood-prone Width}}{\text{Bankfull Width}}$$

$$\text{Width to Depth Ratio} = \frac{\text{Width}_{\text{bkf}}}{\text{Depth}_{\text{mean}}}$$

$$\text{Sinuosity} = \frac{\text{Channel Length}}{\text{Valley Length}}$$

$$\text{Slope} = \frac{\text{Elevation Difference}}{\text{Channel Length}}$$

Precipitation

Precipitation data are based on the long-term data collection location nearest to the stream data collection site. All precipitation data are acquired through the "High Density Radius Retrieval" website maintained by the Minnesota State Climatology Office. Precipitation data are used to examine long-term trends within a watershed, and the relationship and response of discharge, runoff, and baseflow conditions relative to recorded precipitation totals. Long term precipitation data was available at Lake Crystal (Station #214440) in Minnesota.

Double Mass Curve

A Double Mass Curve (DMC) is an analysis based on a cumulative comparison of one independent variable with a cumulative dependent variable. This is useful in hydrologic data as it allows the examination of the relationship between two variables. This technique was used to compare precipitation and stream discharge relationships (*i.e.,* annual and seasonal) and well elevation fluctuations relative to precipitation. When plotted, a straight line indicates consistency in the relationship while a break in the slope indicates a change in the relationship.

When used with long-term discharge data sets, the curve can demonstrate when the change in the relationship began to occur. All double mass curves presented are runoff (*i.e.,* discharge/watershed area) and monthly precipitation in inches. All discharge values are converted to inches by dividing total volume by the watershed area (the annual discharge converted to acre–ft. and then to inches of runoff over the watershed). Additional information on double mass curve development and interpretation can be found on the following website: http://pubs.usgs.gov/wsp/1541b/report.pdf

Web-based Hydrograph Analysis Tool

The Web-based Hydrograph Analysis Tool (WHAT) was developed by Purdue University and designed to separate baseflow and direct runoff using digital filtering algorithms from user specified flow data. Data can be automatically uploaded from the USGS database or manually entered by the user. The analysis can be run over the entire period of record or for dates specified by the user. Subsets of the data can be used to look for a change in the relationship as indicated by the double mass curve or precipitation records. This tool is beneficial to examine the baseflow discharge relationship over time, and can be used to look at long term and seasonal variations.

The supplied datasets were analyzed using a recursive digital filter, based on a groundwater system with "Perennial Streams with Porous Aquifers". The tool and additional information can be found on the following website: https://engineering.purdue.edu/~what/

Ground Water Usage

Permitted groundwater usage was reviewed to examine changes in type of usage and volume over time. Data was collected through the State Water Use Data System (SWUDS) from 1988-2011. The data was used to review total volume appropriated, volume appropriated by county and aquifer type, and well level fluctuations relative to precipitation.

Connectivity

Longitudinal Connectivity

Longitudinal connectivity within the Watonwan River watershed was assessed through the use of desktop reconnaissance tools. ArcMap, Geographic Names Information System (GNIS), Watershed Health Assessment Framework (WHAF), National Inventory of Dams (NID), MNDNR's dam safety records, and Minnesota Department of Transportation's (MNDOT) bridges and culverts inventory were utilized to assess longitudinal connectivity. Because culvert inventories do not document whether individual structures are perched, dams were the only barriers with adequate data to analyze continuity within the surface waters of the Watonwan watershed.

Similarly, the same tools were used to assess longitudinal connectivity of riparian corridors throughout the watershed. Bridges and culverts were divided within the watershed, and amongst subwatershed, to assess abundance and density (*i.e.,* bridges or culverts/mi^2).

Furthermore, riparian corridor and habitat quality was qualitatively assessed at each geomorphology survey site. Vegetation type, root depth, root density, and weighted root density [*i.e.,* (root depth/study bank height) * root density) were all measured and documented. Information gathered was later used in site-specific assessment of stream stability and potential of sediment supply through bank erosion.

Lateral Connectivity

Flood-prone area (*i.e.* active floodplain) is defined as the area adjacent to the stream channel that is under water in flow events that are 2X maximum bankfull depth at the riffle cross section (Rosgen 1996, 2006). Bankfull, in the context of this report, refers to the normal high water flow; typically relating to ~1.5 year return interval flow (*i.e.* channel forming flow). Field surveys are required to calibrate bankfull elevations at a riffle within a study reach, as well as determine flood-prone elevation. Due to the need for field surveys to acquire bankfull and flood-prone elevations, only geomorphology sites were subjected to lateral connectivity analyses. Light Detection and Ranging (LiDAR) imagery digital elevation models (DEMs) were used in conjunction with surveyed elevations to determine flood-prone width at sites with particularly wide flood-prone areas.

Geomorphology

Field Methods

Site selection worked to fulfill several objectives set forth through multi-level coordination that included the MNDNR, MPCA, and local soil and water conservation districts (SWCDs). Sites were selected based on their capacity to identify specific stressors and investigate impairments, represent various channel and valley types found within the watershed's geology, depict stable and unstable stream reaches, and represent channels of varying slopes (*i.e.,* sites stratified across watershed).

At each survey site (Figure 5; Table 2), elevation data was collected to characterize the dimension, pattern, and profile of the reach. At sites with minimal or no canopy cover, a Trimble R6 GPS grade surveying receiver was used to calculate elevations based on distance and angle from multiple satellites; data that is then corrected through a signal from a local base station. At sites where canopy cover hampered the ability of the R6 to connect with multiple satellites, a Trimble S3 total station was used to measure elevation.

In order to characterize the dimension, pattern, and profile of each reach, methods consistent with those taught by Dave Rosgen were employed. A longitudinal profile of 20x bankfull width in length was surveyed. Longitudinal profiles consist of thalweg (*i.e.,* deepest portion of channel), water surface, bankfull, and low bank height (*i.e.,* actual “floodplain” if located above bankfull) elevations throughout the reach. Those elevations incorporate water slope, bankfull slope, channel bed features (e.g., pool, riffle, glide, run), and rate of incision (*i.e.,* low bank height/bankfull height; if greater than 1). These data are necessary to help classify the stream through use of the Rosgen (1994) stream classification system.

Surveying at each site also included a riffle cross section that allowed for the analysis of width-to-depth ratio (*i.e.,* bankfull width/average bankfull depth), entrenchment ratio (*i.e.,* flood-prone width/bankfull width), flood-prone width, bankfull cross-sectional area, and to calibrate bankfull elevations for the reach. Cross sections were started on the left bank (facing downstream) and elevations were surveyed to include all changes in slope across the channel. Starting and ending points for cross sections were positioned so that flood-prone width and entrenchment ratio could be calculated from the data.

Generally, a second cross section was surveyed and monumented within the study reach. Methods used were similar to the methods used for surveying riffle cross sections; however, benchmarks (*i.e.,* rebar posts) were placed at the start and end of the cross sections to allow for annual resurveys and assessment of change over time. Furthermore, a toe pin was placed at the base of a study bank where three pins were driven horizontally into the bank face. The toe pin at each study bank serves as the starting point for the bank survey, whereas the benchmark on top of the bank serves as the ending point. The placement of these benchmarks allows for annual bank erosion assessment, where exposed portions of the horizontal bank pins are used to help validate measured versus modeled bank erosion.

The Bank Assessment for Non-point source Consequences of Sediment (BANCS) model is a combination of the Bank Erosion Hazard Index (BEHI) and Near-Bank Shear-stress (NBS) utilized to predict annual sediment inputs from a specific bank. Bank Erosion Hazard Index and NBS methods developed by Dave Rosgen (2001b) were employed to estimate bank erosion at the study bank, as well as other models: Colorado, Yellowstone, and North Carolina models. A study bank within one of the kayaked reaches was used to validate bank erosion model estimates; however, model estimates varied with actual erosion rates after one year of study. Therefore, the Colorado model was used for all sites in order to standardize the data. Since the model was developed in Colorado, measured bank erosion at each site will help develop a regional model for southern Minnesota rivers.

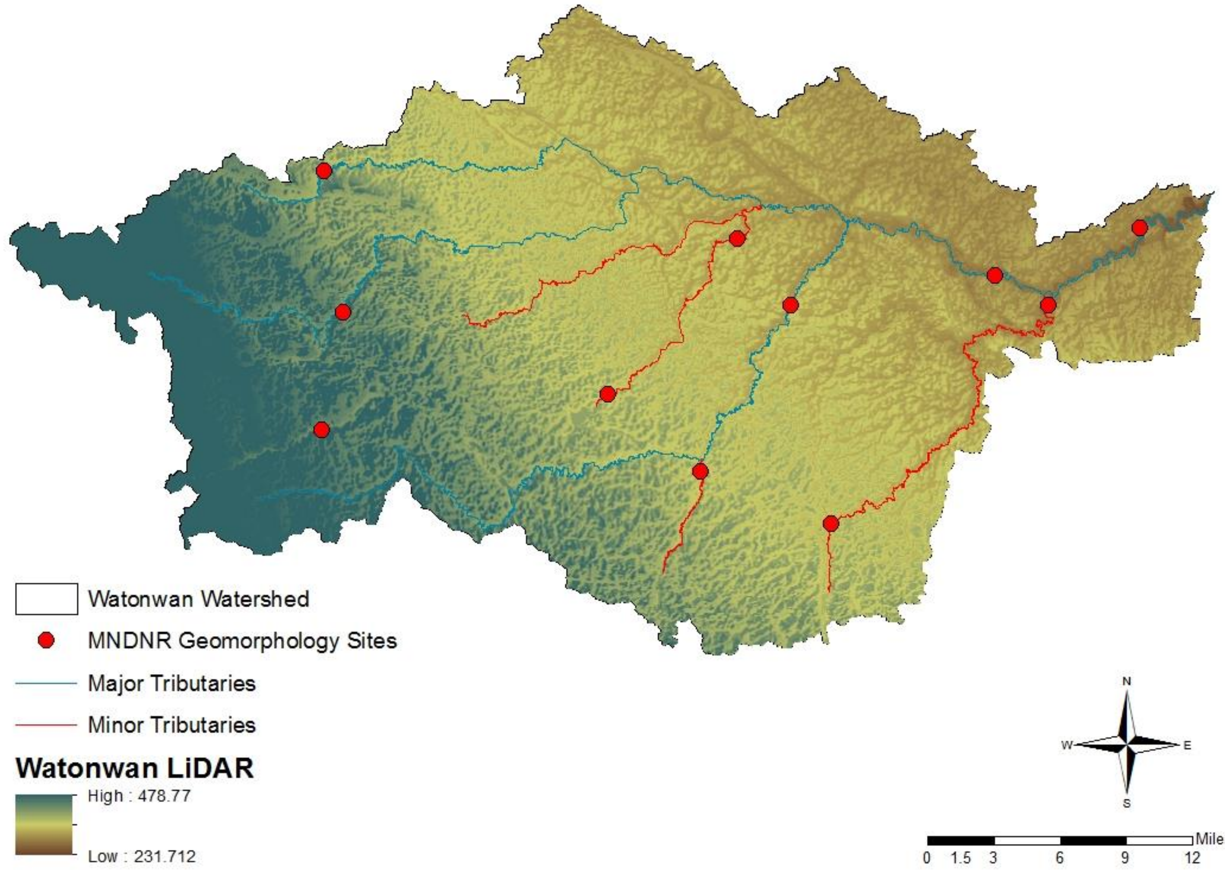


Figure 5. Light Detection and Ranging (LiDAR) imagery depicting the west-to-east slope of the watershed's landscape with the spatial location of geomorphology sites included.

Table 2. List of Watonwan River watershed geomorphology survey sites and associated Assessment Unit Identification (AUID).

Site Name	AUID
North Fork Watonwan River	07020010-513 Headwaters to Watonwan River
Watonwan River	07020010-514 Headwaters to North Fork Watonwan River
Judicial Ditch #1	07020010-548 Headwaters to Irish Lake
Saint James Creek (Lower)	07020010-515 South Line to Butterfield Creek
Saint James Creek (Upper)	07020010-502 Unnamed Lake (83-0037-00) to T106 R31W S19, North Line
South Fork Watonwan River	07020010-517 Willow Creek to Watonwan River
Willow Creek	07020010-521 Headwaters to South Fork Watonwan River
Watonwan River	07020010-510 South Fork Watonwan River to Perch Creek
Perch Creek (Lower)	07020010-523 Spring Creek to Watonwan River
Perch Creek (Upper)	07020010-524 Headwaters (Perch Lake 46-0046-00) to Spring Creek
Watonwan River	07020010-501 Perch Creek to Blue Earth River

Within each study reach, 100 active stream bed particles were measured (*i.e.* pebble counts) throughout the reach (for classification; Wolman 1954, Rosgen 2012) and 100 particles were measured through the riffle cross section (for hydraulic analysis, Rosgen 2012). The D_{50} particle (*i.e.* 50% of particles are smaller than the D_{50} particle) in the representative pebble count helps to classify the reach. For example, a C4 stream is a C channel type with a reach D_{50} particle representing gravel substrate. The D_{84} particle in the riffle cross section is used to calculate roughness coefficients and bankfull discharge estimation.

At the completion of surveying at each study reach, a modified Pfankuch stability rating was conducted. The Pfankuch stability rating is a qualitative assessment predicting stability of the representative channel based on upper, middle, and lower banks, and channel characteristics (Pfankuch 1975, Rosgen 1996, Rosgen 2001c). After each metric is scored a final score is calculated and an adjective rating is given (*i.e.*, poor, fair, or good) based on the stream type for the respective study reach.

Office Methods

Office methods for the analysis of survey elevation data utilized the RIVERMorph Professional, version 5.1 software; developed by Stantec. RIVERMorph was used to develop cross sections, longitudinal profiles, dimensional and dimensionless ratios, and other graphs that were subsequently used to help classify the channel type of respective study reaches. Other measures of pattern, profile, and dimension such as radius of curvature, stream meander length, belt width, sinuosity, and linear wavelength were measured within RIVERMorph's geographic information system (GIS) tool.

ArcMap was another GIS tool used to investigate study reach characteristics. LiDAR data was used in correlation with ArcMap to create valley cross sections at study reaches in order to confirm valley type. Valley type defines boundary conditions of stream channels and helps to understand lateral confinement. LiDAR was also used to assess local slope, stream power, terrain analysis, and locate historical depressional areas. ArcMap was also used in correlation with aerial photography to further assess lateral confinement and stability. Historical aerial photos from 1991 were used to develop streamline shape files that were later overlaid upon current aerial photographs (*i.e.* 2011). This allowed for the assessment of lateral stability as well as changes in radius of curvature, stream meander length, belt width, sinuosity, linear wavelength, and dimensional changes such as channel widening over the last 20 years.

Bankfull elevations (*i.e.* ~1.5 year discharge return interval) are integral measurements taken during field surveys. Using RIVERMorph, predicted bankfull discharge was calculated through the assessment of water slopes and roughness coefficients. United States Geologic Survey (USGS) StreamStats tool was then used to validate bankfull calls made during field surveys (Lorenz et al. 2009). StreamStats provided drainage area and predicted flows, with confidence estimates, for catchments upstream of study reaches. Validation of bankfull field survey calls were attained when bankfull discharge predictions aligned with ~1.5 year discharge return intervals calculated by StreamStats. Additional information on StreamStats can be found on the following website:
http://water.usgs.gov/osw/streamstats/ssonline.html

Regional curves (Appendix I) were another tool used to help validate field survey bankfull elevation calls. Regional curves graphically depict the mathematical relationships that exist amongst drainage area and bankfull dimensions of width, depth, and cross-sectional area (Smith and Turrini-Smith 1999). Although, regional curves are currently under development for south-central Minnesota, the information was still helpful to validate relationships between cross sectional area and drainage area. Regional curves correlate a variety of variables, however, the most commonly used set of variables are cross sectional area and drainage area. Though other factors such as slope and channel type can affect how close a site is compared to predicted cross sectional area, often the regional curve provides a strong estimate of what the cross sectional area of a riffle cross section should be based on drainage area. Development of the curves is regionally based as many factors can affect the dimension of the channel (*e.g.,* precipitation, runoff potential, local geology, local storage capacity, etc.).

Results

Hydrology

Stream data collection near Garden City, MN began in 1940 by the USGS, but was discontinued in 1946. The site was reestablished by the MNDNR in the fall of 1976 and is currently operating. Ideally a continuous, long term data set (*i.e.* >30 years) exists for a site, allowing for in-depth analysis of changes over time. Long term data allows for better analysis within a watershed and can help show trends or pinpoint when relationships began to change. While it would be beneficial to have discharge data from 1946-1976, the existing data set is greater than 30 years and provides a strong data set for analysis. Additional data including daily, monthly, annual, and peak flow statistics have been computed and complied by the USGS for the site.

Discharge Analysis

All discharge data were plotted using monthly and annual average flow values for the period of record to create a hydrograph. A hydrograph is a chart showing the rate of flow (*i.e.* discharge) over time at a sample location. Once plotted, the data can be examined for changes over time. Analysis of monthly flow values over time show that the average discharge volumes have increased (Figure 6). To further examine the increase in discharge volumes, precipitation trends were examined in relationship to monthly discharge volumes over the total watershed (Figure 7) and in annual total discharge versus total precipitation (Figure 8). General precipitation trends will also be examined in the next section.

The hydrograph (Figure 7) depicts total inches of runoff (*i.e.,* discharge over watershed area in inches) and monthly precipitation totals over time. This also shows that while runoff volumes are increasing, precipitation is staying steady over the period of record. When plotted out looking at total annual discharge and precipitaion totals, the change in the relationship over time becomes more apparent (Figure 8).

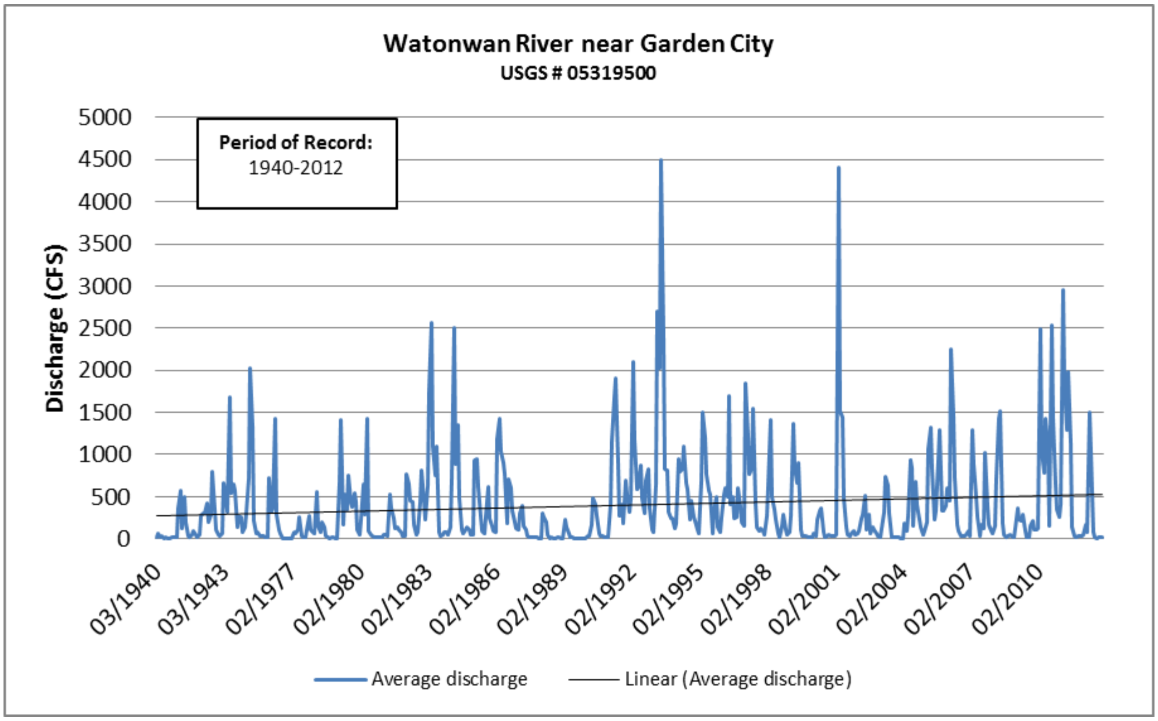


Figure 6. Average monthly discharge in the Watonwan watershed.

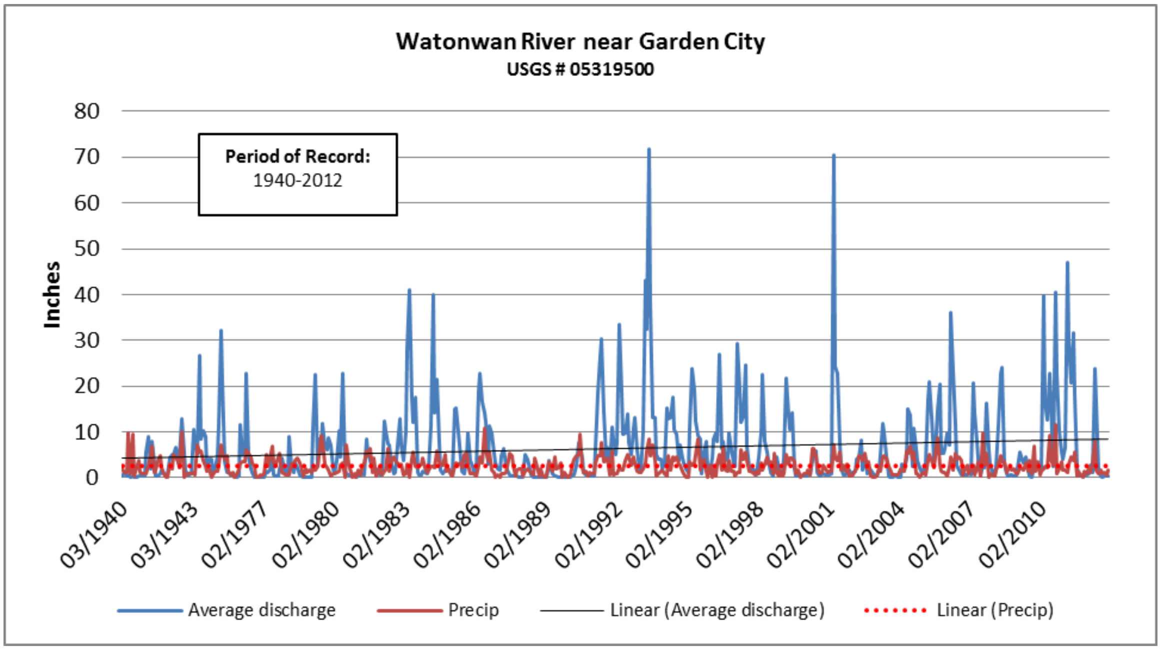


Figure 7. Average precipitation and runoff (*i.e.* discharge/area) in the Watonwan watershed.

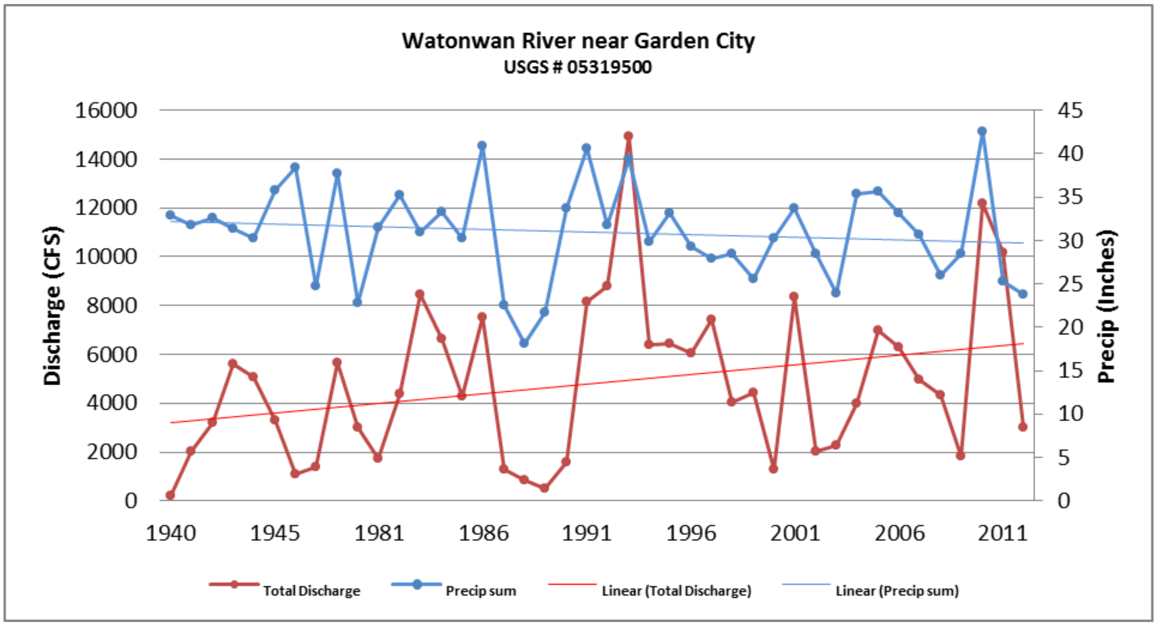


Figure 8. Annual total discharge and precipitation values over time.

Discharge data are also used to create a duration curve (Figure 9). Duration curves are used to examine the discharges and determine when a specific flow volume was exceeded or equaled in a given period, such as how often the flow volume exceeds high (*i.e.* 10th percentile) and low (*i.e.* 90th percentile) flow conditions for the watershed.

A curve with a steep slope throughout indicates a highly variable stream whose discharge is derived from direct runoff. A flat slope indicates the potential presence of surface or ground-water storage, which can help meter out the flow at a slower rate. The curve for the Watonwan is steeper, indicating variability within the system. This is likely related to the "flashiness" or rapid response to rain events within the watershed. It should be noted, however, that while the low flow conditions (*i.e.* < Q90) do have a high slope, no zero flow conditions are recorded. This indicates that while a negligible amount of perennial storage exists within the watershed, there is likely some level of ground water interaction with the river system at low flows.

The Greater Blue Earth River watershed is comprised of the Watonwan, Blue Earth, and Le Sueur Rivers. When all three rivers are plotted out as duration curves (Figure 10), some differences in the watersheds can be noted. The slopes of the main body of the curves (*i.e.* Q15 – Q85) are very similar, with the primary difference being the volume of each watershed. However, the upper and lower ends of the curves reflect some significant differences. It should be noted that the Watonwan has the steepest slopes at both ends, indicating that the watershed reacts faster to rain events due to limited storage capacity within the system.

Using the duration data, trends can be analyzed for various flow conditions. The high flow (*i.e.* Q10) and low flow (*i.e.* Q90) periods were plotted to examine if the number of days at the flow conditions has changed over time. In both cases, the high and low flow conditions have changed over time. The number of days at or below low flow (*i.e.* Q90) conditions has decreased over time, while the number of days at high flows (*i.e.* Q10) has increased over time (Figure 11). It should be noted that this data may change if the 1946-1976 data were available. Plotting out the dataset using 1978 as the starting year does yield similar results, indicating that the change has been occurring over the past 30 years.

Precipitation

Data collected at Lake Crystal indicates that the area has experienced variability in precipitation over time, but has largely stayed within the 25-75th percentile, even during the drought conditions of the 1930's. Data from Lake Crystal was used since it was the closest long-term dataset available near the outlet of the watershed. Since the 1960s yearly precipitation totals have slowly trended upwards until the 1990s (Figure 12). The period with the highest variability occurred from 1975 until 1995, with fluctuations above and below the 25th and 75th quartile. Even with the variability of the annual total values, the seven year average is largely within the 25th-75th percentile values, indicating fairly stable precipitation in the region.

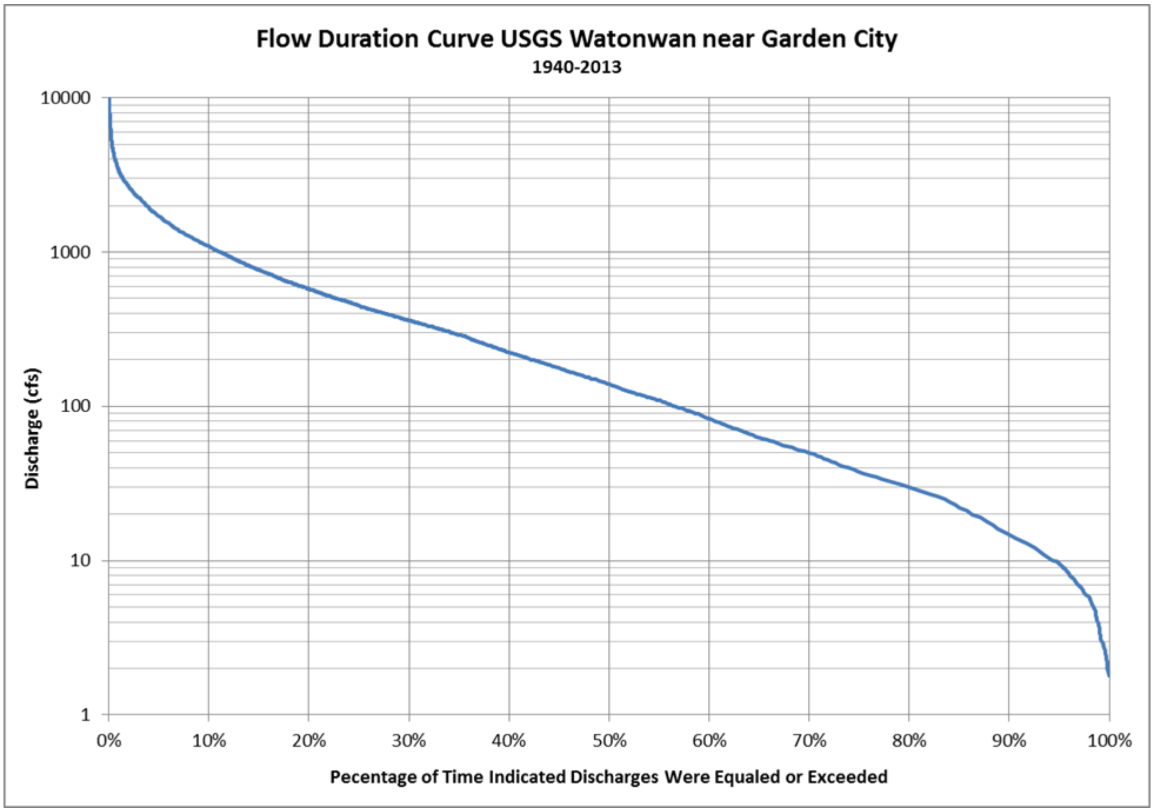


Figure 9. Flow duration curve of Watonwan monthly discharge values.

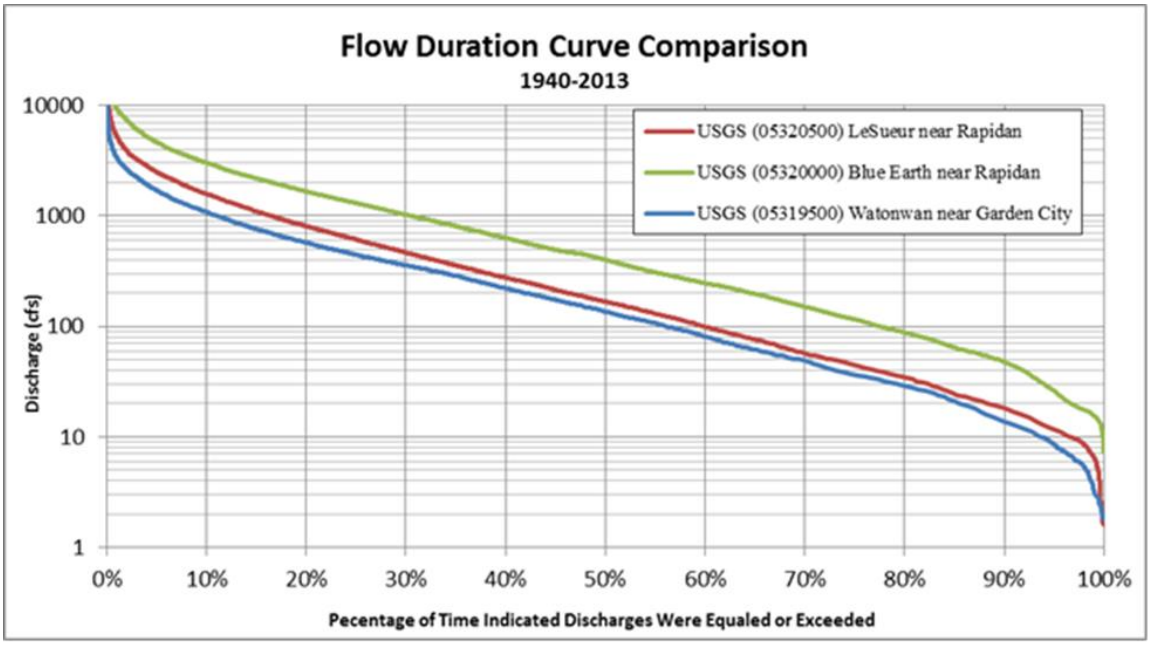


Figure 10. Flow duration curve plotted as discharge over watershed area.

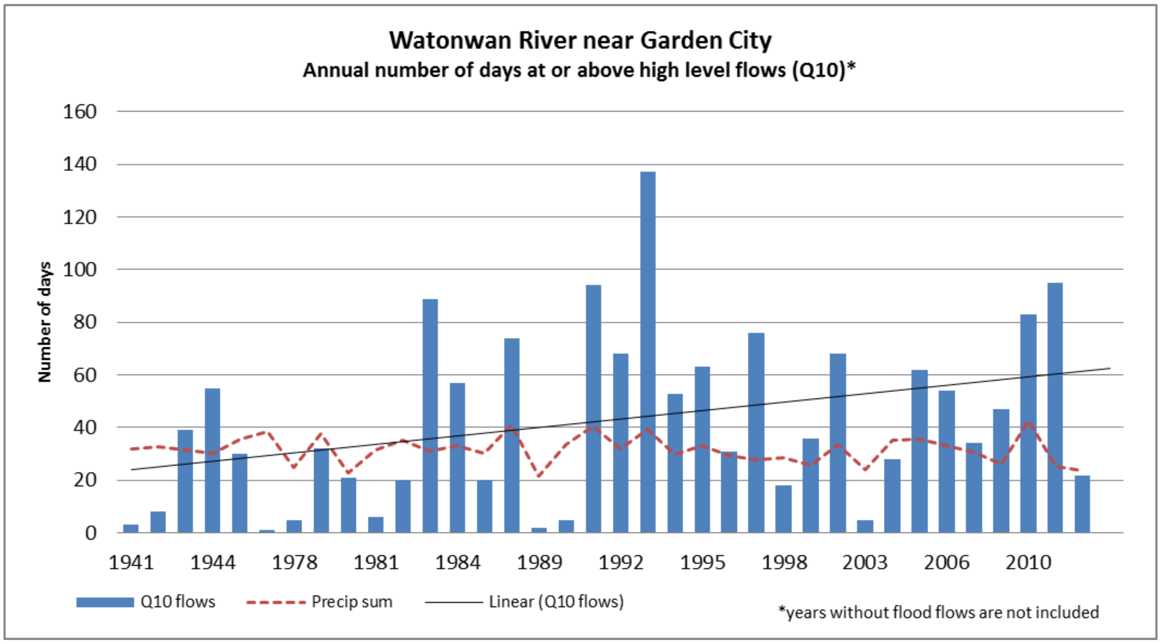


Figure 11. Number of days where flows are at or above high flow volumes (Q10) compared to annual precipitation within the Watonwan watershed.

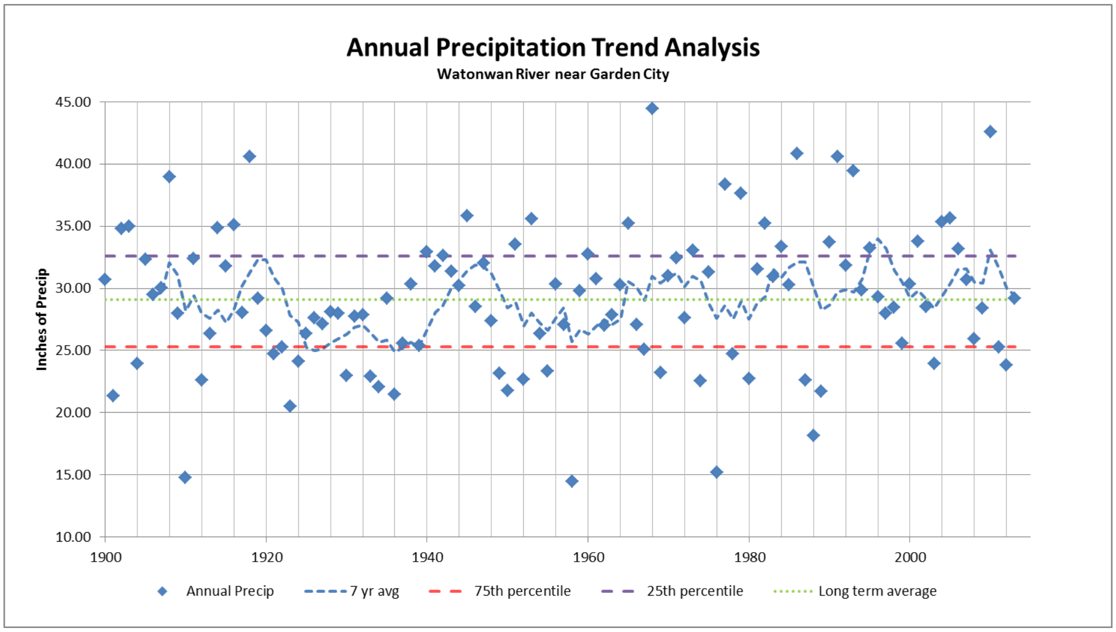


Figure 12. Precipitation trend data using annual precipitation data collected at Lake Crystal.

Double Mass Curve

Double mass curves were developed for the Watonwan River data. Precipitation and discharge data are used to develop the DMC to examine the relationship between precipitation and discharge. This technique was used to compare precipitation and stream discharge relationships (*i.e.* annual and seasonal) over the period or record (Figure 13). Precipitation data for both sets were collected from the Lake Crystal precipitation data station. When plotted, a straight line indicates consistency in the relationship, a break in the slope would mean a change in the relationship.

Before the shift in slope at 1983, there is a fairly strong relationship between runoff and precipitation during the 1930 to 1982 period. A strong relationship also occurs from 1983 to 2012 following an increased slope indicating more water is being discharged from the watershed then can be accounted for by the annual precipitation totals. The one downward anomaly depicted within the 1983 to 2012 period is due to the drought conditions of 1988 and 1989. This change in the slope relationship from 1983 to 2012 indicates runoff from the watershed is increasing relative to the amount of rain. Within the entire data set, both low and high annual precipitation volumes were recorded suggesting that a period of wet or dry conditions does not affect this relationship.

The two periods of record can also be plotted out as average annual discharge. While this does condense the data, it is useful to examine the change between the average values. As seen in Figure 14, the average value has changed in both volume and timing. This is a general comparison, as the missing data may increase or decrease the annual average for the 1930-1983 period of record.

In a recent study, Lenhart et al. (2011a) concluded that the moderate increase in annual precipitation alone cannot explain the average 70% increase in average annual streamflow in the Minnesota River basin. Further, the researchers found a significant increase in streamflow in agricultural watersheds in 1980-2009 as compared to the period of 1940-1979 (Lenhart et al. 2011a). These results are consistent with Schottler et al. (2013) findings where river flows in many south central Minnesota watersheds were significantly higher in the period of 1975-2009 relative to the period of 1940-1974. However, they also found no significant difference in stream flows between the two time periods in several watersheds suggesting that precipitation alone does not explain the difference (Schottler et al 2013).

Web-based Hydrograph Analysis Tool

The discharge data sets were analyzed for changes for run off and baseflow conditions by uploading the data into the Web-based Hydrograph Analysis Tool (Figure 15). This tool is beneficial to examine the baseflow discharge relationship over time. In this case baseflow measurements account for anything that is not direct runoff so the notable increases in the Watonwan system are reflecting hydrologic response to drainage contribution throughout the year and can be used to look at long term and seasonal variations.

The data is a five year window around the time when the runoff and precipitation ratio changed based on the double mass curve data. In terms of total baseflow volume, the WHAT tool has calculated that baseflows have increased over time. Peak flow volumes from the calculated “direct runoff” have also increased in general.

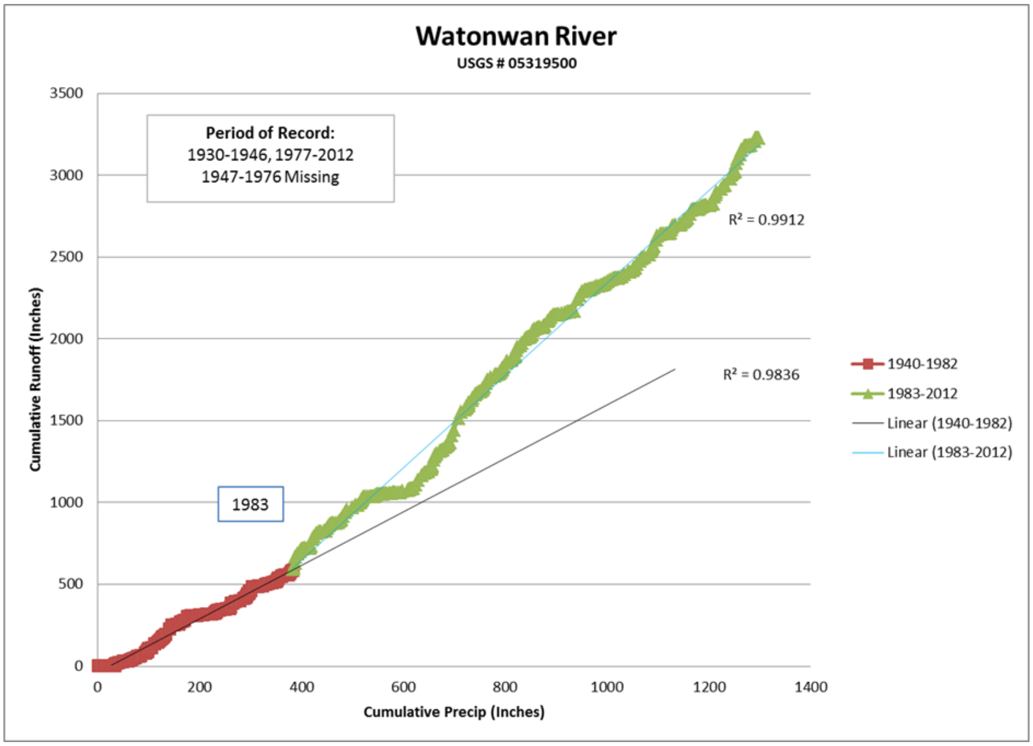


Figure 13. Double mass curve of runoff and precipitation demonstrates an increase in the amount of runoff per inch of precipitation due to a change in the relationship around 1983.

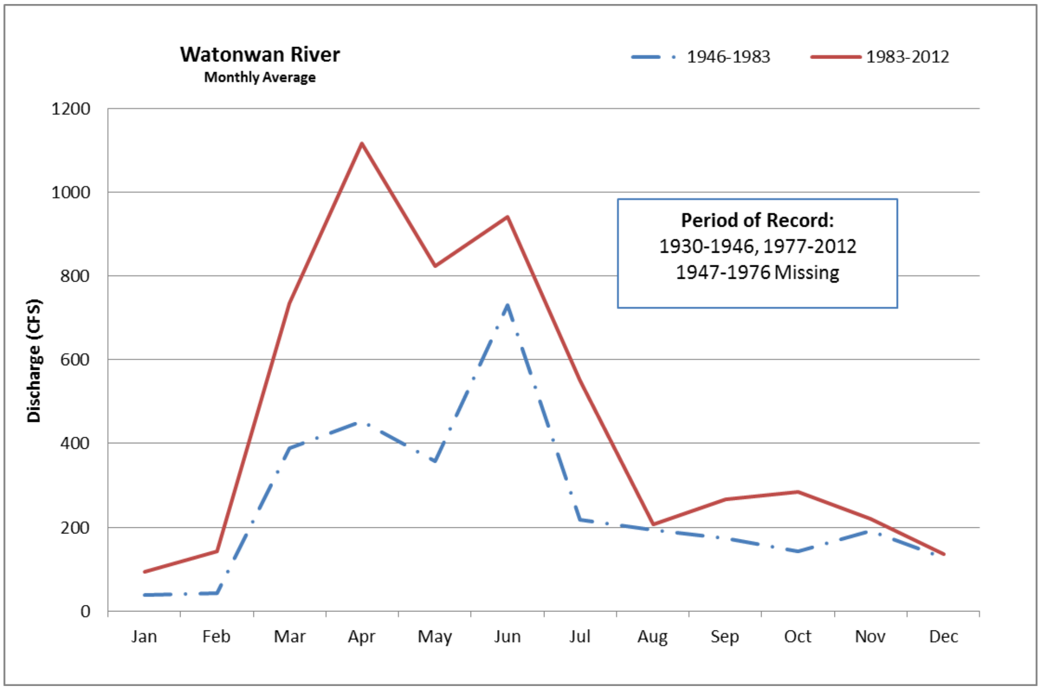


Figure 14. Comparison of average monthly discharge from 1946-1983 and 1983-2012 to demonstrate the degree of change.

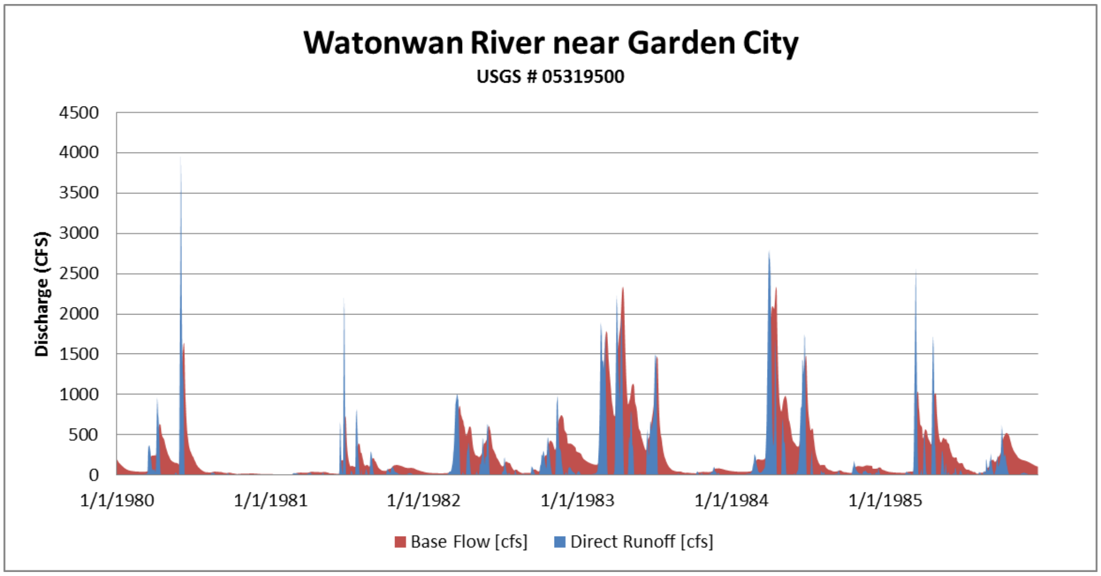


Figure 15. Calculated baseflow and runoff volumes before and after the 1983 precipitation and runoff ratio change.

Ground Water Usage

Lastly, groundwater usage for the watershed was reviewed by compiling all reported permitted usage. All permit data was collected through the State Water Use Data System (SWUDS). The largest appropriation and usage category in the Watonwan River watershed is waterworks, followed by major crop irrigation (Figure 16). Major crop irrigation reported levels were highest in 1988 at over 600 million gallons/year. The volume of major crop irrigation will likely increase since the number of appropriations has increased since 2011.

The type of aquifer used is also an important consideration when discussing discharge from the Watonwan River and groundwater/surface water interaction. The majority of the water appropriated has shifted from relatively shallow wells in quaternary water table aquifers (QWTA) to quaternary buried artesian aquifers (QBAA) (Figure 17). Excessive pumping of the ground water table aquifers may impact the hyporheic connectivity to Watonwan rivers, especially smaller tributaries or branches at periods of low flow, when ground water may be the majority of the base flow conditions. To avoid this impact, appropriation permits are typically suspended when flows in the system fall below the Q90 threshold.

In order to evaluate the potential impact on the water table from the usage, annual groundwater elevation range over time was plotted in a double mass curve vs. precipitation from observation well numbers 83011 (QBAA) and 83013 (QWTA). Using the double mass curve technique eliminates some of the natural variability often recorded in observation wells. While precipitation has been taken into account, it is important to note climatic impacts have not been eliminated, because antecedent groundwater levels are very important in looking at fluctuations.

Over the period of record for the observation well, no significant change in the relationship has occurred. That does not mean that this relationship will not change in the future based on changing land uses or appropriation volumes. Long-term data was not available in the immediate area of the gaging station. Due to the number of appropriations in the area and limited wells, this area would benefit from additional ground water monitoring and study.

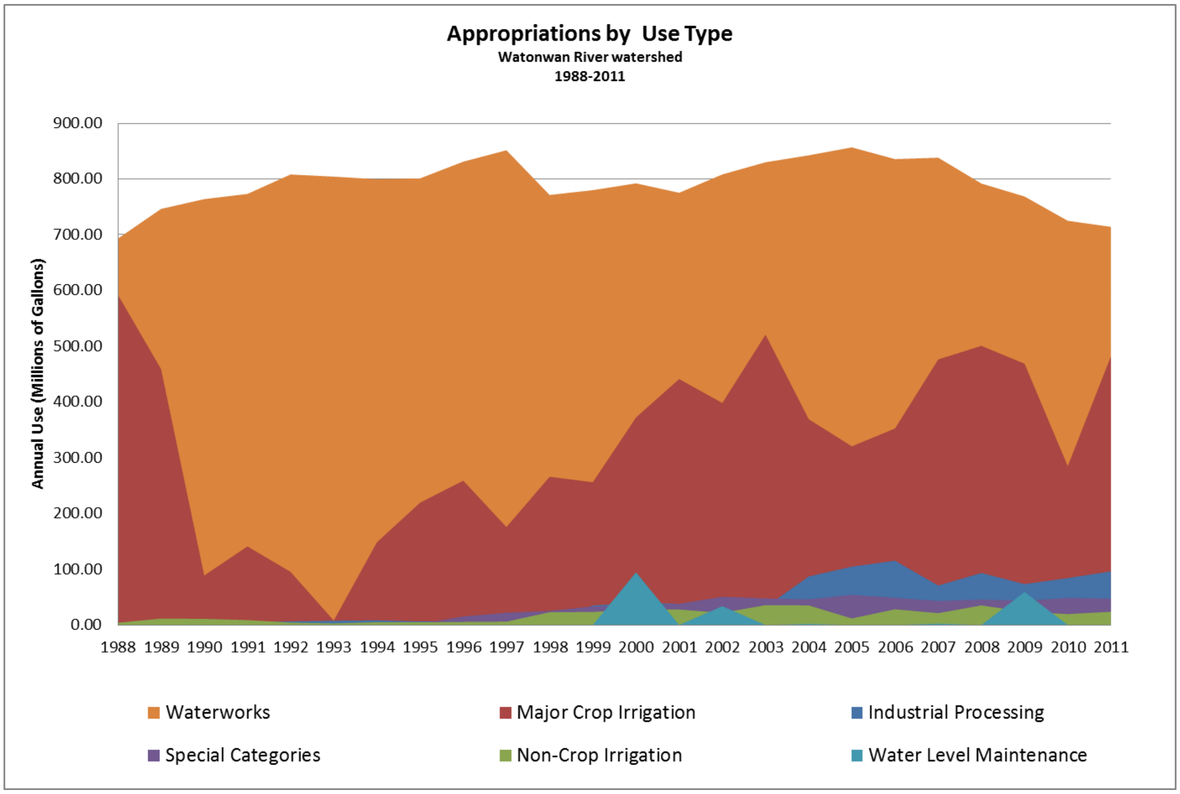


Figure 16. Water appropriations by type.

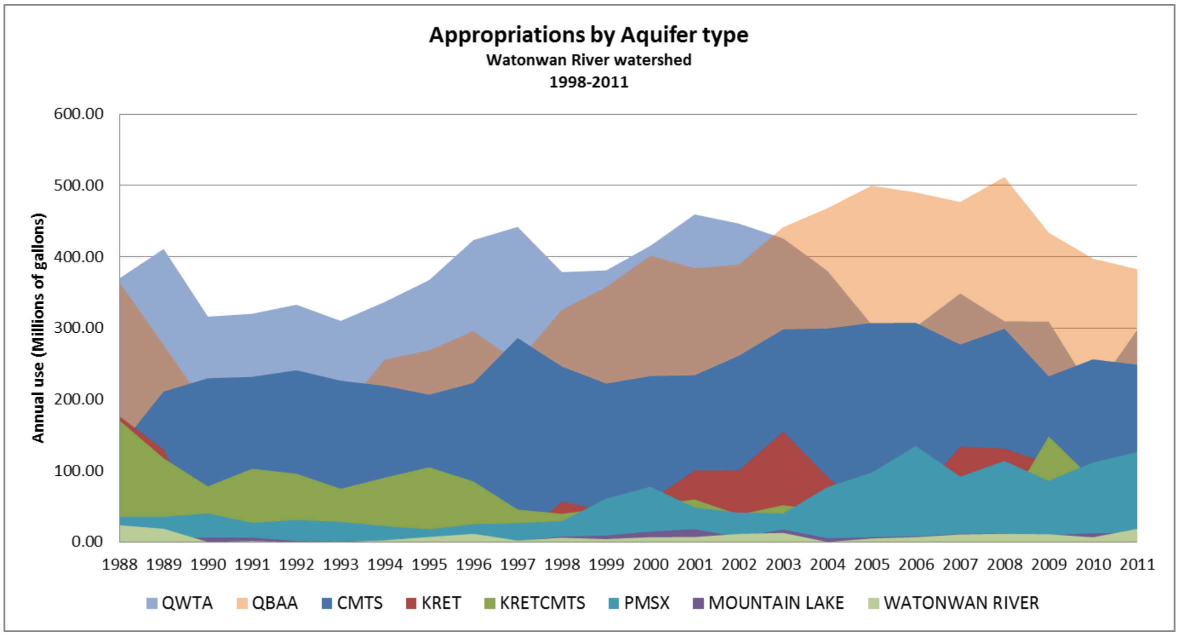
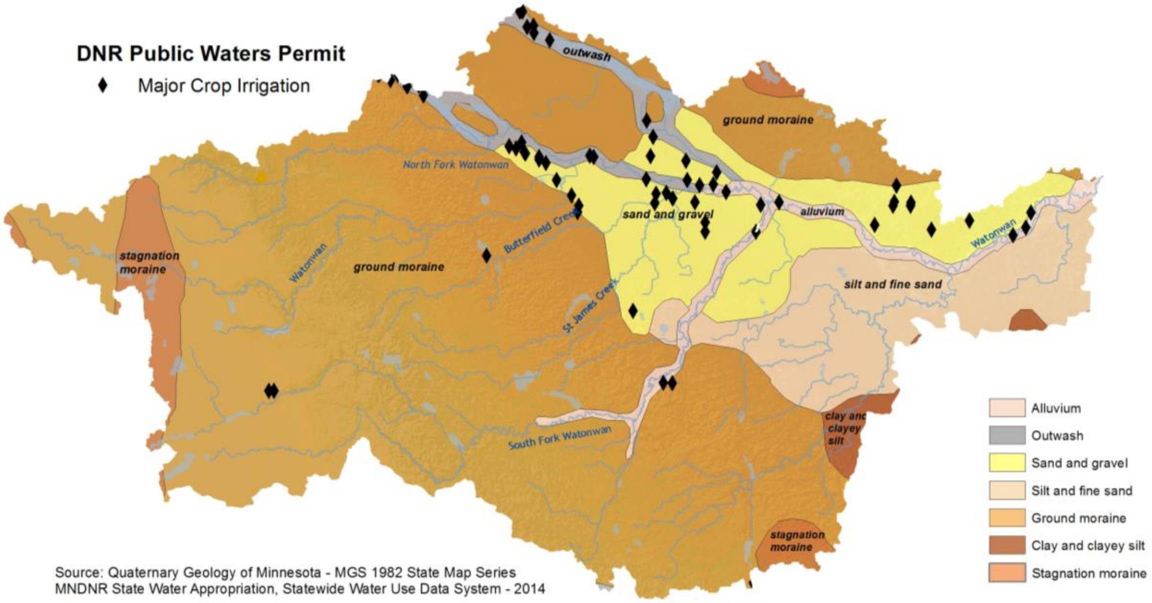


Figure 17. Annual usage by aquifer.



Source: Quaternary Geology of Minnesota - MGS 1982 State Map Series
MNDNR State Water Appropriation, Statewide Water Use Data System - 2014

Figure 18. Major crop irrigation permits and their spatial location in relation to the geologic conditions within the Watonwan watershed.

Connectivity

Longitudinal Connectivity

An extensive search through GNIS, WHAF, NID, and MNDNR's dam safety records indicate eleven dams exist as potential fish barriers within the Watonwan watershed (Figure 19). Seven of the dams identified within the watershed are lake outlet structures [*i.e.*, Banks State Wildlife Management Area (SWMA), and Eagle, Hanska, Long, Mary, Mountain, and Wood Lakes] and likely have no significant effect on MPCA fish community assessment sites (Table 3). One fish exclusionary structure exists between Fish Lake and its outlet, and a concrete spillway exists just downstream of the Hanska Lake outlet; both of which are upstream of MPCA fish community assessment sites. The remaining two potential barriers are dam and diversion structures. The 'Wood Lake diversion' is a dam and water diversion structure positioned in the North Fork Watonwan River that is used to divert water to the Wood Lake SWMA. The 'Watonwan River Diversion' is a low head dam and water diversion structure positioned in the South Fork Watonwan River used to impound water to the level of a pump that transports water uphill to Long Lake.

After settlement, lakes, wetlands, and depressional areas within the Watonwan watershed were altered (*i.e.* outlet structures) or drained (*i.e.* public drainage system). Drainage and outlet structures have had drastic impacts on the longitudinal connectivity, natural drainage network, and quality of aquatic resources within the Watonwan watershed (Figures 20 and 21).

The MNDOT bridge and culvert shapefile in ArcMap indicated that there are 179 bridges (0.20/mi^2) and 152 culverts (0.17mi^2); 331 stream crossings in total (0.38/mi^2) (Figure 22; Table 4). Though the number of bridges and culverts appears to be low in regard to total watershed drainage area, bridges and culverts can have drastic impacts on rivers and streams; especially when improperly sized. Improperly sized bridges and culverts can create flood flow confinement (FFC), which in return can cause channel widening, alter sediment transport capacity, and sediment deposition (Zytkovicz and Murtada 2003).

The MNDOT bridges and culvert shapefile was also used to assess longitudinal connectivity of the riparian corridor. The bridges and culvert shapefile allows for spatial assessment of road crossings and thus breaks in longitudinal connectivity. Longitudinal connectivity of riparian corridors was also assessed locally during field surveys. Nine of the eleven sites had adequate corridors with largely undisturbed vegetated riparian area. Two of the eleven sites (*i.e.,* North Fork Watonwan River, and Watonwan River) had less than adequate riparian corridor connectivity and minimal riparian vegetation width.

Lateral Connectivity

Seven of the eleven geomorphology study reaches have sufficient lateral connectivity to access their floodplains, recharge oxbows, and provide refuge to biota during high flow events. Four of the study reaches (*i.e.*, North Fork Watonwan, South Fork Watonwan, Upper St. James Creek, and the Watonwan River gage station) do not have adequate lateral connectivity to access their floodplains, and therefore, are entrenched. Flood-prone elevations are 2X maximum bankfull depth at a riffle cross section and are typically comprised from ~1.5 year return interval flow. The South Fork Watonwan and Watonwan River

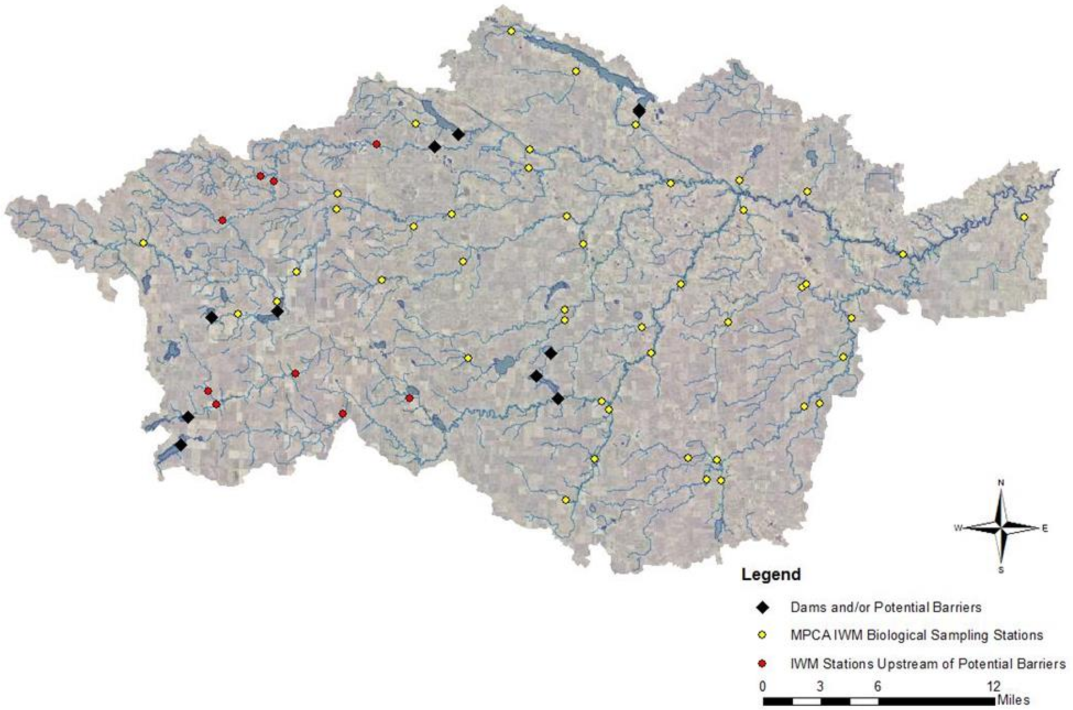


Figure 19. Location of dams and barriers to fish passage throughout the Watonwan River watershed.

Table 3. In-stream structures existing within the Watonwan River watershed.

Waterbody	Structure Type	NID Number
Hanska Lake	Dam/Outlet Structure	MN00070
Hanska Outlet Spillway	Concrete Spillway	MN00070
Mary Lake	Dam/Outlet Structure	MN00107
Eagle Lake	Dam/Outlet Structure	MN00163
Fish Lake (Banks SWMA)	Dam/Outlet Structure	MN00164
Mountain Lake	Dam/Outlet Structure	MN00165
Fish Lake	Fish Exclusion	MN01151
Wood Lake Outlet	Dam/Outlet Structure	MN01251
Long Lake	Dam/Outlet Structure	MN01341
Watonwan River Diversion	Low Head Dam & Diversion Structure	MN01342
Wood Lake Diversion	Low Head Dam & Diversion Structure	MN01343

Figure 20. Outlet structure on Mary Lake in central Watonwan River watershed. Structures throughout the watershed such as this likely changed lake and stream stability, affected sediment deposition, emergent aquatic vegetation, and hydrology.

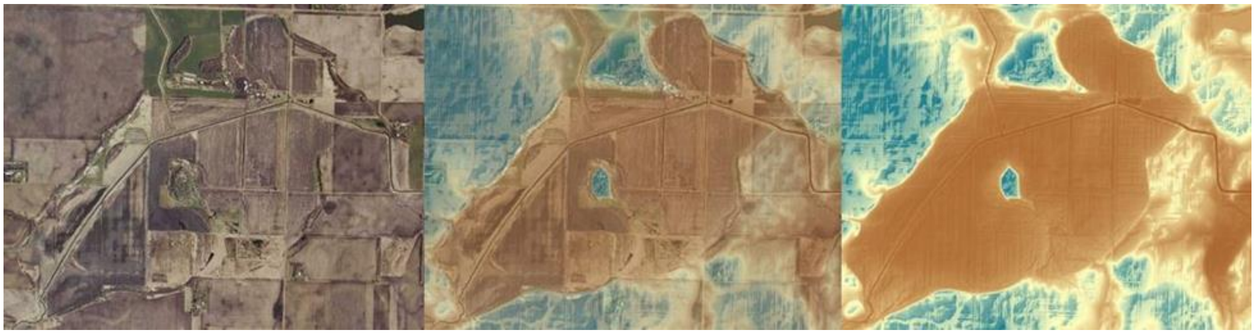


Figure 21. Not all lakes, wetlands, and depressional areas were originally included within the longitudinal connectivity of the Watonwan watershed. Here, the original Mountain Lake can be seen through LiDAR imagery. Mountain Lake was ~900 acres and was drained in 1905-06 as demands for increased agriculture led to the expansion of drainage ditches through south central Minnesota.

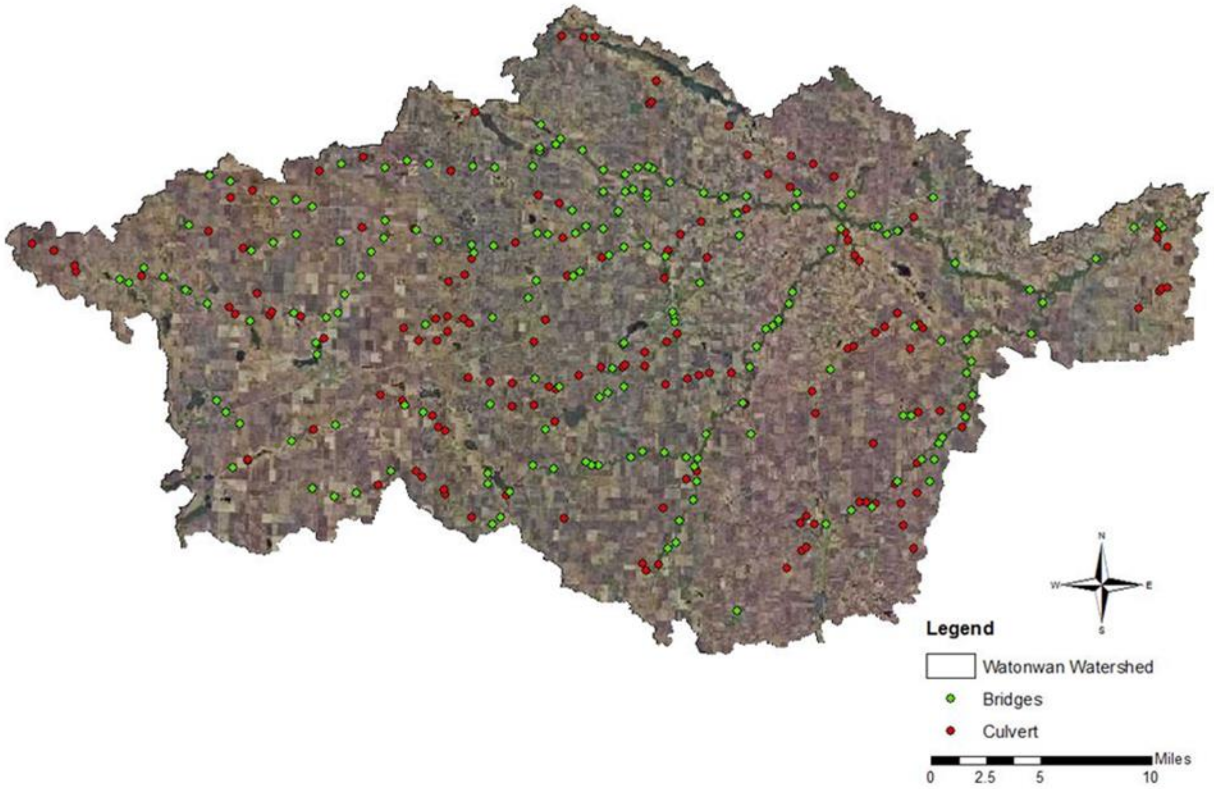


Figure 22. Location of bridges and culverts throughout the Watonwan River watershed.

Table 4. Number and density of bridges and culverts throughout the Watonwan River watershed broken down by study reach drainage area.

Study Stream Reach	**Drainage Area (mi^2)**	**Number of Bridges**	**Density of Bridges ($\#/mi^2$)**	**Number of Culverts**	**Density of Culverts ($\#/mi^2$)**	**Total Road Crossings**	**Density of Road Crossings ($\#/mi^2$)**
North Fork Watonwan River	55.5	9	0.16	4	0.07	13	0.23
Watonwan River	83.1	12	0.14	12	0.14	24	0.29
Judicial Ditch #1	52.2	5	0.10	2	0.04	7	0.13
Saint James Creek (Lower)	124.0	12	0.10	17	0.14	29	0.23
Saint James Creek (Upper)	34.9	3	0.09	3	0.09	6	0.17
South Fork Watonwan River	214.5	43	0.20	28	0.13	71	0.33
Willow Creek	31.1	5	0.16	7	0.23	12	0.39
Watonwan River	678.5	151	0.22	113	0.17	264	0.39
Perch Creek (Lower)	149.7	22	0.15	32	0.21	54	0.36
Perch Creek (Upper)	53.5	2	0.04	6	0.11	8	0.15
Watonwan River	851.4	177	0.21	145	0.17	322	0.38
Watonwan River Watershed	878.0	179	0.20	152	0.17	331	0.38

at the gage station are both F channels. F channels have a low entrenchment ratio (*i.e.* flood-prone width/bankfull width), high width to depth ratio (*i.e.* width at bankfull/mean depth), and moderate sinuosity (channel length/valley length). Streambanks are actively eroding in the absence of extremely high quality riparian vegetation in F channels. F channels are very sensitive to disturbance, have a very high streambank erosion potential and sediment supply, while also having a poor recovery potential (Rosgen 1996; Table 5).

The North Fork Watonwan River and Upper St. James Creek study sites also do not have adequate lateral connectivity to access their floodplains during 2x bankfull flows. These channels are classified as G channels. G channels such as those represented in these study reaches are deeply incised channels (*e.g.* ditched channel in the instance of the north fork site) in depositional material primarily comprised of unconsolidated heterogeneous mixture of gravel, some small cobble, and sand (Rosgen 1996). G channels are extremely sensitive to disturbance, have a very high streambank erosion potential and sediment supply, and have a very poor recovery potential (Rosgen 1996).

Table 5. Vegetation type, streambank and root characteristics, and correlated BEHI adjective ratings for Watonwan River watershed geomorphology study sites.

Site	**Vegetation Type**	**Bank Height**	**Root Depth**	**Root Density**	**Weighted Root Density**	**BEHI Rating**
North Fork Watonwan River	Grass/Cottonwoods	7.0	3	5	2.14	High
Watonwan River	Grass/Deciduous Hardwood	7.5	4	85	45.33	Moderate
Judicial Ditch #1	Reed Canary Grass	6.5	1	30	4.62	Moderate
Saint James Creek (Lower)	Pastured Grasses	4.5	3	30	20.00	Moderate
Saint James Creek (Upper)	Unpastured Grasses	12.0	1	35	2.92	High
South Fork Watonwan River	Deciduous Hardwoods	9.0	7	25	19.44	Moderate
Willow Creek	Unpastured Grasses	7.5	4	85	45.33	Moderate
Watonwan River	Deciduous Hardwoods	10.0	4	10	4.00	High
Perch Creek (Lower)	Pastured Grass/Hardwood	6.0	7	5	5.83	Very High
Perch Creek (Upper)	Reed Canary Grass	5.0	4	50	40.00	Low
Watonwan River	Deciduous Hardwoods	6.5	6.5	40	40.00	Moderate

Geomorphology

Eleven reaches were surveyed in the fall of 2012 and 2013. The following map shows the location and channel classifications for each site (Figure 23). This section provides an in-depth look at the characterization and stabilization of survey sites, starting in the northwest corner of the watershed (*i.e.* North Fork Watonwan River) and generally moving to the south and east to the final site on the lower Watonwan River (*i.e.,* load monitoring and gage station near Garden City).

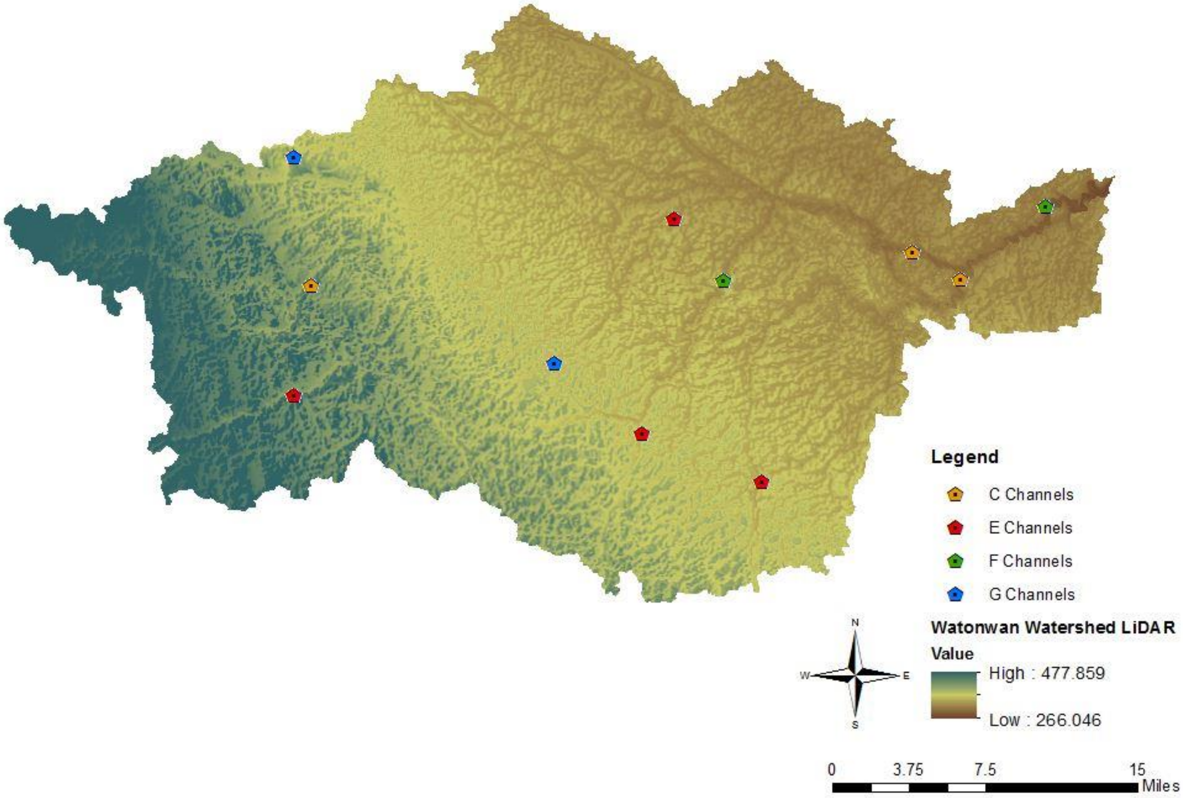
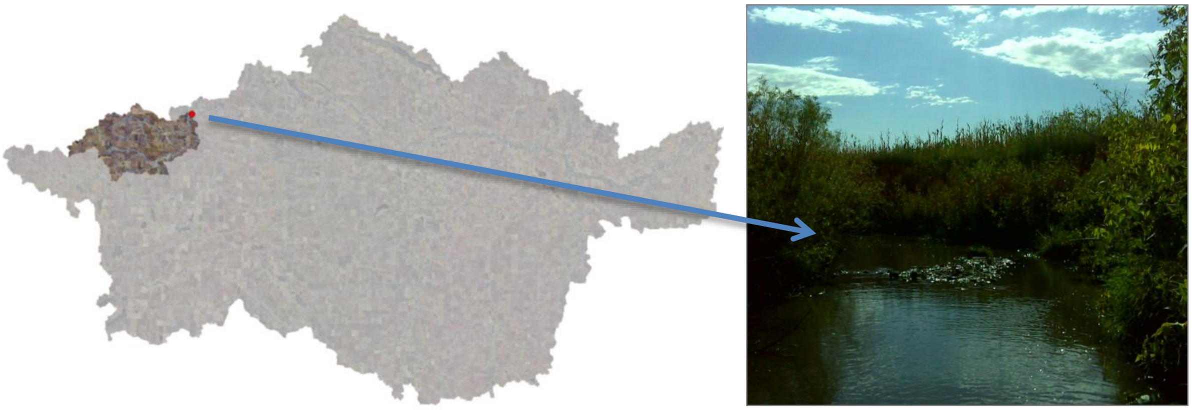


Figure 23. Spatial location and channel classification of geomorphology survey sites within the Watonwan River watershed.

North Fork Watonwan

Table 6. Baseline information for the North Fork Watonwan River geomorphology survey site.

Stream Information			
Stream Name	N Fork Watonwan	**Drainage Area**	33 mi^2
AUID	07020010-513	**Stream Type**	G4c
HUC 8 Watershed	Watonwan	**Valley Type**	8(c) Terraced Alluvial
County	Cottonwood	**Water Slope**	0.0028 ft/ft
Section	16	**Sinuosity**	1.07
Township, Range	107N, 34W	**Reach Erosion Estimates**	0.0198 tons/foot/year
Bank Height Ratio	2.11 (Deeply Incised)	**Pfankuch Stability Rating**	120 (Poor)



The North Fork Watonwan River is impaired for turbidity. The survey reach is located in Cottonwood County three miles northwest of the town of Darfur. The 33 square mile drainage area consists of 90.7% cultivated crops, 4.1% perennial vegetation and 5% other land cover (WHAF 2014). Land adjacent to the survey reach includes a 5-30 foot wide strip of perennial grasses, willows, and scattered hardwood trees on each side of the stream followed by row crops. The river was channelized through the reach between 1950 and 1991. The entrenched (*i.e.* vertically contained) channel lies within an unconfined terraced alluvial valley (Figure 24). Channelized or ditched streams actively erode in the bed (*i.e.* incision) and on the banks (*i.e.,* scour, sloughing, bank failure) as they adjust to a more stable form. Streams that become entrenched abandon their floodplain and are thus also confined (*i.e.* laterally contained), normally resulting in a decrease in channel sinuosity (Rosgen 1996).

The G4c stream is low gradient and generally described as an entrenched 'gully' with a low width-to-depth ratio. G channels are unstable with grade control problems and high bank erosion rates. There is a minor bankfull bench starting to develop within the channel (Figure 25) and a series of riffles and pools were surveyed, as indicated on the longitudinal profile (Figure 26). A beaver dam was constructed at a

Figure 24. The channel at the North Fork Watonwan geomorphology survey site was straightened at some point between 1950 and 1991.

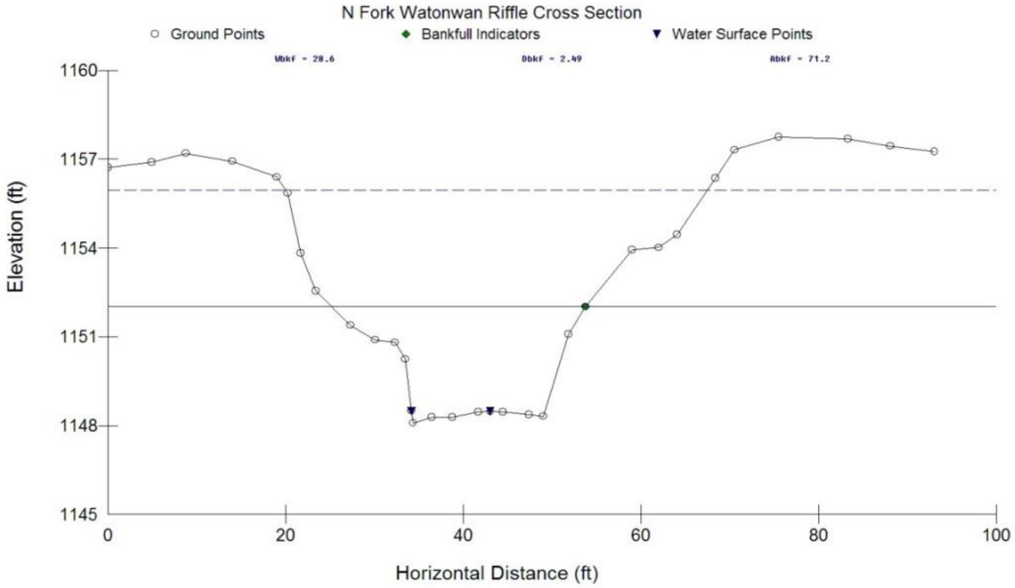


Figure 25. Cross sectional profile of riffle within the North Fork Watonwan River geomorphology survey site. Bankfull benches are beginning to be developed within the channel.

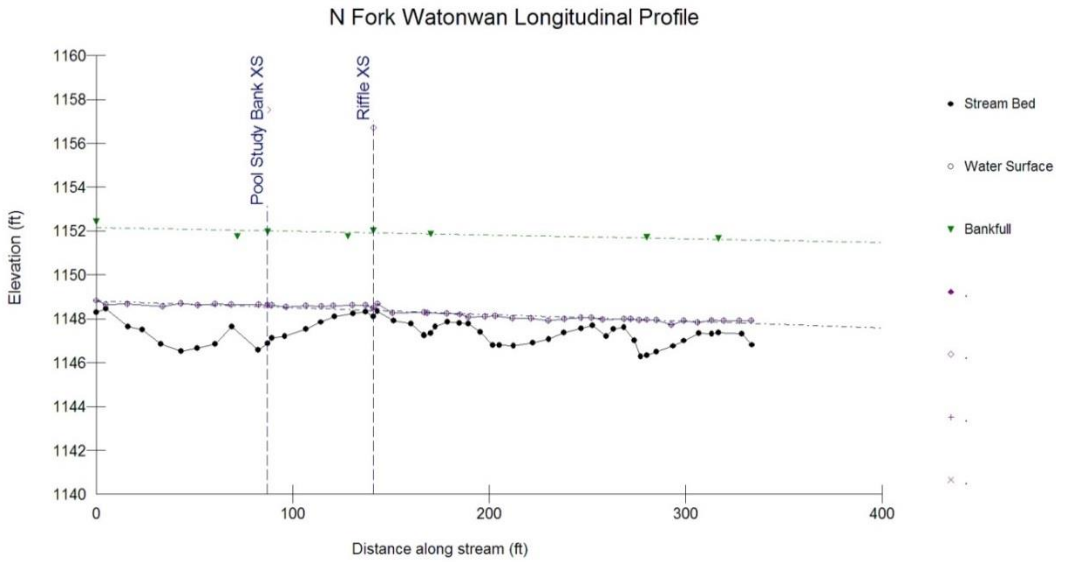


Figure 26. Longitudinal profile of the North Fork Watonwan River geomorphology survey site.

riffle within the survey reach sometime after the initial survey in September 2012 and prior to the re-survey in September 2013.

In regards to management implications, G4 streams have an extreme sensitivity to disturbance, very poor recovery potential, very high sediment supply and streambank erosion, and are highly influenced by vegetation (Rosgen 1994; Appendix II). The G stream resulted from past disturbance (*i.e.* channelization). The stream will likely continue to widen until aggradation creates an adequate bankfull bench and an adequate floodplain inside the channel; subsequently, returning to a more stable channel form (*i.e.* the channel's potential stream type; C4).

The sediment supply from streambank erosion was estimated using the BANCS (*i.e.* BEHI matched with NBS) model. This reach is contributing 0.0198 tons of sediment (*i.e.* 39.6 pounds) per linear foot of streambank annually when using the Colorado erosion rate curve (Rosgen 2001). Erosion predictions assume the 350 foot reach delivers 6.9 tons of sediment (~0.7 dump truck loads) annually. At the monumented pool cross section, the model estimates the bank erosion to be 0.25 feet per year for the 10 foot high bank while the actual measurement indicates an erosion rate of 0.67 feet per year (Figure 27).

The road crossing 130 feet upstream from the start of the survey reach provides an example of what happens when road crossings are improperly sized. The amount of sediment deposited in the three barrel culvert relates to the fact that the road crossing was built too wide for the bankfull channel; therefore, sediment is being deposited and developing a floodplain in the other culvert barrels (Figures 28 and 29). In order for a stream to maintain stability, it must transport the water and sediment of its watershed. Ideally, sites like this would have a culvert large enough to handle the bankfull discharge, and then have floodplain relief culverts at the floodplain elevation to allow flood flows to stay on the floodplain and not become bottlenecked (Zytkovicz and Murtada 2013). An indirect impact of these culverts stems from the channelization of the stream that directed the flows straight into the culverts. Historically, the North Fork Watonwan River was naturally meandering. In order for this low gradient headwater type channel to be stable, it will continuously work to increase sinuosity. Much of the lateral bank erosion noted in the study reach stems from the channelization that took place historically.

Summary

The stream was channelized between 1950 and 1991 and has limited floodplain access. The bankfull bench was not well established and the perennial buffer was too narrow. There is evidence of widening and past incision in the G4 channel. The stream reach is currently a high supplier of sediment, as indicated in the bank erosion assessment. The North Fork Watonwan site will continue to adjust to its dimension, pattern, and profile until the floodplain bench is established within the channel.

Management Recommendations

Before designing restoration for an unstable river, it is essential to determine the causes of disequilibrium (Rosgen 1996). It must be determined whether or not the problem is a symptom of a larger watershed issue, and what the benefits to habitat, water quality, and overall stream health are as a result of proposed restoration. Additional surveys in the North Fork Watonwan River would

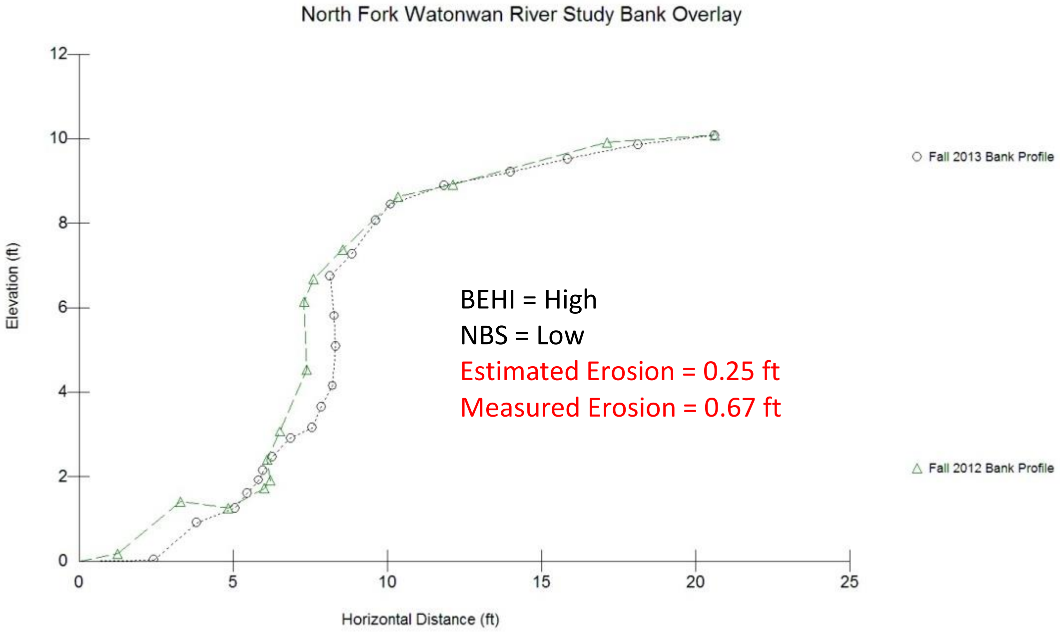


Figure 27. Cross sectional profile of monumented pool study bank from 2012 and 2013 surveys along with BEHI, NBS, estimated, and measured erosional rates.

Figure 28. Sediment deposition within the culvert barrels indicate improper sizing.

Figure 29. Triple barrel culvert, two barrels filling with sediment and providing flood plain relief during high flows.

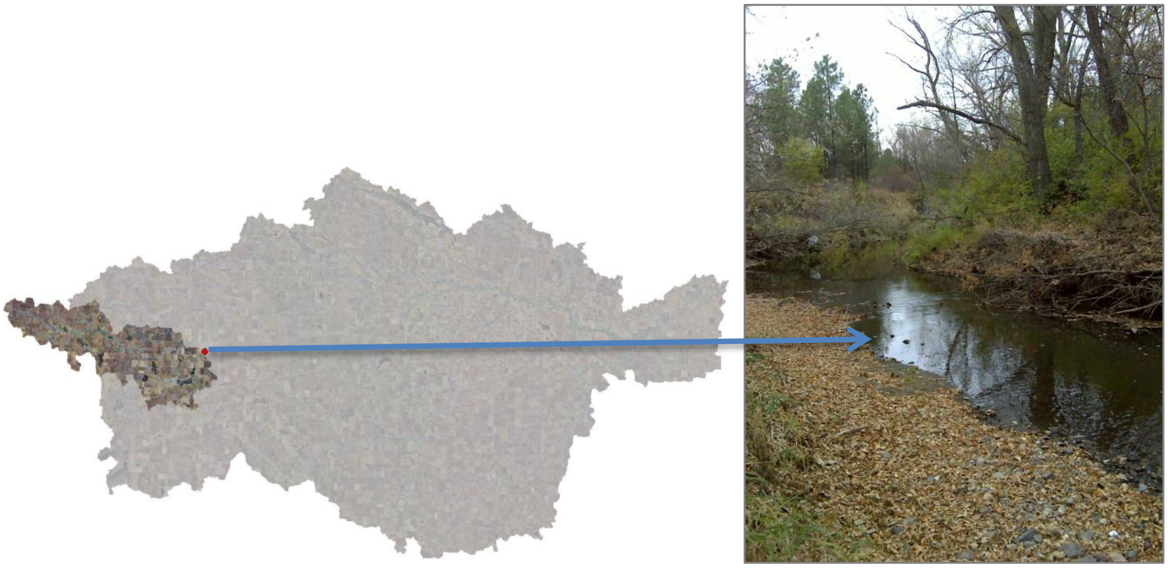
help determine the degree of channel instability throughout the watershed and prioritize restoration efforts. Aerial photography and LiDAR investigations indicate a history of ditching and intensive row crop agriculture throughout the watershed.

Establishment of a wider perennial vegetated buffer is a starting point, especially on the south side of the channel where the river is consuming rows of crops and taking valuable farmland. The stable stream type under the present hydrology and sediment regime is an E or C stream type. If the landowner and stakeholders are interested in a future restoration effort, design parameters need to include proper dimension, pattern (*i.e.* meander geometry), and profile (*i.e.* riffle/pool spacing). Properly sized road crossings (*i.e.* bridges and culverts) will also help improve stream stability, sediment transport, and overall stream health.

Upper Watonwan River

Table 7. Baseline information for the upper Watonwan River geomorphology survey site.

Stream Information			
Stream Name	Watonwan	**Drainage Area**	61 mi^2
AUID	07020010-514	**Stream Type**	C4
HUC 8 Watershed	Watonwan	**Valley Type**	8(a) Confined Alluvial
County	Cottonwood	**Water Slope**	0.0027 ft/ft
Section	15	**Sinuosity**	1.2
Township, Range	106N, 34W	**Reach Erosion Estimates**	0.0278 tons/foot/year
Bank Height Ratio	1.84 (Deeply Incised)	**Pfankuch Stability Rating**	102 (Fair)



The Upper Watonwan River site has fecal coliform, turbidity, and fish impairments. The gravel bed stream is a low gradient, meandering, riffle/pool channel formed in an alluvial valley. The riparian corridor is densely populated with perennial grasses and deciduous and coniferous trees extending beyond 50’ on either side of the channel. Row crop agriculture is the dominant land use upstream of the study site at 86.4%, followed by perennial vegetation at 5.2%, water at 1.7%, and other land uses constituting 6.7% (WHAF 2014).

The upper Watonwan River was channelized between 1938 and 1950 in order to construct a road and bridge crossing (Figure 30). It appears to have evolved to the more stable “C” stream type. There were low flows observed in the fall of 2012 and 2013 when the surveying occurred; however, distinct riffles, three-foot deep pools, and a tight vegetative corridor existed. The upper Watonwan is barely reaching its floodplain during high flows (Figure 31). If floodplain connectivity is lost, the stream will become unbalanced as the channel acclimates to convey all flood flow and energy. In addition, the bank height

Figure 30. The upper Watonwan River was channelized between 1938 and 1950 in order to construct County Road 1 and a bridge crossing.

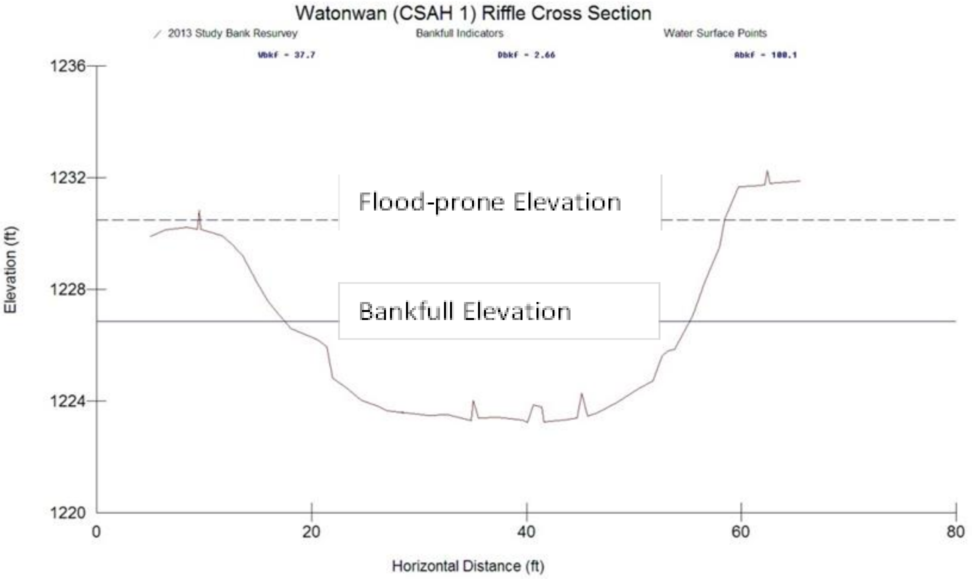


Figure 31. Cross sectional profile indicating that the upper Watonwan River barely accesses its floodplain.

ratio [BHR (*i.e.* Lowest Bank Height / Max Bankfull Depth)] is 1.7, indicating a deeply incised channel. Streams with high BHRs generally contribute disproportionate amounts of sediment from banks and bed due to high shear stress. In regards to management implications, C4 stream types have a very high sensitivity to disturbance, good recovery potential, high sediment supply, very high streambank erosion potential, and riparian vegetation plays a significant role in maintaining stability (Rosgen 1994; Appendix II).

The sediment supply from streambank erosion is moderate to low compared to other Watonwan sites. The BANCS model estimated that this reach is contributing 0.0278 tons of sediment per linear foot of streambank annually using the Colorado erosion rate curve (Rosgen 2001). At the monumented riffle cross section, the model estimates the erosion to be 0.153 feet per year for the seven foot high bank while the actual measurement indicates an erosion rate of 0.0042 feet per year. The BEHI rating is moderate and NBS is low when using method #5 (*i.e.* near-bank maximum bankfull depth to mean bankfull depth), a method that is linked to the riffle cross section.

Summary

Overall, this site is moderately stable for the Watonwan watershed. 0.0042 tons per foot of bank erosion was observed, but some raw banks were documented further downstream. The wide forested riparian buffer provides streambank protection, especially during channel forming flows. Historical photos and LiDAR provide evidence of past channel alterations. A cobble dominated riffle was at the start of the longitudinal profile, 220 feet from the road crossing at the first sweeping bend, where the valley is relatively narrow. Further downstream, the flood-prone width and valley width is greater.

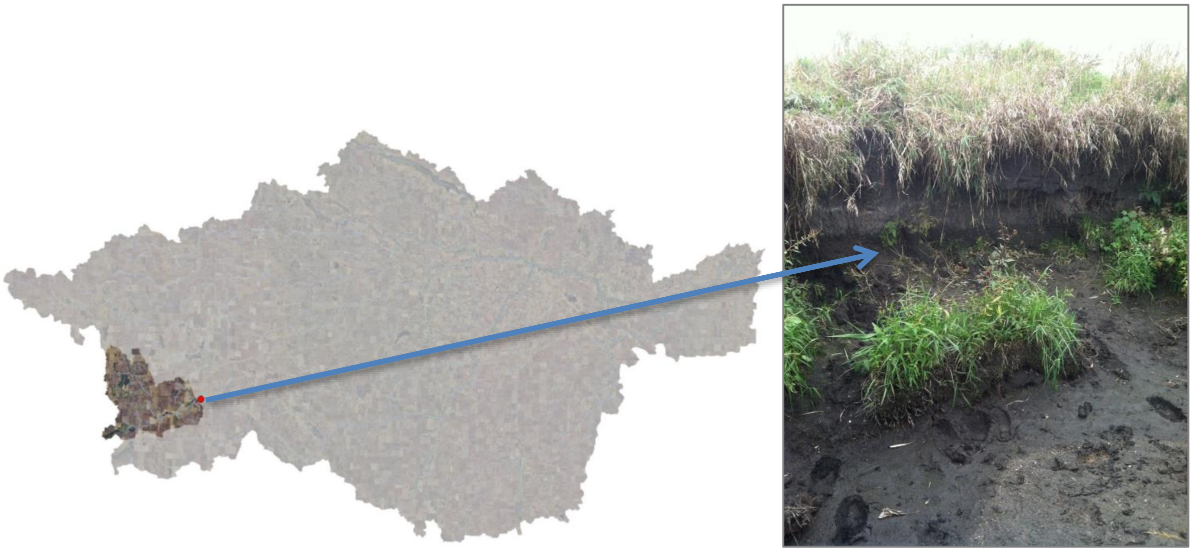
Management Recommendations

Future management recommendations include protecting and maintaining the wide buffer. Vegetation or hydrology alternations could negatively affect the stream, as it is already showing limited floodplain connectivity in areas. A “C” channel is likely the stable form for this stream under the present hydrology and sediment regime. There is evidence of disproportionate stream dimensions at the upstream bridge. A floodplain culvert set at a higher elevation would benefit the health of the stream during higher flows, reducing the pinch point at the bridge.

Judicial Ditch #1

Table 8. Baseline information for Judicial Ditch #1 geomorphology survey site.

Stream Information			
Stream Name	Watonwan	**Drainage Area**	29.6 mi^2
Assessment Unit	07020010-548	**Stream Type**	E5
HUC 8 Watershed	Watonwan	**Valley Type**	Lacustrine (unconfined)
County	Cottonwood	**Water Slope**	0.0022 ft/ft
Section	16	**Sinuosity**	1.57
Township, Range	105N, 34W	**Reach Erosion Estimates**	0.0144 tons/foot/year
Bank Height Ratio	1.07 (Stable)	**Pfankuch Stability Rating**	111 (Poor)



Judicial Ditch (JD) 1 is listed as a DNR Public Watercourse and has a biological fish impairment. Overall, JD 1 is 22.3 miles long from its headwaters to Irish Lake and the survey reach is 2.5 miles south of Mountain Lake. Judicial Ditch 1 has been channelized both upstream and downstream of the study site (Figure 32). The absence of channelization near the study site results in a highly sinuous reach throughout a deeply rooted and vegetated lacustrine valley. While the landuse in the watershed consists of 85.7% cultivated crops (WHAF), the survey reach and landuse in its immediate vicinity is undisturbed herbaceous wetland vegetation. The meander pattern can be described as unconfined meander scrolls and/or distorted meander loops (Figure 33) (Rosgen 2009).

Figure 32. Judicial Ditch #1 was historically channelized both upstream and downstream of the geomorphology survey site (green area) that represents the naturally meandering channel this system once was.

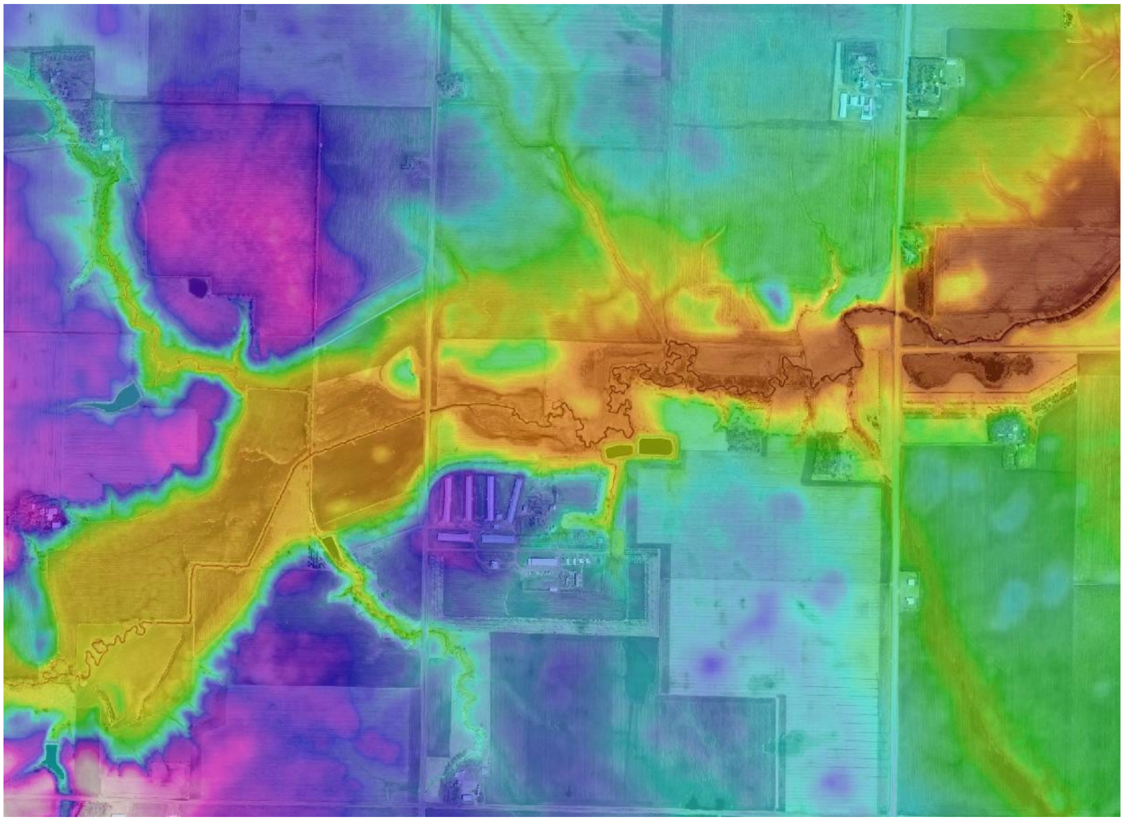


Figure 33. Unconfined meander scrolls and distorted meander loops can readily be seen within LiDAR imagery of the Judicial Ditch #1 geomorphology survey site.

The streambed was dry during both site visits in the falls of 2012 and 2013. The channel is a narrow, deep "E" channel, highly dependent on riparian vegetation for stability (Figure 34). During bankfull, and high flows, the channel fills to its top and splays out onto its floodplain. Channels such as this (*i.e.* E5 stream types) have a very high sensitivity to disturbance, good recovery potential, moderate sediment supply, high streambank erosion potential, and riparian vegetation plays a significant role in maintaining stability (Rosgen 1994; Appendix II).

While this channel fits the preferred stream type for the historic valley and watershed conditions, it is likely not a 'reference' quality stream. Streambank profiles and aerial photography indicate accelerated change. The monumented riffle cross section with bank and toe pins yielded 1.526 feet of erosion between the falls of 2012 and 2013. This was an erosion rate that was much higher than that of the predictive model, especially considering the lack of a significant precipitation event between assessments. Land use and channel change upstream of the study reach plays a role in the evolution of the channel as well as the vegetated valley. Furthermore, this stream reach is attempting to adapt to current conditions (*i.e.,* climate, hydrology, and landuse alterations).

The sediment supply from streambank erosion was high when compared to other sites within the Watonwan watershed. The BANCS model estimated that the 465 foot reach is contributing 0.0238 tons of sediment per linear foot of streambank annually when using the Colorado erosion rate curve (Rosgen 2001). At the monumented pool cross section (Figure 35), the model estimated bank erosion rates to be 0.42 feet per year, while the actual measurement indicated an erosion rate of 1.526 feet per year at the six foot tall densely vegetated outside bend. The BEHI rating is moderate and NBS is high when using method #5, a method that is linked to the surveyed pool cross section.

Summary

Judicial Ditch 1 is an E channel showing signs of changes to the pattern and dimension. If the channel becomes too wide and/or deeply incised, it will change to an unstable stream type and further contribute to turbidity issues. While the vegetated corridor throughout the reach is aiding in stream stability, the overall Pfankuch stability rating is poor for an E channel. The health of the stream is likely declining due to upstream ditching, unstable flows, and land use. The channel was completely dry in the fall of 2012 and 2013, which is not a good indication of aquatic habitat.

Management Recommendations

Future management recommendations include protecting and maintaining the wide buffer. A watershed approach to increase water storage and incorporate targeted conservation practices on the landscape is the desired management recommendation. Modifying future upstream ditch projects to reduce sediment contributions, while still providing the needed hydraulic capacity for agricultural drainage, can result in positive outcomes for environmental and economic goals. Incorporating properly designed multiple stage ditches allows the channel to move sediment in equilibrium without aggrading or degrading the channel; therefore, improving water quality and reducing future maintenance.

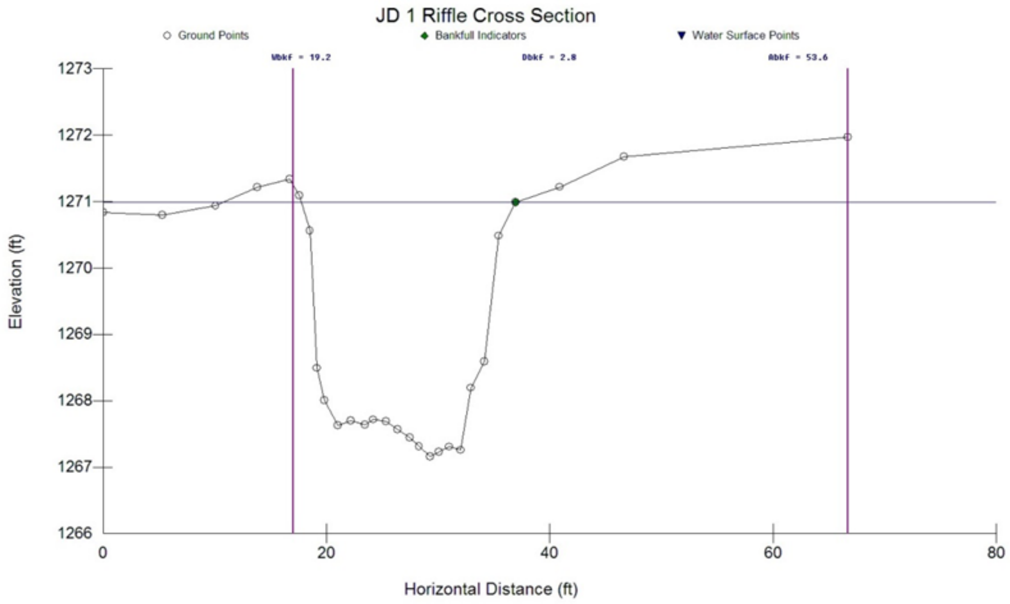
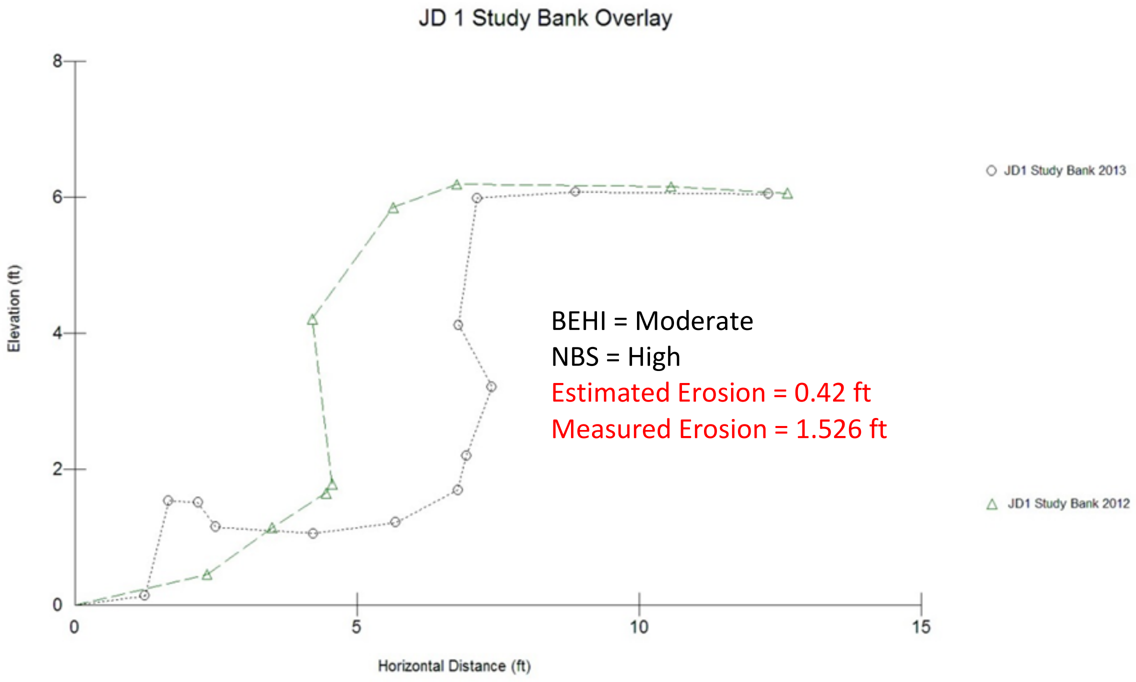


Figure 34. Riffle cross sectional profile that characterizes the deep and narrow nature of "E" channel types.



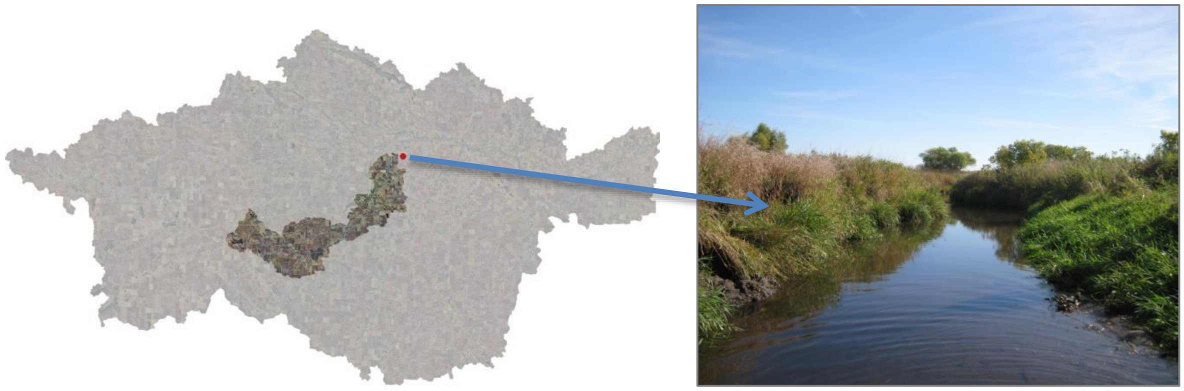
BEHI = Moderate
NBS = High
Estimated Erosion = 0.42 ft
Measured Erosion = 1.526 ft

Figure 35. Cross sectional profile of 2012 and 2013 bank surveys indicating significant annual change and erosion for the six foot high bank.

Lower St. James Creek

Table 9. Baseline information for lower St. James Creek geomorphology survey site.

Stream Information			
Stream Name	St. James Creek	**Drainage Area**	54 mi^2
Assessment Unit	07020010-505	**Stream Type**	E5
HUC 8 Watershed	Watonwan	**Valley Type**	Terraced Alluvial (unconfined)
County	Watonwan	**Water Slope**	0.002 ft/ft
Section	3	**Sinuosity**	1.1
Township, Range	106N, 31W	**Reach Erosion Estimates**	0.0117 tons/foot/year
Bank Height Ratio	1.82 (Deeply Incised)	**Pfankuch Stability Rating**	109 (Poor)



Lower St. James Creek was surveyed approximately five miles northeast of the city of St. James. There are currently no listed impairments. The drainage area is 54 square miles and the land use consists of 86.2% cultivated crops, 4.7% perennial cover, 1.3% water, and 7.8% other land uses (WHAF). According to the Quaternary Geology of Minnesota Map (MGS 1982 State Map Series), mapped surficial sediments include sand and gravel associated with glacial lake sediment and the Des Moines Lobe.

A perennial buffer strip, periodically hayed, lined the survey reach for no less than 50 feet on either side of the channel. Aerial photography and LiDAR also indicate evidence of historical channelization (Figure 36). The stream reach is classified as an E5 with low sinuosity. Stream types such as this (*i.e.* E5) have a very high sensitivity to disturbance, good recovery potential, moderate sediment supply, high streambank erosion potential, and riparian vegetation plays a significant role in maintaining stability (Rosgen 1994; Appendix II). While gravel dominated the riffle (Figure 37), the pebble count from the entire reach indicated a sand bed stream. Minor pool filling (*i.e.* siltation) was observed. Vegetated (*i.e.*

reed canary grass) sloughs bordered the sides of the channel and it was rare to clearly identify a bankfull bench. Two to three feet of water filled the channel at the time of surveys in the fall 2012 and 2013.

The BANCS model estimated the 500-foot reach is contributing 0.0114 tons of sediment per linear foot of streambank annually when utilizing the Colorado erosion rate curve (Rosgen 2001). At the monumented cross section, the model estimated the bank erosion rate to be 0.25 feet per year, while the actual measured erosion rate was 0.102 feet per year (Figure 38). The BEHI rating was moderate and the NBS rating was moderate when using method #5, a method that was linked to the surveyed pool cross section.

Summary

Lower St. James Creek is an E channel with gravel, sand, silt, and clays in the stream bed. If disturbance causes the channel to become over wide and/or deeply incised, it will change to an unstable stream type and contribute to the Watonwan River turbidity issues. While the vegetated corridor throughout the reach is helping with stream stability, the overall Pfankuch stability rating is poor for an E channel. One study bank pin was buried due to a reed canary grass slough, and bank sloughing features were commonly observed. It was difficult to identify a bankfull bench and it appears the once over wide channel is trying to narrow and build a stable bench over time.

Management Recommendations

Future management recommendations include protecting and maintaining the wide buffer. Implementation of a watershed approach to increase water storage and incorporate targeted conservation practices on the landscape is the desired management recommendation. Changes to upstream landuse and hydrology can cause the channel to evolve to an unstable form, even if the riparian vegetation remains intact.

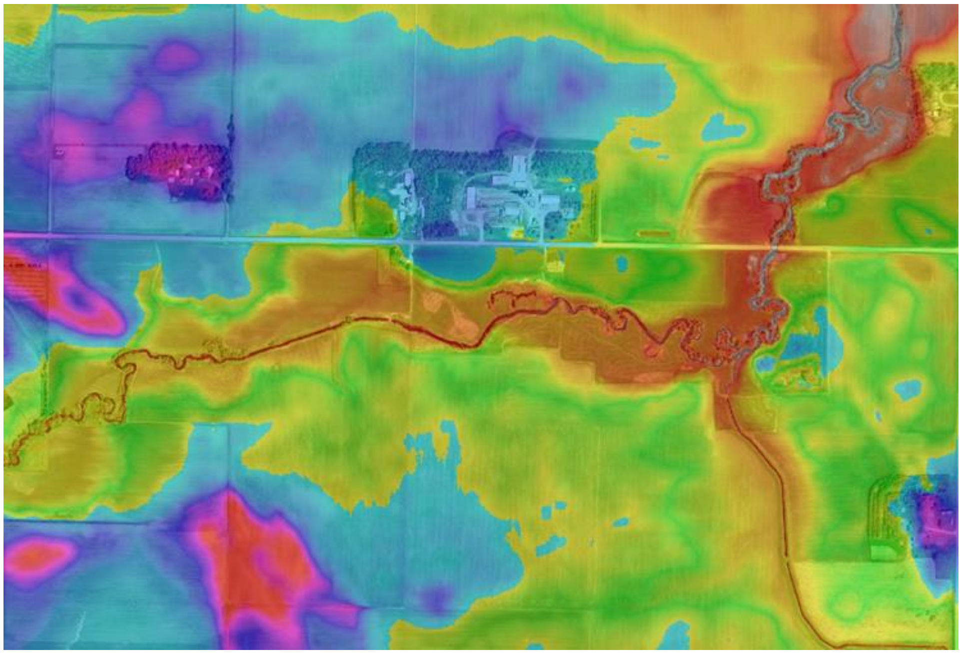


Figure 36. LiDAR imagery depicts historical channelization within the lower St. James Creek geomorphology survey site.

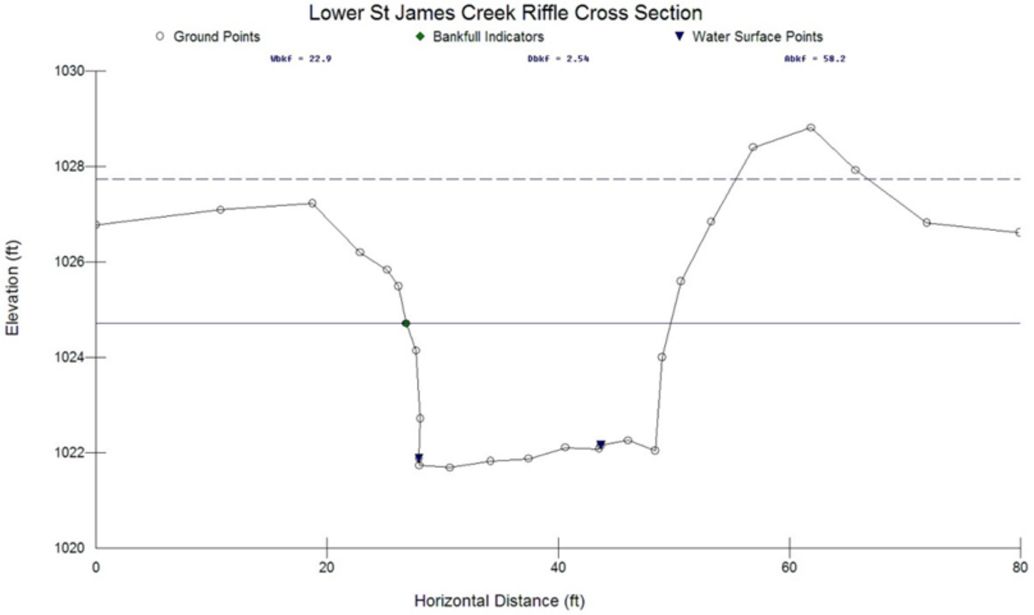
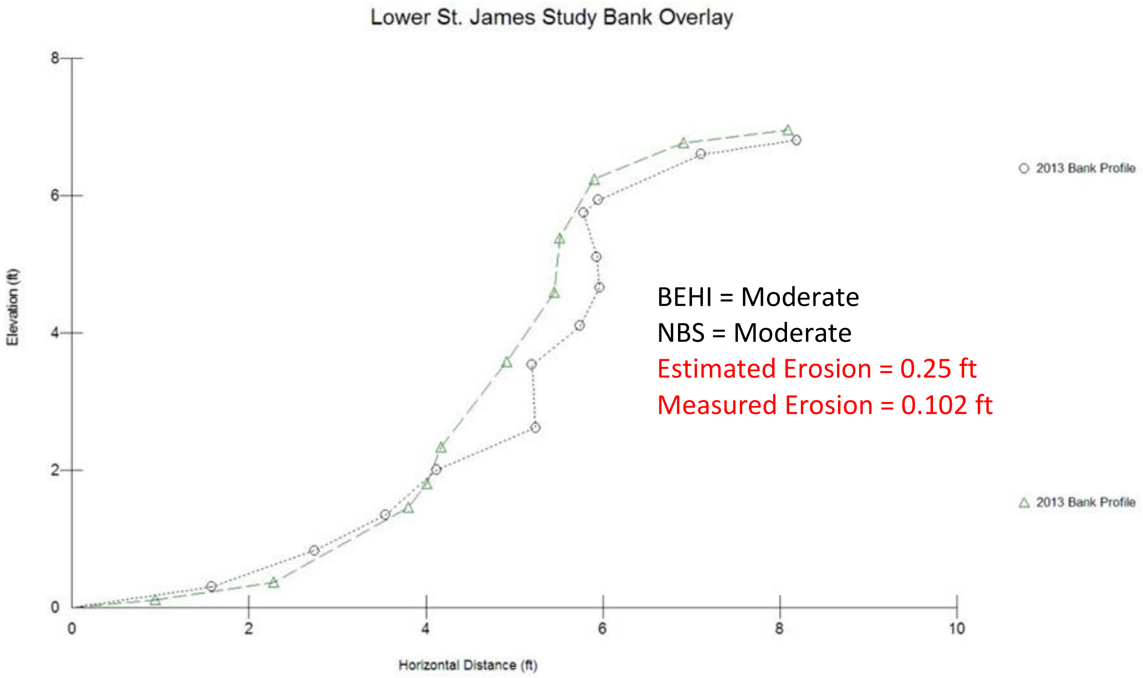


Figure 37. Riffle cross sectional profile with bankfull and floodprone elevation indicated.



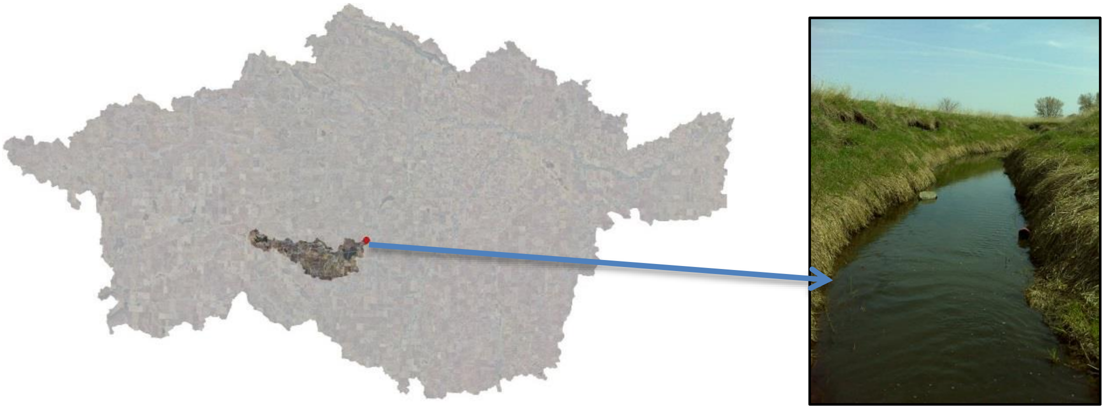
BEHI = Moderate
NBS = Moderate
Estimated Erosion = 0.25 ft
Measured Erosion = 0.102 ft

Figure 38. Cross sectional profile of 2012 and 2013 bank surveys depicting annual change and erosion for the seven foot high bank.

Upper St. James Creek

Table 10. Baseline information for the upper St. James Creek geomorphology survey site.

Stream Information			
Stream Name	St James Creek	**Drainage Area**	15.5 mi^2
Assessment Unit	07020010-532	**Stream Type**	G5
HUC 8 Watershed	Watonwan	**Valley Type**	Terraced Alluvial (unconfined)
County	Watonwan	**Water Slope**	0.002 ft/ft
Section	33	**Sinuosity**	1.23
Township, Range	107N, 31W	**Reach Erosion Estimates**	0.029 tons/foot/year
Bank Height Ratio	2.04 (Deeply Incised)	**Pfankuch Stability Rating**	96 (Fair)



The upper St. James Creek site is located between Kansas Lake and MN Hwy 4 southwest of the city of St. James. The landuse upstream is primarily cultivated crops 87.5%, with 3.9% perennial cover, 3% water, and 5.6% in other land uses (WHAF). According to the MPCA, there is currently not enough data available to determine the recreation, aquatic life, or fish consumption condition (*i.e.* no impairments listed). The stream reach was surveyed once in the fall of 2012 with a dry stream bed and resurveyed in the spring 2014 at moderately low flow. A wide perennial buffer (*i.e.* >50ft) borders the stream on both sides of the channel throughout the surveyed reach. Similar to other sites, there is evidence of past stream channelization upstream and downstream (Figure 39).

A bankfull bench was not easily identifiable throughout the reach; therefore, USGS stream stats and local regional curves based on drainage area, cross sectional area, and/or discharge helped to determine the 1.5-2 year bankfull flow. The stream is classified as a G channel and does not access its floodplain at two times bankfull flows (Figure 40); and is therefore entrenched. This unstable channel form is a result

Figure 39. Aerial photography depicts historical channelization of the upper St. James Creek geomorphology survey site.

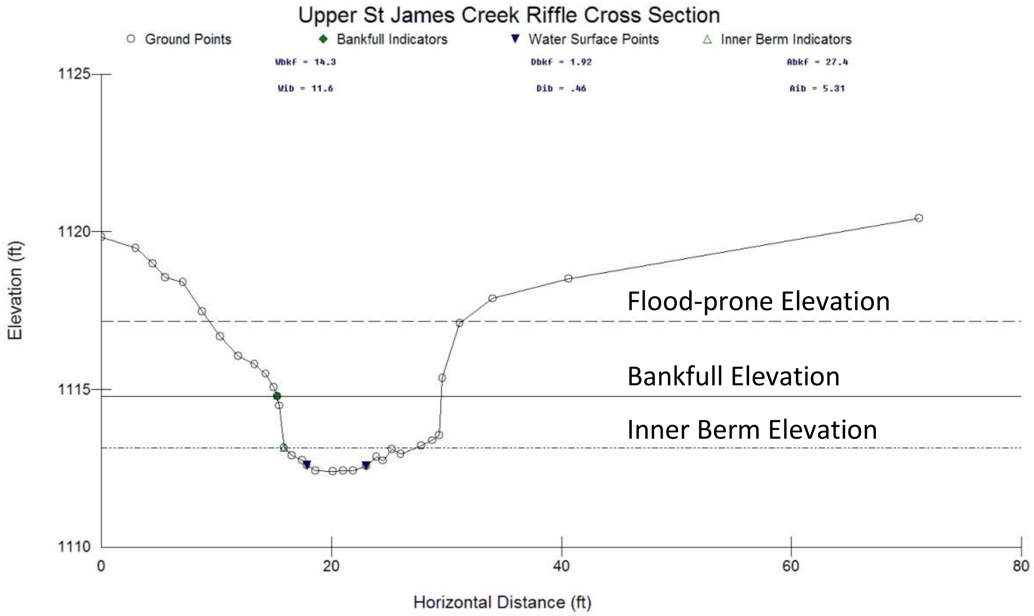


Figure 40. Riffle cross sectional profile indicates the channel is entrenched.

of past channelization. There were primarily silts, clays, and organic material soils. There was small gravel throughout the riffles, but pools were mostly silt or muck material soil.

The BANCS model estimated that the 340-foot reach is contributing 0.029 tons of sediment per linear foot of streambank annually when using the Colorado erosion rate curve (Rosgen 2001). The BEHI rating scored high while the near bank stress ratings were low for the assessed banks. The site was visited in fall 2012 and spring 2014; however, a cross section was not monumented and data to validate the predicted annual bank erosion estimates are not available. Compared to other sites, upper St. James Creek does not contribute a significant amount of streambank erosion.

Summary

Upper St. James Creek is functioning as a G channel due to past channelization. Channels such as this (*i.e.* G5) have extreme sensitivity to disturbance, very poor recovery potential, very high sediment supply, very high streambank erosion potential, and high vegetative controlling influence (Rosgen 1994; Appendix II). The vegetated buffer is helping stream stability and the overall Pfankuch score was fair. The survey reach is one mile downstream from Kansas Lake. According to a local resident, the creek downstream from Kansas Lake rarely has ample flow. The bounce in the lake presumably relieves flashy flows directly downstream. Furthermore, during drier periods, the lake level likely sits below the sill of the outlet providing for a level of precipitation to affect the lake level before it will begin to flow to the outlet to St. James Creek.

Management Recommendations

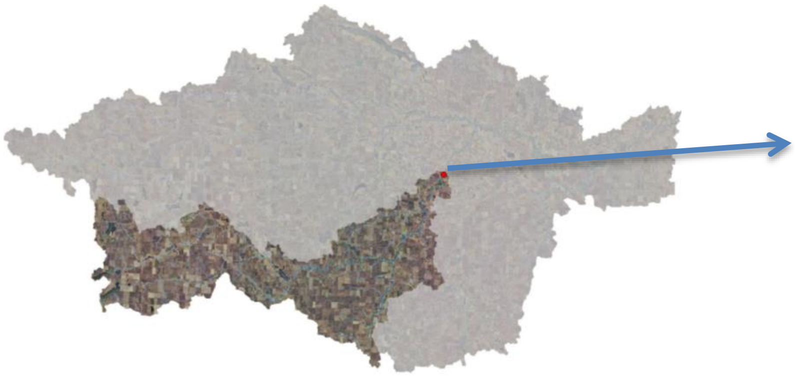
Minimal changes to upper St. James width and pattern were observed downstream of Kansas Lake through the survey site since 1991. The lake appears to be acting like a shock absorber and slowing down the runoff response time after precipitation events. To improve the health of upper St. James Creek, and specifically Kansas Lake, BMPs targeted to reduce nutrients and sediment entering the lake will help maintain a healthy fishery in Kansas Lake. High nutrients and sediments in a lake can cause algae blooms and reduce water clarity.

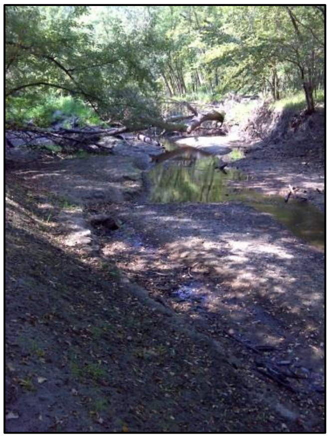
The probable stable stream type under the present hydrology and sediment regime is an E or C stream type. If the landowner and stakeholders are interested in a future restoration effort, design parameters need to include proper dimension, pattern (*i.e.* meander geometry), and profile (*i.e.* riffle/pool spacing). Properly sized road crossings (*i.e.,* bridges and culverts) will also help improve stream stability, sediment transport, and overall stream health.

South Fork Watonwan River

Table 11. Baseline information for the South Fork Watonwan River geomorphology survey site.

Stream Information			
Stream Name	S Fork Watonwan	**Drainage Area**	190 mi^2
Assessment Unit	07020010-517	**Stream Type**	F5
HUC 8 Watershed	Watonwan	**Valley Type**	Terraced Alluvial (unconfined)
County	Watonwan	**Water Slope**	0.0026 ft/ft
Section	14	**Sinuosity**	1.5
Township, Range	106N, 31W	**Reach Erosion Estimates**	0.0956 tons/foot/year
Bank Height Ratio	1.73 (Deeply Incised)	**Pfankuch Stability Rating**	138 (Poor/Unstable)





The South Fork Watonwan River is impaired for fecal coliform and turbidity. At Eagle's Nest County Park, the South Fork meanders through a native bottomland forest comprised of mature maple, oak and ash trees. Land draining to the park includes the following uses: 87% cultivated crops, 5.2% perennial cover, 1.6% water, and 6.2% other land uses (WHAF).

The river is over wide, classified as an F5 channel, and does not effectively transport sediment and bedload through the system. The river is not accessing its floodplain during two times bankfull flows (Figure 41). Both sides of the stream are exposed to stress, resulting in high streambank erosion contributions. Reconnaissance upstream from Trunk Hwy 60 through the golf course indicates severe instability and systemic issues as the river transitions between an incised C and F channel. Bankfull indicators are virtually absent as bank erosion is apparent on both sides of the channel. Bank height ratio calculations indicate the stream is deeply incised. Streams with high bank height ratio values generally contribute disproportionate amounts of sediment from banks and bed due to high sheer stress. Channels such as this (*i.e.* F5 stream type) have a very high sensitivity to disturbance, poor recovery potential, very high sediment supply, very high streambank erosion potential, and riparian vegetation plays a moderate role in maintaining stability (Rosgen 1994; Appendix II). Depositional features are common in this stream type, and over time, tend to promote development of a floodplain inside the bankfull channel (Rosgen 1996). Low flows were observed during the late summer 2012 and 2013 surveys.

There were numerous extensive woody debris channel blockages consisting of predominately larger materials (*i.e.,* branches, logs, and trees) occupying 30-50% of the active channel cross section in several areas. Remnants of a golf course bridge were observed in a log jam blocking almost half of the channel upstream from the county park. Excess woody material in the channel results from channel changes, primarily widening, as banks collapse (Rosgen 2006). Generally, this is a symptom of the problem rather than the cause as the river is adapting to alterations upstream and trying to develop a more stable dimension, pattern, and profile. Often when channels widen, there is evidence of a loss of sinuosity (*i.e.* shortening the overall path and pattern). Figure 42 shows the changes to stream pattern from 1991 to 2011. The composite reach pebble count indicated the stream has a sand dominated bed, but the system is becoming overwhelmed with fines (*i.e.* silts and clays). Therefore, the excess of fines overshadows the gravel riffles of the streams historic conditions.

It appears reduced resiliency and unraveling is occurring in mid-sized rivers (*i.e.* Strahler stream order 4) located in bottomland mature hardwood forests where cumulative upstream hydrologic changes create more frequent bankfull or high flow events (Figure 42). These changes to pattern and profile were also documented by the MNDNR in the Big Cobb River of the Le Sueur River Watershed. Factors including upstream channel straightening and ditching, additions in flow paths, and vegetation alterations transform these downstream channels into a state of disequilibrium. The result is channel widening, a pinched channel at crossings, poor pool and riffle habitat quality, and the inability to effectively transport sediment.

The native hardwood forest land at Eagle's Nest Park has been historically documented and can be traced as far back as the 1850 Public Land Survey maps (MGIO 2014). Native hardwood forest such as that found at Eagle's Nest Park is noted as having moderate biological significance, according to the Minnesota County Biology Survey (MNDNR 2014b).

The BANCS model estimated the 460-foot reach is contributing 0.0956 tons of sediment per linear foot of streambank annually using the Colorado erosion rate curve (Rosgen 2001). This is the highest sediment yielding reach surveyed in the Watonwan watershed. The predicted annual bank erosion from the survey reach is 43.97 tons/year (~4.4 dump truck loads). At the monumented cross section, the model estimates the bank erosion to be 0.153 feet per year while the actual measurement indicates an erosion rate of 0.035 feet per year. The BEHI rating was moderate and the NBS was low when using method #5, a method linked to the pool cross section. However, the bank selected for pins was not a significant contributor.

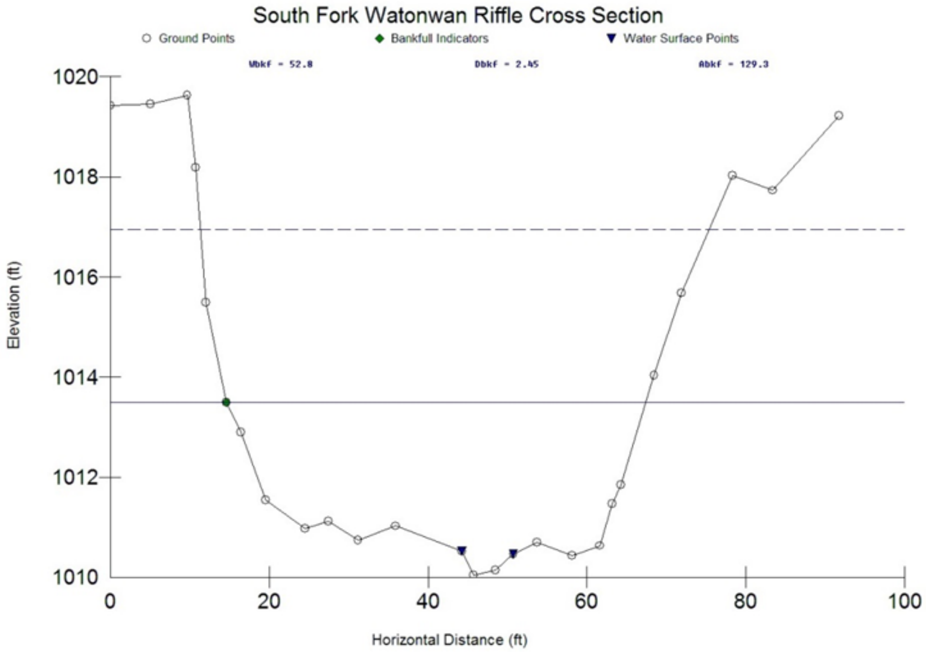


Figure 41. Riffle cross sectional profile indicates that the South Fork of the Watonwan River at Eagle's Nest County Park does not access its floodplain at two times bankfull flows.

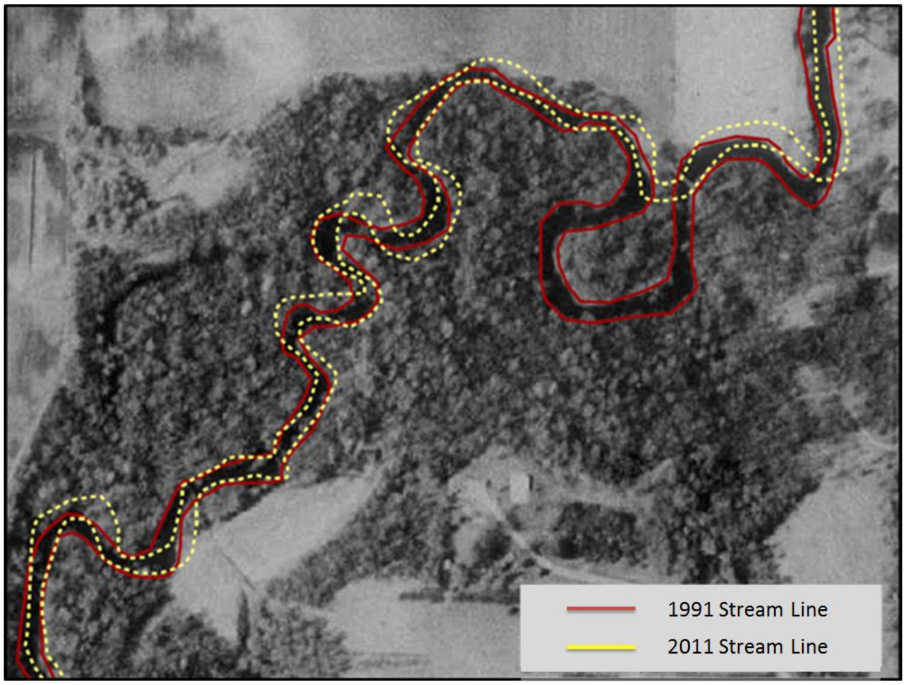


Figure 42. Stream lines from 1991 and 2011 aerial photography are overlaid to depict the change in sinuosity and pattern of the South Fork Watonwan River at Eagle's Nest County Park.

Summary

The South Fork Watonwan site is an entrenched (*i.e.* vertically contained) channel with a high sediment supply. While the stream is buffered by mature hardwoods in an unconfined alluvium valley, the site is in a state of disequilibrium. The high Pfankuch rating of 138 indicates the stream is in very poor condition. High flows are typical in the spring followed by low baseflows in late-summer and fall, as observed in 2012-2014 (Figure 43). Channels such as this (*i.e.* F stream types) are not the stable form for alluvial valleys, and they usually exhibit poor habitat quality, higher water temperatures, and excessive sediment supply that typically result in poor aquatic communities and high turbidity. In the future, it is likely the stream will continue to straighten and widen until a new floodplain can be created within the old channel. Until a new floodplain can be established, stability of the South Fork Watonwan study site may not be realized.

Management Recommendations

Ideally, the reference condition for this river should be a C channel (*i.e.,* meandering channel with developed floodplain connectivity, point bars, and other depositional features). A bankfull bench and eventually a floodplain will need to develop within the channel in order to move to a more stable form. A large portion of the lower South Fork Watonwan is widening and/or incising, losing sinuosity, likely increasing slope, and moving to an unstable form. A watershed approach to restoration is recommended to work to improve the health and hydrologic functions of the watershed. After addressing a portion of the systemic issues and better understanding the hydrology trends in the watershed, a prioritized watershed management plan could be developed for prioritizing stream channel restoration. Actions must be prioritized, targeted, and measurable in order to ensure limited resources are spent where they are needed most. The MNDNR plans to continue additional investigation in the South Fork Watonwan in 2014-15, to determine the extent of the disequilibrium, provide additional data to the MPCA's Stressor Identification team, assist with future conservation targeting, and prioritize restoration.

At this time, priority management recommendations throughout the South Fork include: establishing deep rooted vegetated grass buffers, protecting existing buffers, implementing best management practices on ag lands (e.g. cover crops), maintaining floodplain connectivity, accurately sizing future crossings to match channel dimensions, provide floodplain flow relief, and increase water storage capacity during the spring months in order to reduce spiking in the hydrograph. Stabilization projects, such as J-hooks, are not recommended in F channels because the stream's energy is merely directed toward the other incised bank.

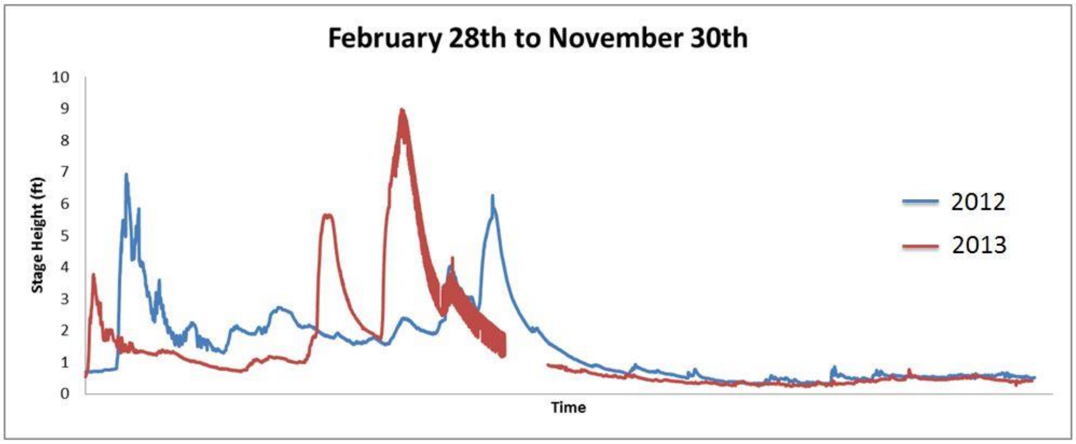
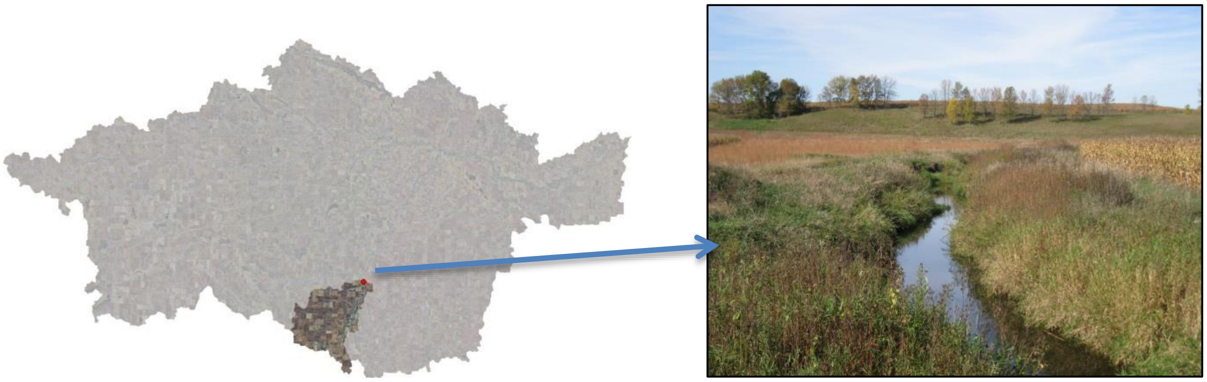


Figure 43. February 28th to November 30th stage heights for the Watonwan River at the USGS gage station near Garden City, MN. Spring melt and precipitation events typically lead to heightened stream flows, whereas heightened evapotranspiration rates through summer and seasonally dry climate in the fall lead to reduced flow (*i.e.* baseflow levels or below).

Willow Creek

Table 12. Baseline information for Willow Creek geomorphology survey site.

Stream Information			
Stream Name	Willow Creek	**Drainage Area**	27 mi^2
Assessment Unit	07020010-521	**Stream Type**	E6
HUC 8 Watershed	Watonwan	**Valley Type**	Lacustrine (unconfined)
County	Watonwan	**Water Slope**	0.00009 ft/ft
Section	19	**Sinuosity**	1.1
Township, Range	105N, 31W	**Reach Erosion Estimates**	0.0448 tons/foot/year
Bank Height Ratio	1 (Stable)	**Pfankuch Stability Rating**	106 (Poor)



Willow Creek is listed as impaired for fish bioassessment. The geomorphology survey site is positioned in the lower portion of the watershed, approximately one mile before the confluence with the South Fork of the Watonwan River. The creek is buffered by perennial vegetation, approximately 30 feet on one side and 100 feet on the other. The primary land use throughout the watershed is comprised of 90% cultivated crops, 3.7% perennial cover, and 6.2% other land uses (WHAF).

The stream is narrow, deep, and classified as an E channel representing good floodplain connectivity. Streams such as this (*i.e.* E4 stream types) have a very high sensitivity to disturbance, good recovery potential, moderate sediment supply, high streambank erosion potential, and riparian vegetation plays a significant role in maintaining stability (Rosgen 1994; Appendix II). The Willow Creek survey site has a very low water surface slope (*i.e.* 0.00009 ft/ft) and is located in a depression, as shown on the LiDAR image (Figure 44). A low water slope is typical of E channels, but approximately 400ft downstream of the surveyed reach a beaver dam was found in both 2012 and 2013 that likely influenced the shallow slope and pebble count during surveys. There is evidence of past channelization on Willow Creek (*i.e.* 50.4% of stream miles have historically been channelized) (Figure 45). The sinuosity is low for what is typically found in E channels (*i.e.* typically >1.5).

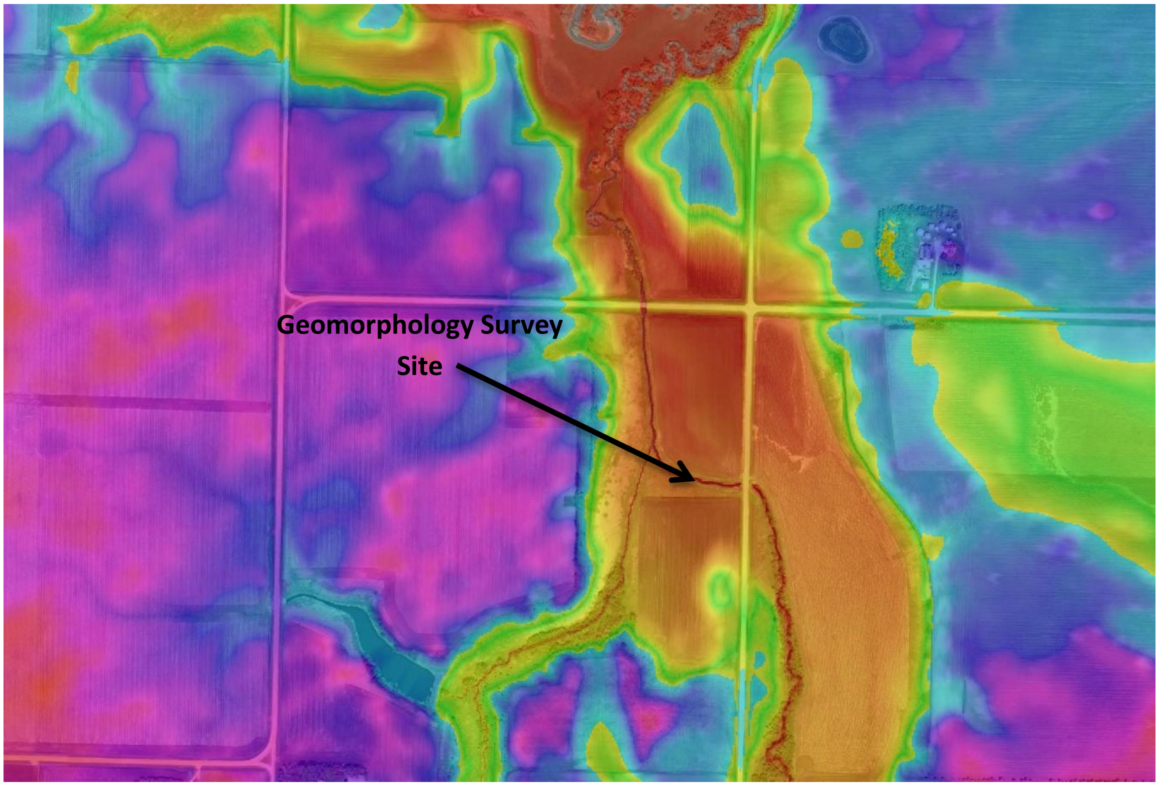


Figure 44. LiDAR imagery depicting subtle topography at the Willow Creek geomorphology survey site. This topography in accordance with beaver dams resulted in very low water slopes during 2012 and 2013 surveys.

Figure 45. Historical aerial photography depicts past channelization within the Willow Creek subwatershed.

The bankfull bench was difficult to survey throughout the reach; therefore, bankfull elevations were based primarily on regional curves and USGS stream stats return intervals. The longitudinal profile shows a minimal undulation in the streambed (Figure 46). Homogeneous silt, clay, and organic materials dominated the streambed while pools and riffles were not distinct. The channel held two to three feet of water in 2012 and 2013; likely due to the presence of the beaver dam.

The BANCS model estimated that the 300-foot reach is contributing 0.0448 tons of sediment per linear foot of streambank annually when using the Colorado erosion rate curve (Rosgen 2001). The predicted annual bank erosion from the survey reach was thus estimated to be 13.43 tons/year (*i.e.* ~1.4 dump truck loads). At the monumented cross section, the model estimates the bank erosion to be 0.153 feet per year for the seven foot high bank while the actual measurements indicate an erosion rate of 0.0004 feet per year. The BEHI rating was moderate and NBS rating was low when using method #5, a method that is linked to the pool cross section.

Summary

Willow Creek is an E channel with low sinuosity. The deep-rooted, densely vegetated buffer helps with stream stability. Bank sloughs (*i.e.* reed canary grass and sediment) were observed throughout the reach, while the toe pin and lower bank pin were buried during the second site visit in 2013. The overall Pfankuch stability rating was poor for an E channel, as the lower banks showed cutting and deposition and the channel substrate quality rated poor (*i.e.* excess of fine material).

Management Recommendations

Future management recommendations include protecting and maintaining the dense deep-rooted buffer. This E channel may be working to develop more sinuosity, which results in the observed bank sloughs (*i.e.* cutting of one bank and deposition on the other bank). It is recommended that the channel be allowed to evolve to the appropriate dimension, pattern, and profile to meet hydrologic and land use conditions. A watershed approach to maintain or increase water storage, while incorporating targeted conservation practices on the landscape is the desired management recommendation. Changes to upstream land use and flow paths can cause the channel to change to an unstable form, even if the riparian vegetation remains intact.

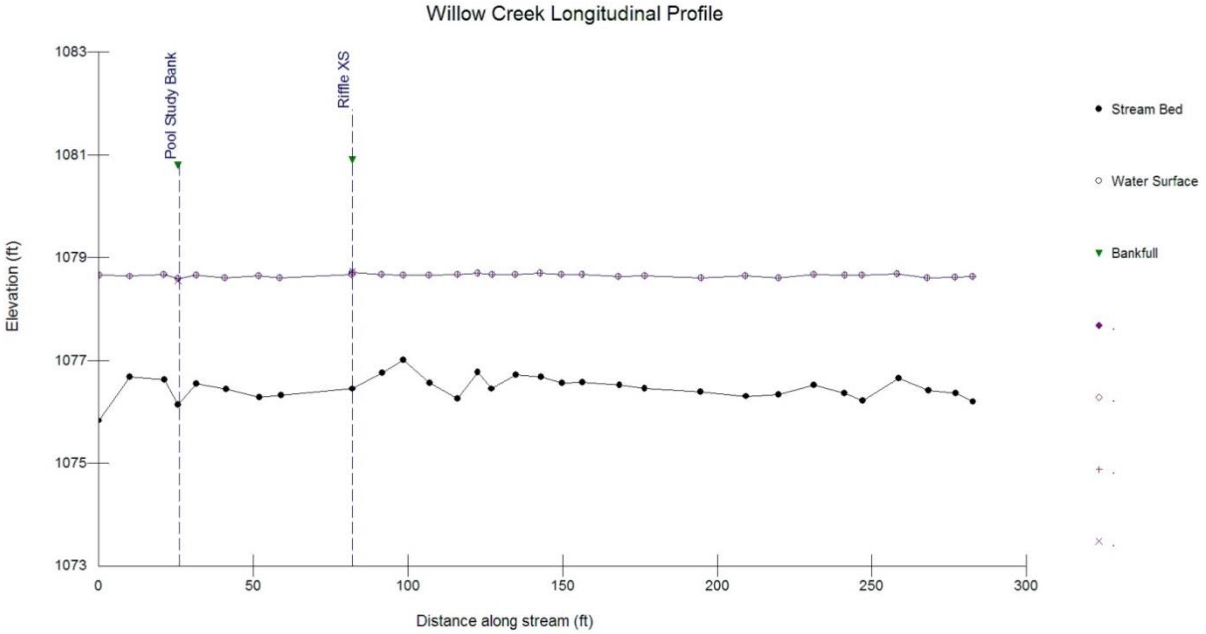
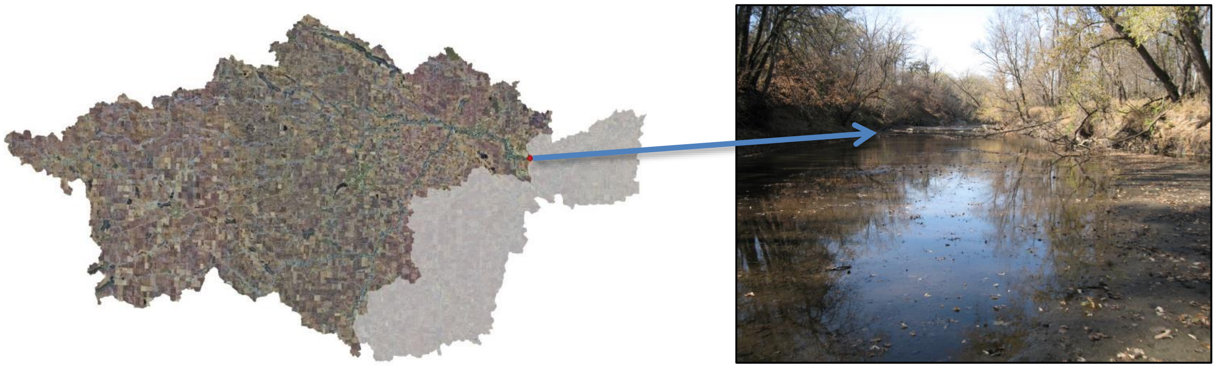


Figure 46. Longitudinal profile of Willow Creek geomorphology survey site depicting minimal undulation in the streambed.

Middle Watonwan River

Table 13. Baseline information regarding the middle Watonwan River geomorphology survey site.

Stream Information			
Stream Name	Watonwan	**Drainage Area**	671 mi^2
Assessment Unit	07020010-510	**Stream Type**	C5c-
HUC 8 Watershed	Watonwan	**Valley Type**	Alluvial Fill (unconfined)
County	Blue Earth	**Water Slope**	0.0005 ft/ft
Section	5	**Sinuosity**	1.04
Township, Range	106N, 29W	**Reach Erosion Estimates**	0.0256 tons/foot/year
Bank Height Ratio	1.45 (Moderately Incised)	**Pfankuch Stability Rating**	109 (Fair)



The Watonwan River was surveyed between County Highways 30 and 32 (north of 160th Street). At 671 mi^2, the watershed at this survey reach is much larger than the previously discussed sites. Cultivated crops dominate the landscape at 86.2% of the total land area, followed by 5.7% perennial cover, 1.7% water cover, and 6.2% in other land uses (WHAF). The bankfull width of the river is approximately 90 feet with low gradient. Depositional features, such as point bars, mid-channel bars and transverse bars were commonly observed throughout this reach, as well as the larger kayaked stretch from CSAH 30 to Garden City. The channel shows evidence of widening; however, the width to depth ratio at the riffle is 14.7, a moderate cross sectional area for an alluvial valley type (Figure 47). The river at this site still has good floodplain connectivity with a wide mature hardwood buffer. Bankfull indicators were infrequent; therefore, additional review in the office with regional curves and USGS stream stats was required. The sinuosity (*i.e.* channel length/valley length) was low (*i.e.* 1.04) through the 1,800ft survey reach, but from Blue Earth CSAH 30-32 overall sinuosity increases to 1.5.

A bar sieve and competence worksheet was completed to determine the size of bedload material moving at bankfull flows based on upstream supply (WARSSS worksheet 5-22). The purpose is to calculate sediment competence to assess bed stability. The particles measured and the worksheet

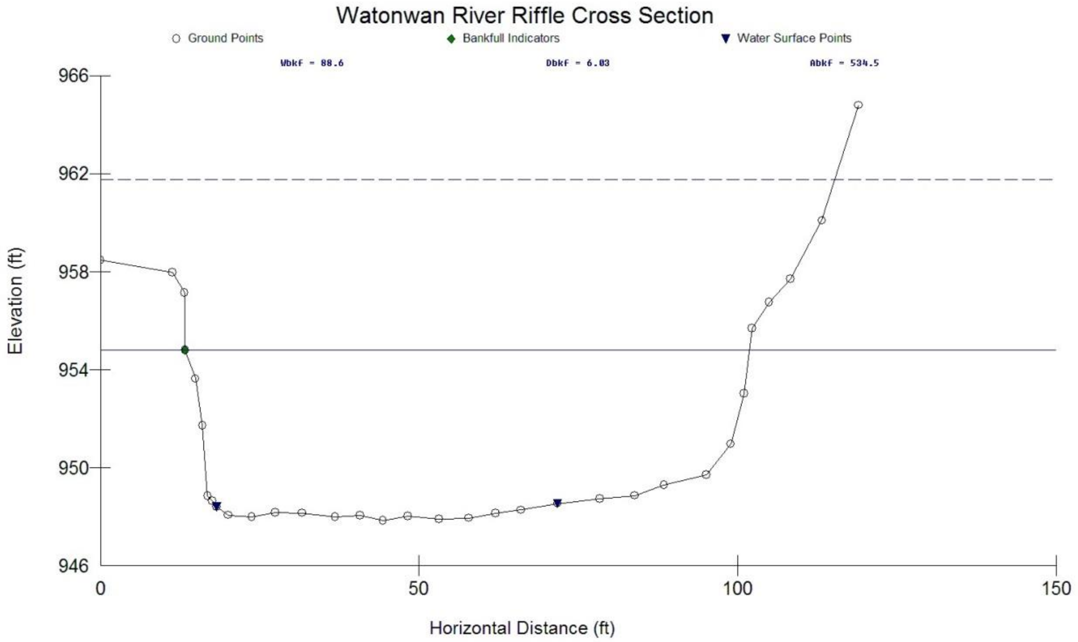


Figure 47. Riffle cross section surveyed in fall 2012.

equations indicate the river is in a stage of aggradation (*i.e.* raising local base level due to depositional process over time). The bar sieve sample was taken on a point bar on the lower two-thirds of a bend, half way between the bankfull stage and the thalweg. The largest particle was 30 mm; calculations based on mean depth and slope show the channel is not currently capable of entraining the largest particle in the sieve, concluding the system is aggrading.

The BANCS model estimated the 1800-foot reach is contributing 0.0256 tons of sediment per linear foot of streambank annually when using the Colorado erosion rate curve (Rosgen 2001). The predicted annual bank erosion from the survey reach is 45.63 tons/year (*i.e.* ~4.5 dump truck loads). At the monumented cross section, the model estimates the bank erosion to be 0.25 feet per year while the actual measurements indicate an erosion rate of 0.095 per year (Figure 48). The BEHI rating was high, and NBS was low when using method #5, a method linked to the pool cross section. Vegetative surface protection was often lacking on the low banks. Stratification was also noted as layers of gravel were observed in the alluvial banks.

Summary

The Middle Watonwan River is a widening and aggrading C5c- channel. Gradients less than 0.001 are denoted as C5c- to indicate the slope condition (Rosgen 1996). Channels such as this (*i.e.* C5 stream types) have a very high sensitivity to disturbance, good recovery potential, high sediment supply, very high streambank erosion potential, and riparian vegetation plays a significant role in maintaining stability (Rosgen 1994; Appendix II). The river is buffered by mature floodplain forest in a terraced alluvial valley. Aggradation and excess bedload leads to a decrease in the quality of the pools and riffles, and therefore, degrading aquatic habitat quality. The local landowner said the upper portion of the survey reach hasn't changed as much as the lower portion of the reach, which used to have a five foot or greater hole and now is only knee deep. A Pfankuch stream stability rating of 109 was recorded, indicating the river is in fair condition. High flows are typical in the spring followed by low baseflows in late-summer and fall, as observed in 2012 and 2013 field seasons.

Management Recommendations

For the alluvial valley, the C channel is the preferred stream type. However, if the channel extensively widens it will likely lose floodplain access and further impede sediment transport and degrade habitat until it can evolve to build a floodplain within the channel. Protecting the existing riparian vegetation community will help stability. Properly sizing bridges on the mainstem, and providing floodplain connectivity, will help improve the health of the lower portion of the watershed. Given the large size of the drainage area, the widening and aggradation is more of a systemic issue caused by upstream land use and alteration. Channels in a state of disequilibrium may take decades or even centuries to reach a new equilibrium and show real reductions in sediment loads. As previously mentioned, a watershed approach to increase water storage and incorporate targeted conservation practices on the landscape is the desired management recommendation. Planned prioritized stream restoration is a favorable approach. However, resource managers must be careful not to lock the stream in place, pass the problem downstream, degrade habitat, or decrease connectivity (*i.e.,* lateral, vertical, or longitudinal), or degrade water quality.

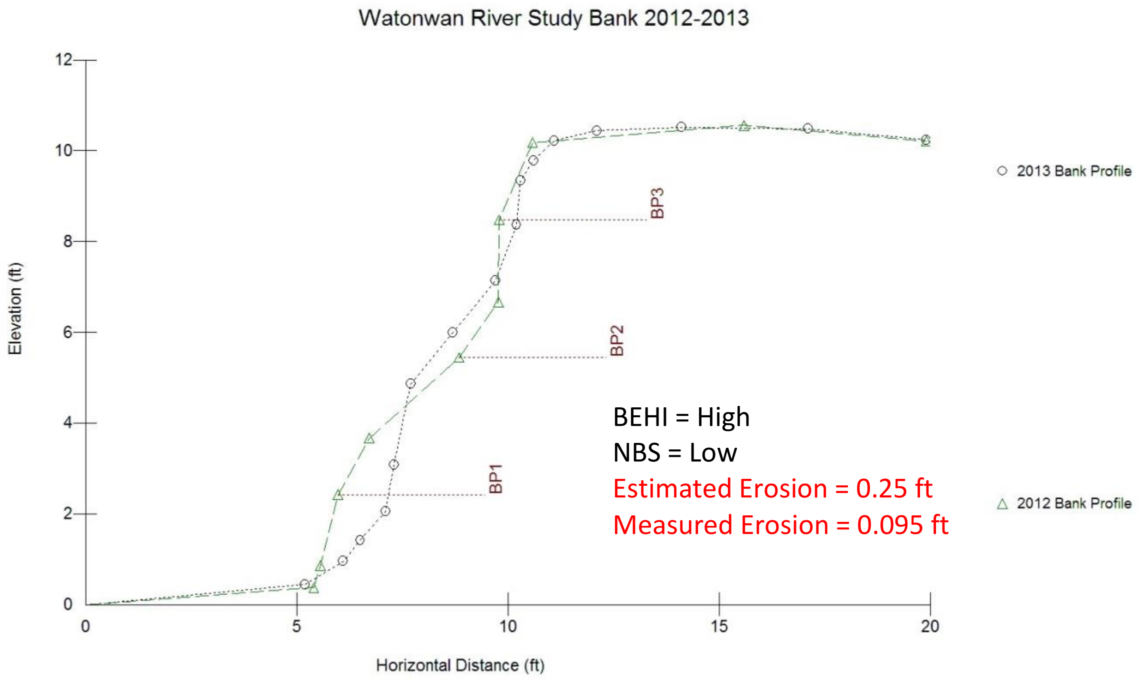


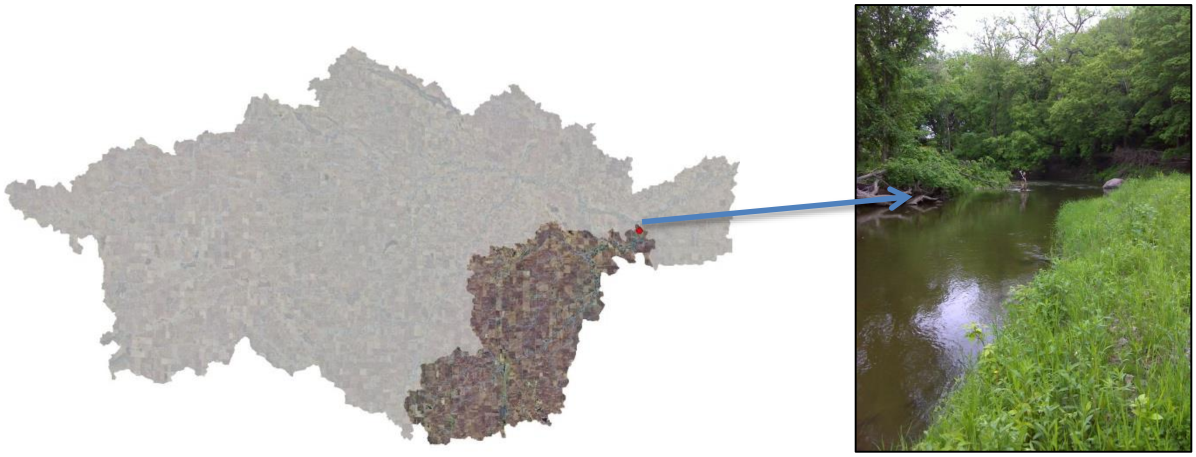
Figure 48. Cross sectional overlay of monumented streambank surveyed in 2012 and 2013. The lowest bank pin was exposed 1.7 feet, the middle pin was buried, and the top pink was exposed 2.4 inches. The bank height is 10.5 feet.

While completing streambank erosion estimates downstream via kayak, a smaller ravine tributary with deep fine sediment filled alluvial fans was spreading out into the river channel. Thus, adding additional sediment into the turbidity impaired river. Comprehensive sub-watershed conservation targeting can help resolve issues, such as this eroding ravine example, when addressing cumulative hydrology and sediment issues in the Watonwan watershed.

Lower Perch Creek

Table 14. Baseline information for the lower Perch Creek geomorphology survey site.

Stream Information			
Stream Name	Perch	**Drainage Area**	150 mi^2
Assessment Unit	07020010-523	**Stream Type**	C4
HUC 8 Watershed	Watonwan	**Valley Type**	Terraced Alluvial (unconfined)
County	Blue Earth	**Water Slope**	0.0019 ft/ft
Section	5	**Sinuosity**	1.6
Township, Range	106N, 29W	**Reach Erosion Estimates**	0.0336 tons/foot/year
Bank Height Ratio	1.55 (Deeply Incised)	**Pfankuch Stability Rating**	103 (Fair)



There are currently no impairments listed for Lower Perch Creek. The geomorphology survey was conducted approximately one mile from the confluence with the Watonwan River. The landuse for the watershed is comprised of 89.4% cultivated crops, 4.1% perennial cover, 0.5% water and 6.1% other land uses (WHAF). The riparian corridor is vegetated with perennial grasses and common floodplain tree species. The site is used as cattle pasture at times; although at the time of the survey there were no livestock present and the vegetation was deep rooted and grasses greater than six inches tall.

The C4 stream type is slightly entrenched, meandering, gravel-dominated, riffle/pool channel with good floodplain access. Channels such as this (*i.e.* C4 stream types) have a very high sensitivity to disturbance, good recovery potential, high sediment supply, very high streambank erosion potential, and riparian vegetation plays a significant role in maintaining stability (Rosgen 1994; Appendix II). An undulating stream bottom with three deep pools was surveyed over the 712' reach (Figure 49). Channel materials were dominated by gravel; however, cobble, boulders, sand, silt, and clay were also

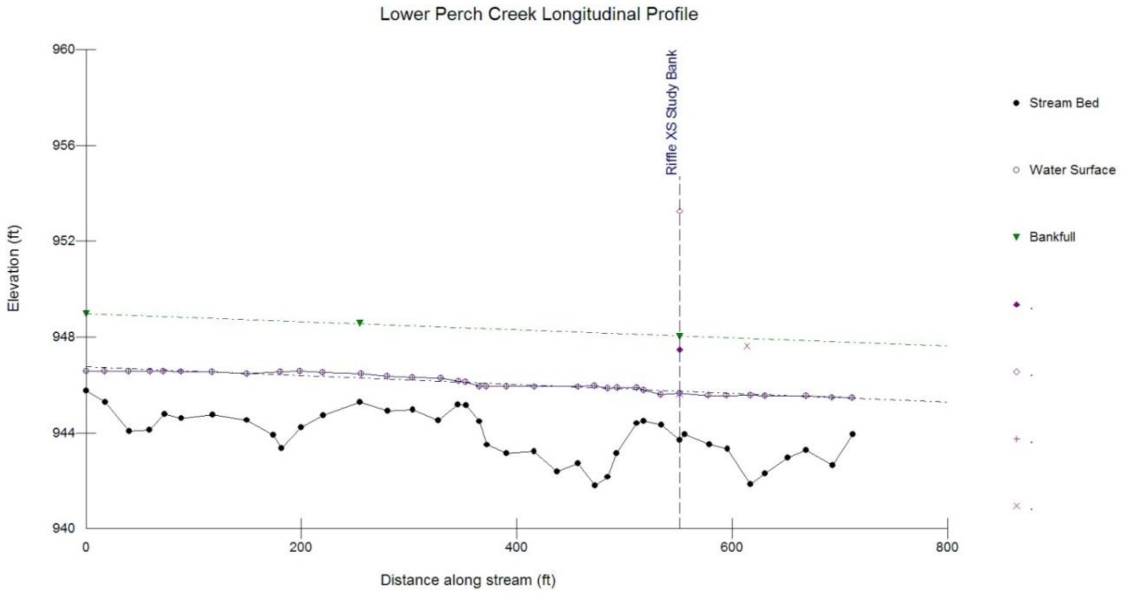


Figure 49. Longitudinal profile of lower Perch Creek geomorphology site depicting undulating bottom with three significant pools.

documented. The riffle cross section indicates a high width-to-depth ratio (w/d) of 26.15. The riffle was located on an outside bend, which may be causing a slightly higher w/d ratio. However, high w/d ratios often indicate that the stream is losing stability and reducing the ability to efficiently transport sediment.

The BANCS model estimates the 700-foot reach is contributing 0.0336 tons of sediment per linear foot of streambank annually when using the Colorado erosion rate curve (Rosgen 2001). The predicted annual bank erosion from the survey reach is 23.49 tons per year (*i.e.* ~2.3 dump truck loads). Banks were stratified and included highly erodible sand; therefore, bank adjustments were made accordingly to the BEHI assessment. At the monumented cross section, the model estimated the bank erosion to be 0.575 feet per year on the 6.8 foot high bank. After heavy spring rains, the three bank pins were exposed from 1.15 to 2.08 feet. There were depositional gravels, sands, and silts at the lowest portion of the bank extending into the streambed where the toe pin was located (Figure 50). The overall difference in toe pin area from June 2013 to July 2014 was 5.82 square feet resulting in an average erosion rate of 0.006 feet. The BEHI rating was very high and the NBS rating was high when using method #5, a method linked to the riffle cross section.

Summary

Overall, the lower Perch Creek site appears to be fairly stable with good pool quality and satisfactory riffles for a low gradient stream (Figure 51). Lower Perch Creek has the desired C4 stream classification. If the channel becomes too wide and/or deeply incised, it will change to an unstable stream type as it loses floodplain access. The overall Pfankuch stability rating was fair. Aerial photography indicated little lateral change since 1991, with the exception of a few outside bends. Recent images indicate a lot of sand and fine material deposited outside the low flow channel and in floodprone areas. It is likely the last big event (*i.e.* September of 2010 event) that left excess sand and bedload near the channel. The Quaternary Geology of Minnesota 1982 Map indicates silt and fine sand throughout much of the Perch Creek watershed. Glacial Lake Minnesota sediments are associated with the Lower Perch Watershed (Runkel et al. 2011).

Management Recommendations

Future management recommendations include protecting and maintaining the wide buffer. Manage the grazing on-site to maintain root density and depth as rates of lateral bank movement are influenced by the presence and condition of the riparian vegetation.

Targeted conservation in the upper part of the watershed will also help improve and protect the current health of the watershed. Properly sized road crossings (*i.e.* bridges and culverts) will also help improve stream stability, sediment transport, and overall stream health.

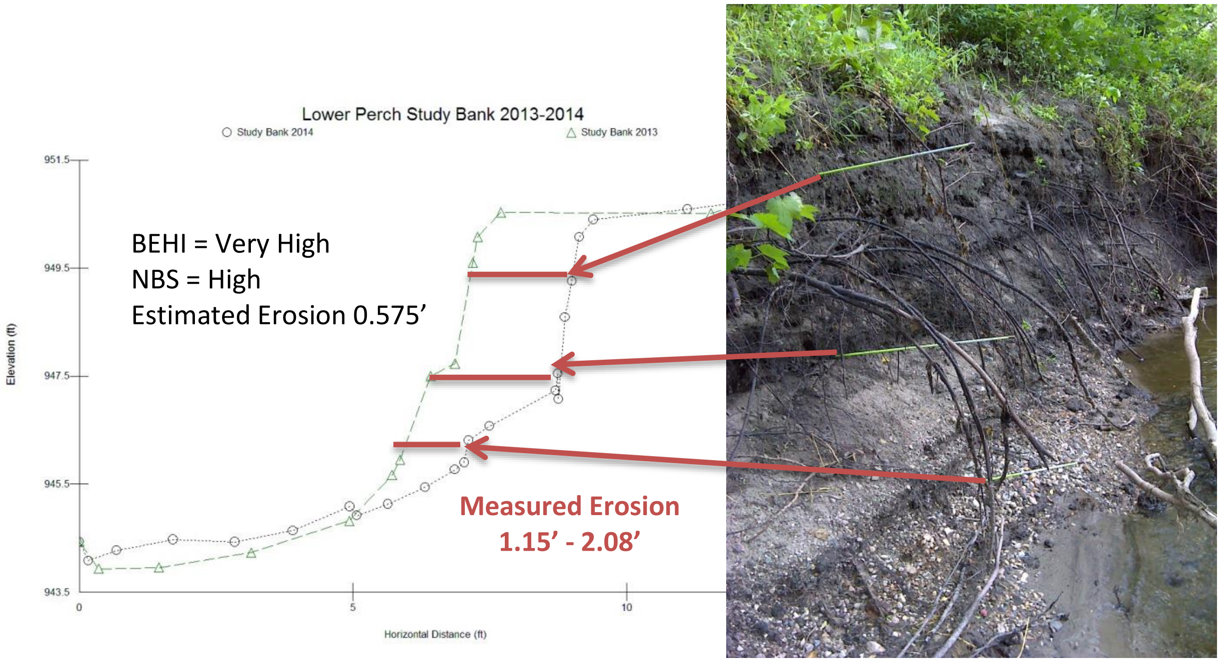


Figure 50. Cross sectional overlay of monumented streambank surveyed in 2013 and 2014. The lowest bank pin was exposed 1.15 feet, the middle pin was exposed 2.08 feet, and the top pink was exposed 1.83 feet. Gravel, sands, and silts were deposited near the toe of the bank.

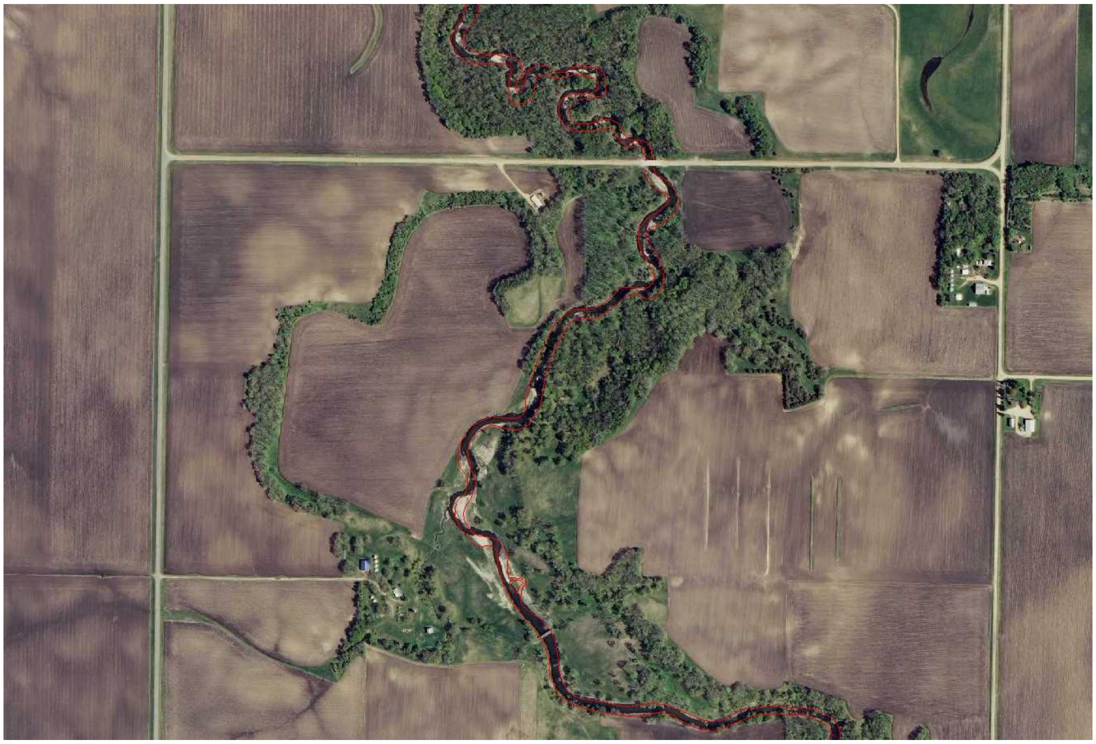
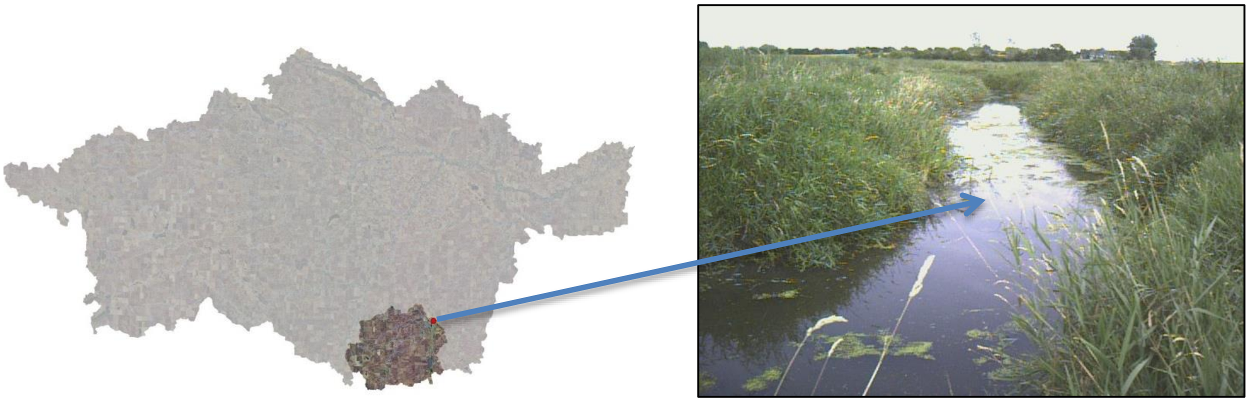


Figure 51. Streamline overlays created from historical aerial photography indicate that the stream reach in which the lower Perch Creek geomorphology site is located within has not seen many significant changes to pattern, profile, or dimension since 1991.

Upper Perch Creek

Table 15. Baseline information for the upper Perch Creek geomorphology survey site.

Stream Information			
Stream Name	Perch	**Drainage Area**	47 mi^2
Assessment Unit	07020010-524	**Stream Type**	E6
HUC 8 Watershed	Watonwan	**Valley Type**	Lacustrine (unconfined)
County	Watonwan	**Water Slope**	0.00016 ft/ft
Section	31	**Sinuosity**	1.4
Township, Range	105N, 30W	**Reach Erosion Estimates**	0.0071 tons/foot/year
Bank Height Ratio	1.14 (Slightly Incised)	**Pfankuch Stability Rating**	70 (Fair)



Upper Perch Creek is listed as a DNR Public Watercourse and impaired for turbidity and aquatic life. The survey reach is northwest of the town of Truman and directly north of the 490 acre Perch Creek DNR Wildlife Management Area (WMA). There is evidence of channelization upstream of the geomorphology survey site through the WMA; however, the surveyed reach is a narrow meandering E channel in a lacustrine valley dominated by reed canary grass and cattails. The land use in the watershed consists of 85.5% cultivated crops, 4.3% grasslands, 4.2% open water and wetlands, 5.4% development, and 0.6% other land uses (USDA 2011). The survey reach and land use directly adjacent is undisturbed herbaceous wetland vegetation. The meander pattern of the stream can be described as unconfined meander scrolls and irregular meanders (Rosgen 2006).

The bed of this narrow and deep E channel is dominated by silt-clay and mucky organic sediments. Channel types such as this (*i.e.* E6 stream types) have a very high sensitivity to disturbance, good recovery potential, moderate sediment supply, and high streambank erosion potential, while riparian vegetation plays a significant role in maintaining stability (Rosgen 1994; Appendix II). The streambed was dry during the summer 2012 survey, but the water depth was approximately 3 feet deep in the pools during the survey in August 2013 (Figure 52). The sinuosity, w/d, and entrenchment ratios indicate that the channel is in a relatively stable state for the E stream type (Figure 53).

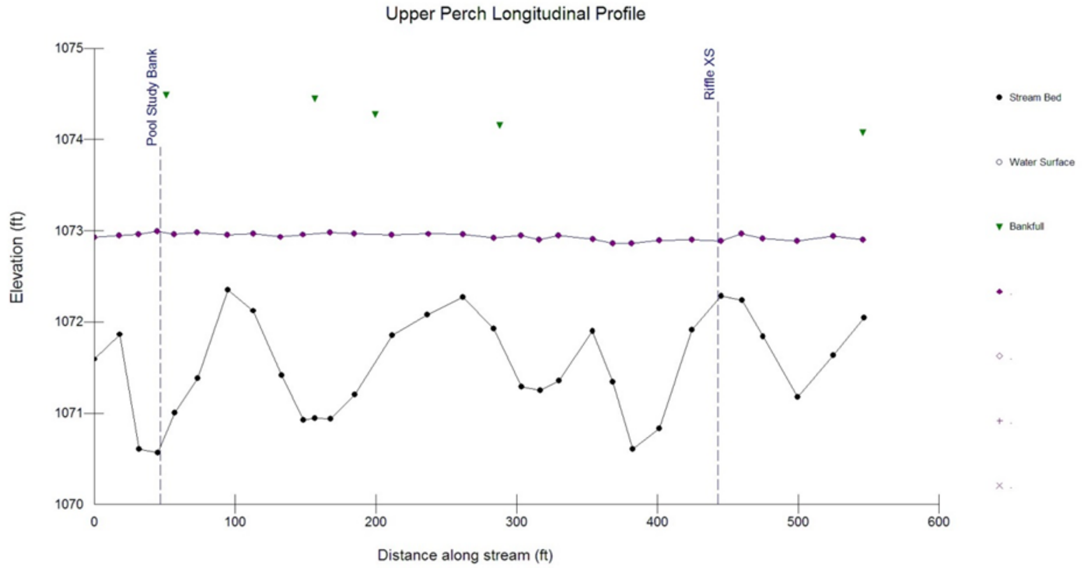


Figure 52. Longitudinal profile of upper Perch Creek geomorphology survey site depicting deep pools.

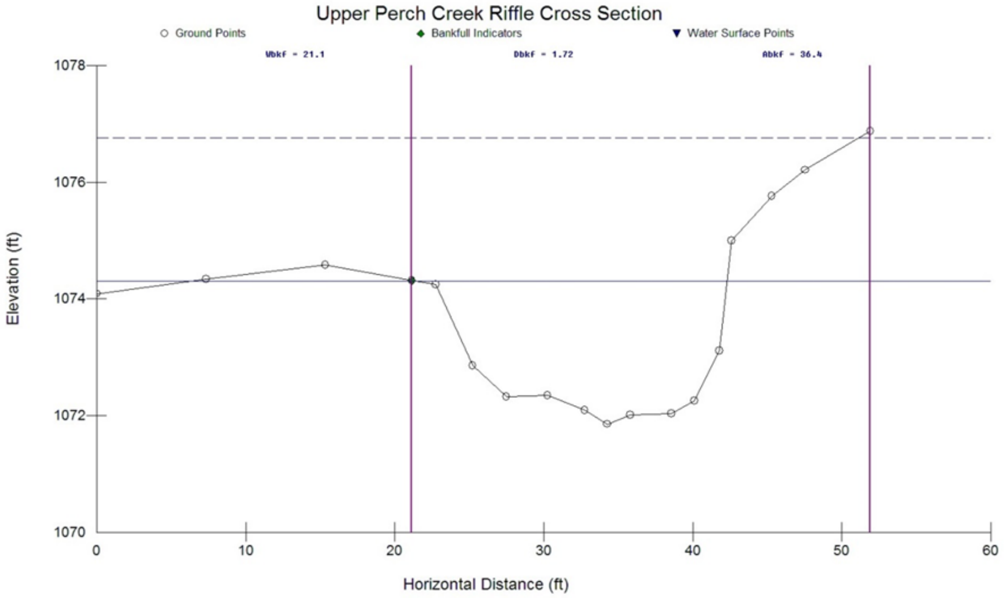


Figure 53. Cross sectional profile of upper Perch Creek geomorphology survey site depicting flood flow elevations that access the river's flood plain.

The Pfankuch stability rating shows the stream is in fair condition with a score of 70. Although, there are signs of channelization and narrow buffers in other areas of the watershed, this specific site can be classified as 'reference' for south central Minnesota. A reference reach is a stable stream, not necessarily pristine, but one representing the stable form for its particular valley type; therefore, its pattern, profile, and dimensions can be compared to an impaired reach.

Upper Perch Creek and surrounding lands are listed as having significance to biodiversity according to the Minnesota County Biological Survey. MNDNR non-game staff monitor and research Blanding's turtles *Emys blandingii*, a threatened species in Minnesota, within in the upper Perch Creek watershed. Streams and wetlands provide important aquatic habitat for Blanding's turtles. Flashy spring rains causing gully and accelerated lateral streambank erosion can be detrimental to the Blanding's turtles. DNR staff have also observed northern pike using the riparian corridor during spawning periods.

The sediment supply from streambank erosion is low compared to other Watonwan sites. The BANCS model estimated the 545-foot reach is contributing 0.0071 tons of sediment per linear foot of streambank annually when using the Colorado erosion rate curve (Rosgen 2001). At the monumented pool cross section, the model estimated the bank erosion to be 0.072 feet per year while the actual measurements indicated an erosion rate of 0.0044 feet per year for the four-foot tall bank. The BEHI rating was low and the NBS rating was moderate when using method #5, a method that was linked to the pool cross section.

Summary

Overall, the creek is stable with good pool and riffle spacing and quality. During bankfull flows, and higher flows, energy is allowed to dissipate on the floodplain and neighboring wetland complex. Channels such as this (*i.e.* E6 stream channels) are very stable unless the banks are disturbed and significant changes in sediment and/or streamflow occur (Rosgen 1996).

Management Recommendations

Future management recommendations include protecting and maintaining the wide buffer and floodplain connection to keep the stream as a stable E channel. Water storage and perennial vegetation percentages are higher for this sub-watershed compared to other surveyed reaches in the Watonwan. This site provides an example of water storage and landscape diversity in an upper watershed of the GBERB. Maintain the hydrologic regime to allow for the landscape to continuously provide ecosystem services (*i.e.,* benefits from nature, such as clean water, carbon sequestration, and quality habitat).

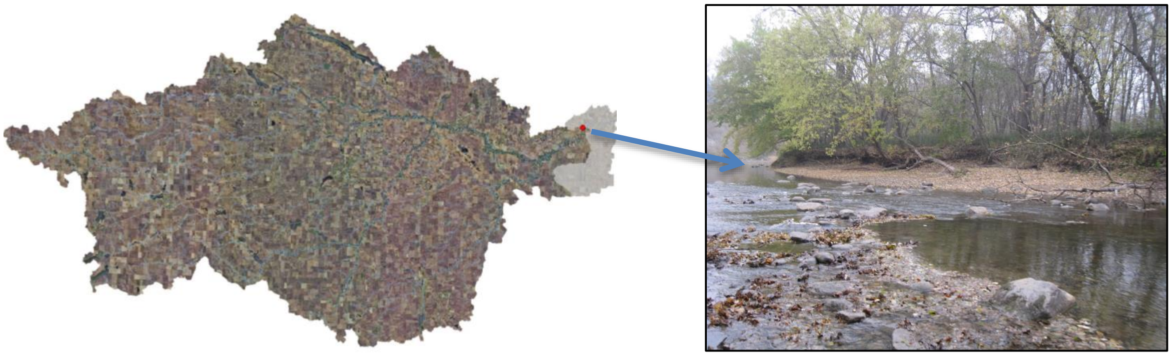
In the Perch WMA, upstream of the survey site, evidence of past channelization is apparent (Figure 54). Review of aerial photography depicts that the channelization occurred sometime between 1962 and 1991. There are spoil piles limiting the ability for the stream to access its floodplain and it is expected this channel would be classified as a G stream type. Channels classified as G channels, when compared to E channels, have lower recovery potential from disturbances, higher sediment supply, and higher streambank erosion (Rosgen 1994; Appendix II). If partners and stakeholders are on board, this stream should be restored to its natural form (*i.e.,* dimensions, pattern, and profile). Compared to natural channels, channelized streams have higher nitrates, phosphates, pH, turbidity, velocities, and proportion of particulates as well as much longer nutrient uptake lengths and much lower species diversity (*i.e.* systems dominated by tolerant species; Kuenzler et al. 1977, Ahiablame 2009, Meyer and Wallace 2001). Any future work would be coordinated with stakeholders and conditions would be applied given the biologic diversity and Blanding's turtle population in the area.

Figure 54. Aerial photography and LiDAR imagery depicts historical channelization within close proximity to the upper Perch Creek geomorphology survey site.

Lower Watonwan River (downstream of gage station near Garden City)

Table 16. Baseline information for the lower Watonwan River geomorphology survey site.

Stream Information			
Stream Name	Watonwan	**Drainage Area**	847 mi^2
Assessment Unit	07020010-501	**Stream Type**	F4
HUC 8 Watershed	Watonwan	**Valley Type**	Terraced Alluvial (unconfined)
County	Blue Earth	**Water Slope**	0.0009 ft/ft
Section	28	**Sinuosity**	1.1
Township, Range	107N, 28W	**Reach Erosion Estimates**	0.0412 tons/foot/year
Bank Height Ratio	2.01 (Deeply Incised)	**Pfankuch Stability Rating**	94 (fair - mod.unstable)



Water quality impairments in the lower Watonwan River include turbidity, fecal coliform, and mercury in the water column and fish tissue. The drainage area of the Watonwan watershed is 847 mi^2 at the Lower Watonwan geomorphology survey site, located downstream from the stream gage and Watonwan load monitoring station. The watershed land use is 86.6% cultivated crops, 6.2% perennial cover, 0.9% water, and 5.9% other land uses (WHAF).

The survey started approximately 600 feet downstream from the gage at the start of a riffle dominated by cobble and small boulders (Figure 55). The river is over widened, not accessing its floodplain at two times bankfull flows, and is classified as an F channel (Figure 56). The stream is entrenched (1.06 ratio) and the w/d ratio is 30.39 (*i.e.* high). An F channel is not a stable channel for alluvial valleys; they usually exhibit poor habitat quality, higher water temperatures, and excessive sediment supply resulting in poor aquatic communities and high turbidity (Rosgen 1996).

Historic resources (*i.e.* aerial photography and plat maps) indicate the river was once channelized to construct the bridge at its current location. Therefore, this survey reach has lower sinuosity and is not representative of upstream and downstream areas where the sinuosity is more typical of a C channel

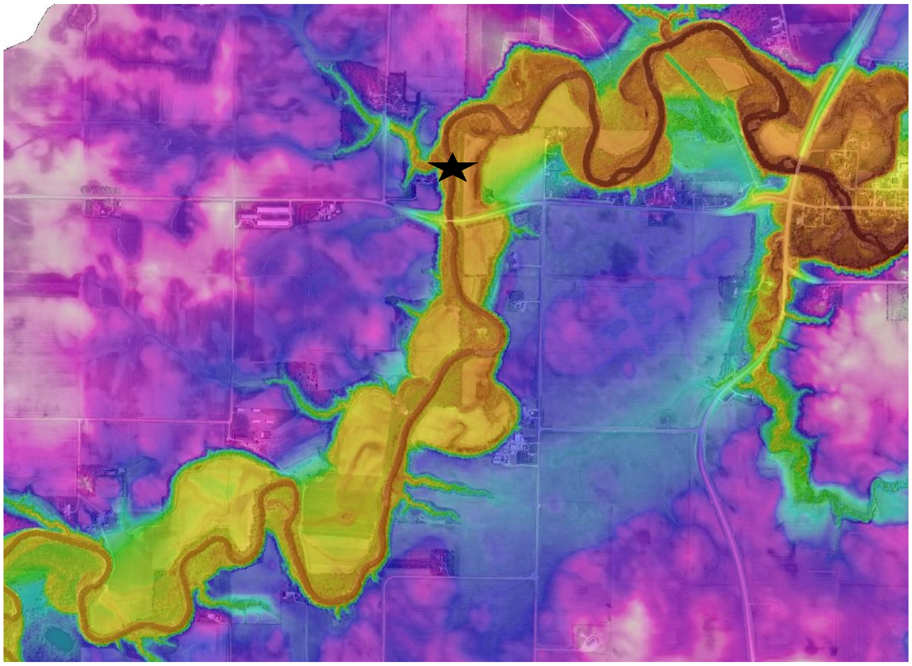


Figure 55. The lower Watonwan River geomorphology survey site is located just downstream of CSAH 13.

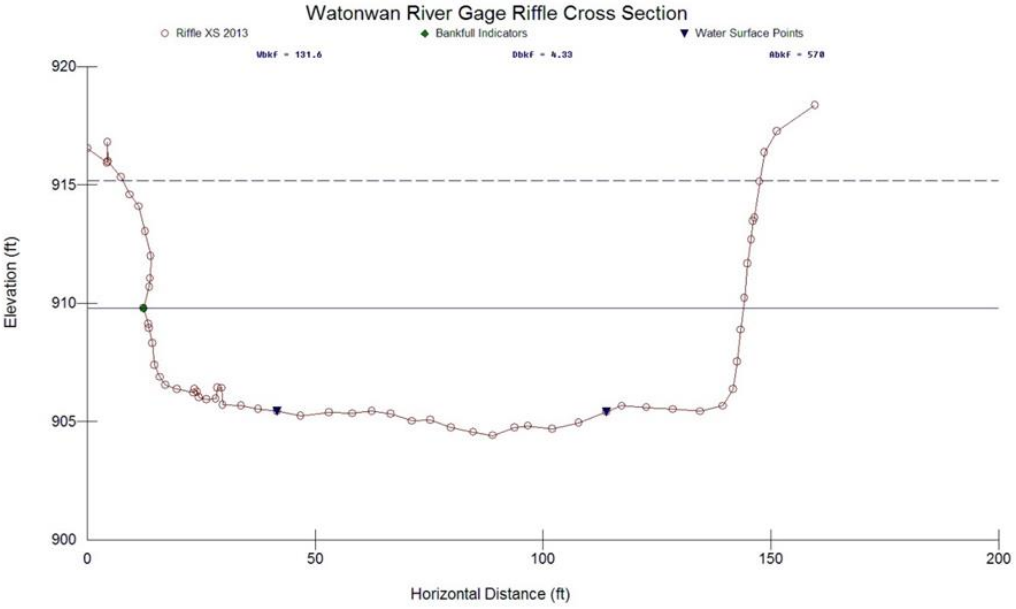


Figure 56. Riffle cross sectional profile at the lower Watonwan River geomorphology survey site indicating that the channel is over wide and does not access its floodplain at 2x bankfull flows.

(*i.e.* >1.2). Visual observations via kayak reconnaissance showed evidence of floodplain connectivity both upstream and downstream of the geomorphology study reach.

This survey reach is more of a transitional zone, where the channel type changes from an F channel to a C channel. The two apparent riffles throughout the reach are comprised of cobble and boulders resulting from glacial materials and serve as grade control. As previously mentioned, much of the lower Watonwan River has a low gradient due to the influence of the Rapidan Dam (*i.e.* dam ~11 miles from the confluence with the Blue Earth River; Figure 57). The longitudinal profile indicates a change in water slope approximately half way through the reach due to the riffle grade control (Figure 58). The water slope (*i.e.* 0.0009) from the first half of the channel was used to calculate bankfull flows and tied in with bankfull (*i.e.* 1.5 yr return interval) discharges associated with the long term hydrologic monitoring gage.

The sediment supply from streambank erosion was average when compared to other Watonwan sites. The BANCS model estimates this reach is contributing 0.0412 tons of sediment per linear foot of streambank annually when using the Colorado erosion rate curve (Rosgen 2001). Erosion predictions indicate the 1,230 foot reach delivers 50.7 tons of sediment (*i.e.* ~5 dump truck loads) annually. At the riffle cross section, the model estimates the bank erosion to be 0.15 feet per year. Erosion rates at the riffle will be further validated during the 2014-15 field seasons. The BEHI rating was moderate and the NBS rating was low when using method #5, a method that was linked to the cross section.

Summary

Overall, the forested riparian buffer is greater than 50 feet wide on each side of the channel. While aerial photography does not indicate significant change to the pattern of the stream since 1938, there is evidence of channel widening and a loss of sinuosity. The thalweg and/or low flow channel observed during the 2013 survey takes up very little of the overall channel. In places where the thalweg is next to the banks, there is evidence the woody debris is causing the convergence of scour and increasing near bank stress. The river is likely in an aggradation and widening phase; the reduction in stream power and high sediment loads cause portions of the stream to start aggrading. Until a new floodplain can be established, stability of the lower Watonwan (gage site) at the study reach may not be realized.

Management Recommendations

Considering the Lower Watonwan River is an F channel at the study reach, there are few “quick fixes” that can be implemented to restore stability. The good news is that other portions of the Watonwan River still have good floodplain connectivity and the majority of the main stem’s riparian corridor is buffered with perennial vegetation. Targeted best management practices implemented on the landscape can relieve the system from changes in runoff responses that are currently taking place (refer to hydrology section). Prioritized stream restoration, such as toe wood sod mats, could be incorporated in areas where channel dimensions are extremely over wide compared to up and downstream conditions. However, first we need to address the systemic issues in the watershed and continue evaluating hydrologic trends, then a plan can be developed for prioritizing stream channel restoration. Actions must be prioritized, targeted, and measurable in order to ensure limited resources are spent where they are needed most.

Figure 57. Much of the lower Watonwan River is influenced by the Rapidan Dam on the Blue Earth river; approximately 11 miles downstream of the confluence of the Watonwan and Blue Earth Rivers.

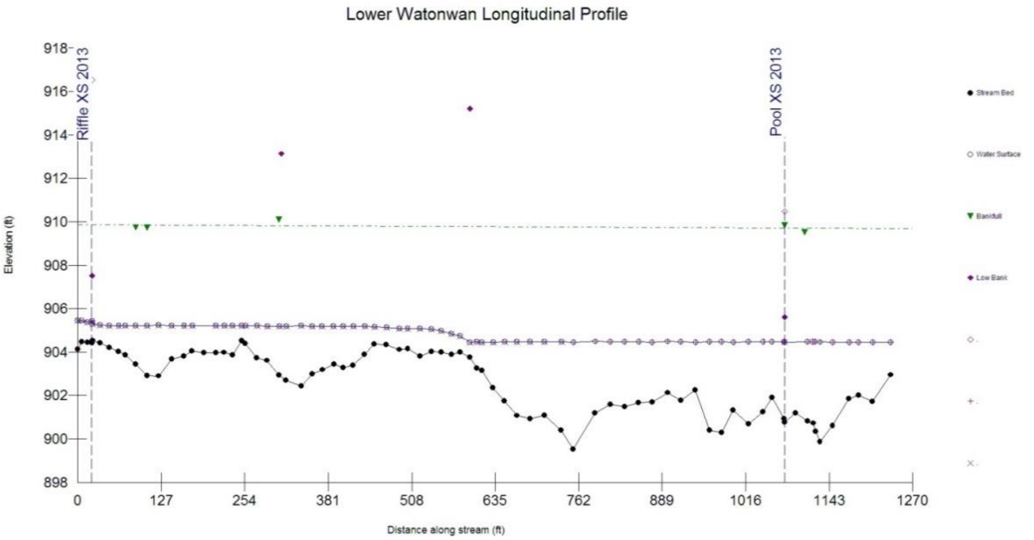


Figure 58. Longitudinal profile of the stream channel at the lower Watonwan River geomorphology survey site.

Planned prioritization of stream restoration is a favorable approach. However, resource managers must be careful not to lock the stream in place, pass the problem downstream, degrade habitat, decrease connectivity (*i.e.,* longitudinal, lateral, or vertical), or further degrade water quality. A high priority should be to implement adequate perennial buffers, especially on vulnerable outside bends with highly erodible soil conditions. An example of an outside bend with sandy soils is 0.7-miles downstream from the Lower Watonwan survey site where the stream appears to be a C4 (Figure 59 and 60). A BANCS assessment indicated an extreme BEHI and Low NBS. For the 500 foot outside meandering bend, the estimated contribution is 202 tons per year (*i.e.* ~20 dump trucks per year). While some of the material is depositing in the channel, some will be transported at bankfull flows.

Figure 59. Example of bank erosion and mass wasting found within the lower reaches of the Watonwan watershed.

Figure 60. Example of bank erosion and mass wasting found within the lower reaches of the Watonwan watershed.

Bank Assessment for Non-point Source Consequences of Sediment (BANCS) Model Results

The BANCS model is a combination of the Bank Erosion Hazard Index (BEHI) (Figure 61) and Near-Bank Stress (NBS) (Figure 62) utilized to predict annual sediment inputs from a specific bank. MNDNR staff navigated the main stem Watonwan River from Blue Earth County Road 30 to US Hwy 169 via kayak, assessing streambank erosion sites during the summer of 2013 at relatively low flows ranging from 45 to 700 cubic feet per second (cfs). The final reach of the Watonwan from US Hwy 169 to the confluence with the Blue Earth River was completed in May 2014 with flows slightly over 300 cfs. Most banks assessed in these reaches were on outside bends where it was apparent that streambank erosion was occurring in excess of the deposition rate on the inside point on the meander bend. Height and length of study banks were generally measured with a laser rangefinder. Near bank shear-stress was calculated using equation 2 [i.e. radius of curvature (measured off aerial photography) versus bankfull width equation]. Any sites that had a mid-channel bar, or transverse bar near the bank of interest, were given extreme NBS scores due to the stress exhibited from those riverine features. All bank erosion estimates were determined from the Colorado erosion rate curve established by Dave Rosgen. The Colorado BEHI rating tables are considered more of a moderate estimate compared to the more generous Yellowstone data or more conservative North Carolina data set. The Wildland Hydrology Level 3 training held in southcentral Minnesota in September 2013 found the Colorado data set to be the most applicable when evaluating monumented banks in the Seven Mile Creek watershed. A specific Minnesota rating table is being developed, but one does not exist as of yet.

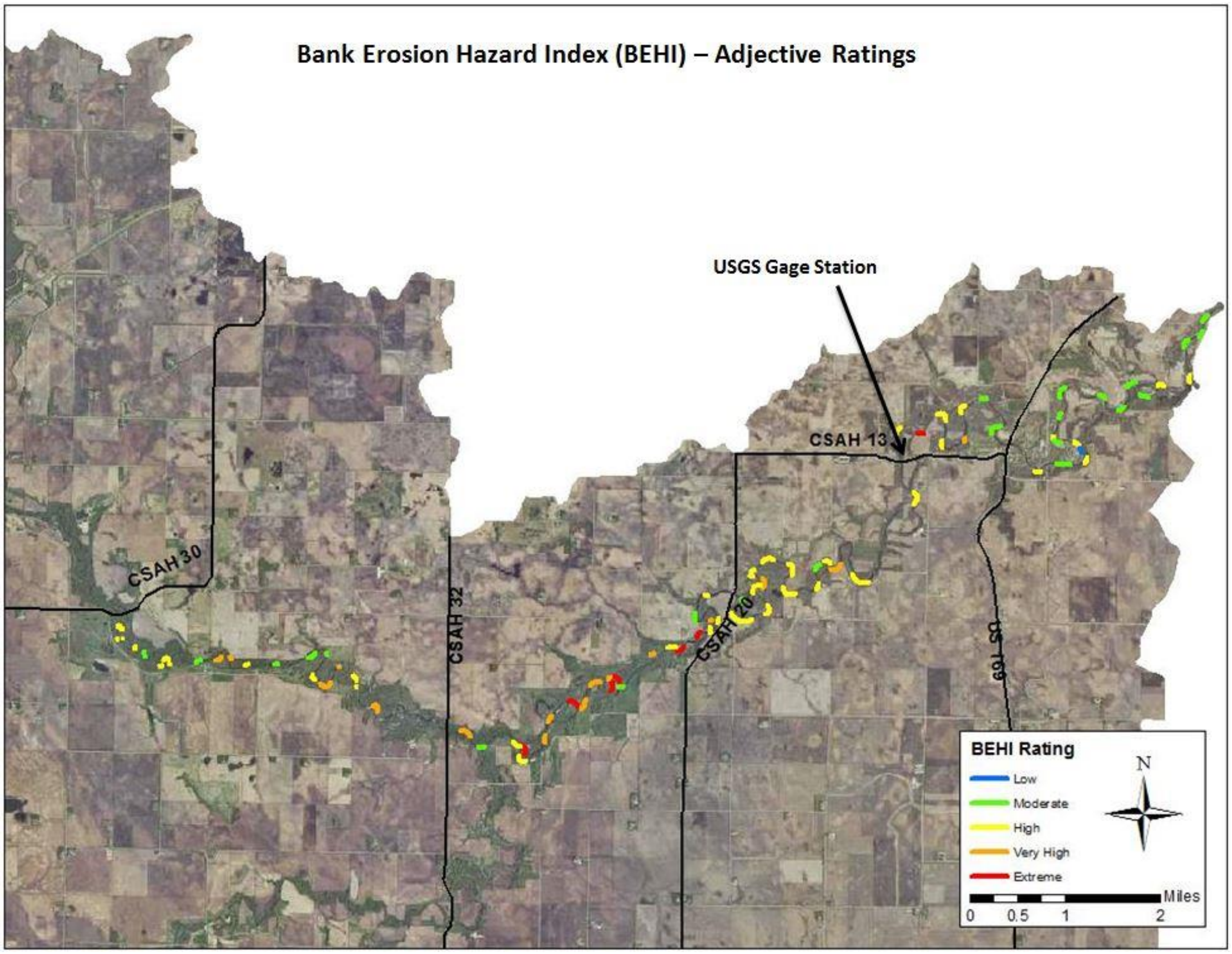


Figure 61. Bank Erosion Hazard Index (BEHI) adjective ratings for the lower section of the Watonwan River in which Bank Assessment for Non-point source Consequences of Sediment (BANCS) assessments were conducted.

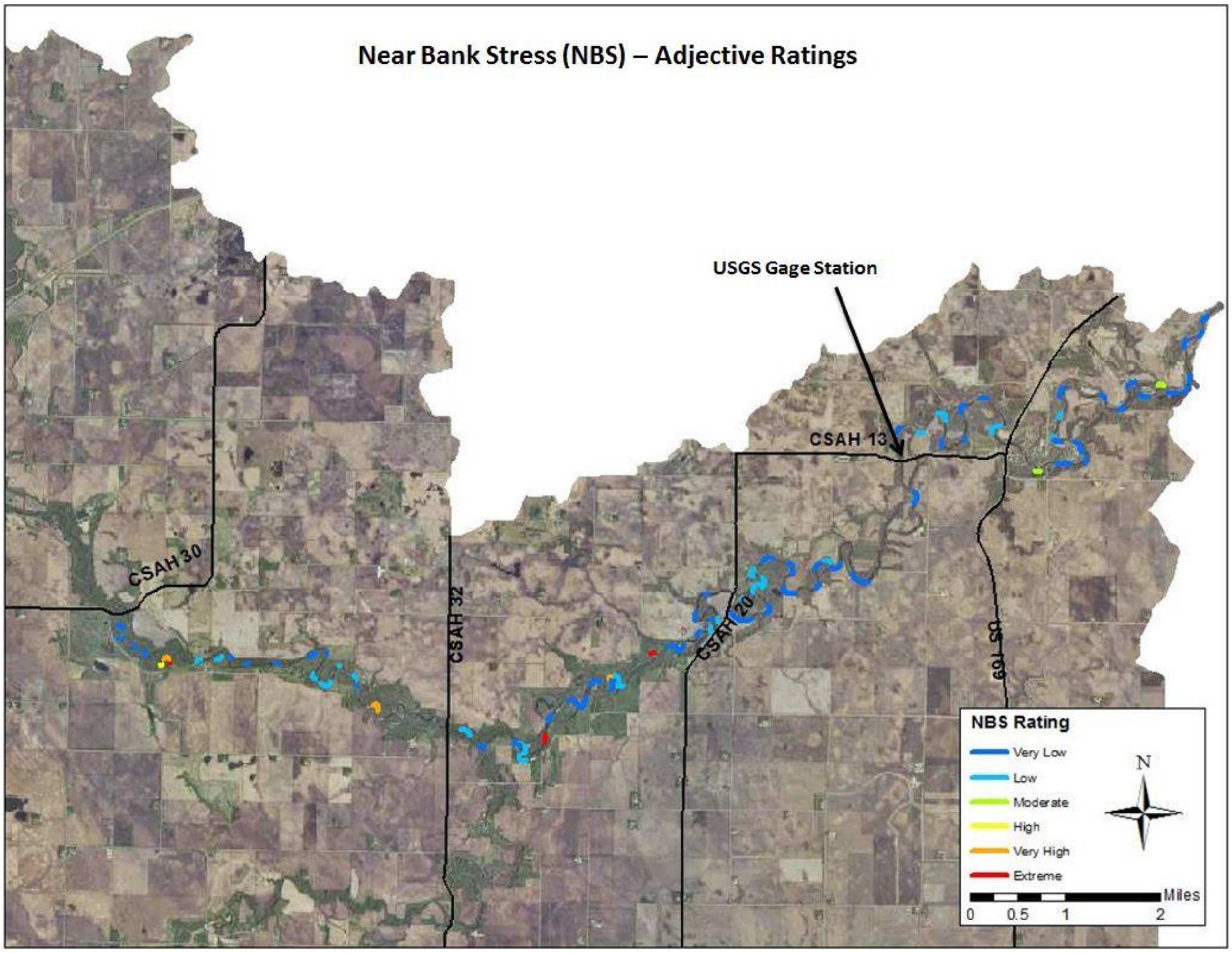


Figure 62. Near Bank Stress (NBS) adjective ratings for the lower section of the Watonwan River in which Bank Assessment for Non-point source Consequences of Sediment (BANCS) assessments were conducted.

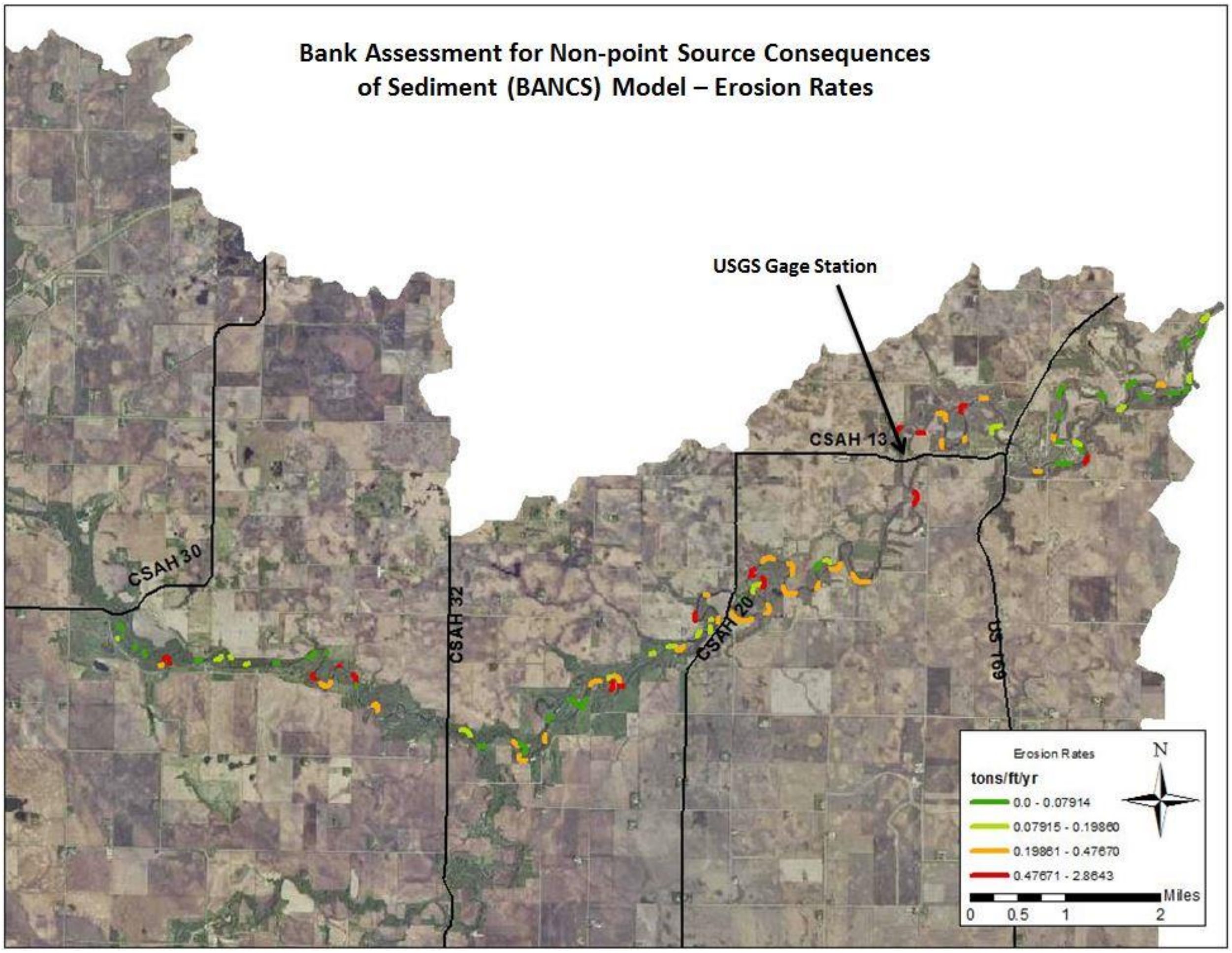


Figure 63. Bank Assessment for Non-point Source Consequences of Sediment (BANCS) model erosion rates for banks assessment within the lower reaches of the Watonwan River.

Table 17. Annual sediment yield for banks assessed during BANCS assessments conducted in the lower reaches of the Watonwan watershed.

Stream Reach	Reach Length (mi)	Bank Range (ft)	Erosion Range (tons/ft/yr)	Total Bank Length (ft)	Annual Sediment Yield (tons/yr)
CSAH 30 to CSAH 32	6.217	44 - 800	0.01780 - 2.8643	6,184	1,714.30
CSAH 32 to CSAH 20	5.531	100 - 800	0.03550 - 1.6794	10,240	2,486.06
CSAH 20 to Gage	5.473	140 - 1300	0.0666 - 0.5561	8,230	3,245.82
Gage to HWY 169	2.904	200 - 900	0.0124 - 0.6356	4,400	1,150.35
HWY 169 to Outlet	5.199	50 - 900	0.0000 - 0.4767	9,900	746.17
CSAH 30 to Outlet	25.324	44 - 1300	0.0000 - 2.8643	38,954	9,342.70

Figures 63 and 64 provide an example of an actively eroding outside meandering bend between CSAH 32 and CSAH 20. The Watonwan River through this stretch is a C channel in an unconfined alluvial terraced valley. The sandy outside bend with shallow rooted perennial vegetation receded 200 feet from 1991-2013 (9.09 ft/yr), according to aerial photographs.

At the time of the survey in June 2013, the BEHI was ranked as extreme and the NBS was very low using NBS method 2 (*i.e.* ratio of radius of curvature to bankfull width). Using these ratings, the model underestimates the annual rate of lateral erosion (0.165 ft/yr Colorado model, 0.985 ft/yr Yellowstone model, and 1.00 ft/yr North Carolina model). To accurately match up the loss with aerial photographs, the NBS must be classified as very high to extreme (Colorado 7.03 – 17.97 ft/yr, Yellowstone 2.25 – 2.76 ft/yr, and North Carolina 5.2 – 7.5 ft/yr). It is likely NBS method 5 will provide a more accurate NBS ranking, especially since the thalweg appears to be abutting the eroding bend. However, the water level was too high and survey equipment was not along at the time the BANCS assessment was completed. Overall, the Colorado curve matches up better than the Yellowstone or North Carolina data set.

With the very high NBS adjustment, the erosion rate increases from 0.1 tons of sediment per linear foot per year to 4.4 tons of sediment per linear foot per year when using the Colorado erosion rate curve (Rosgen 2001). The predicted annual bank erosion is 78.8 tons/year (*i.e.* ~7.8 dump truck loads) for the 700 foot long bank.

It is well documented that streambanks, bluffs, and terraces are large contributors of sediment to the Minnesota River basin, with heavy emphasis on the GBERB (Wilcock et al. 2009). Some erosion is natural, due to the geology of the area; however, many watersheds are evolving at a rapid pace due to current land management practices, climate, and hydrological runoff response. Several studies have found that streams in the Minnesota River Basin are exhibiting erosion rates far in excess of naturally occurring mechanisms (Blann et al. 2009; Belmont et al. 2011). Some of the reaches where BANCS assessments were performed have shown recent change in the dimension, pattern, and profile; concluding the assessed reaches are unstable. As these rivers continue to evolve they will widen and become shallower, generally causing quality aquatic habitats to degrade. Overtime, the river will create a new stable floodplain within portions of the old channel as it adapts to current hydrological regimes. Although outside bends are typically looked at with the BANCS assessments, many reaches have shown widening through old alluvial material and are contributing more to the excess bedload issue. Crews from the United States Geological Survey (USGS) are collecting bedload samples along with suspended load samples to get a better understanding of the total sediment budget throughout Minnesota. Additional data collection is anticipated in upcoming years to shed additional light on bedload contributions.

Figure 64. Mass wasting of streambank leading to increased rates of lateral channel migration.

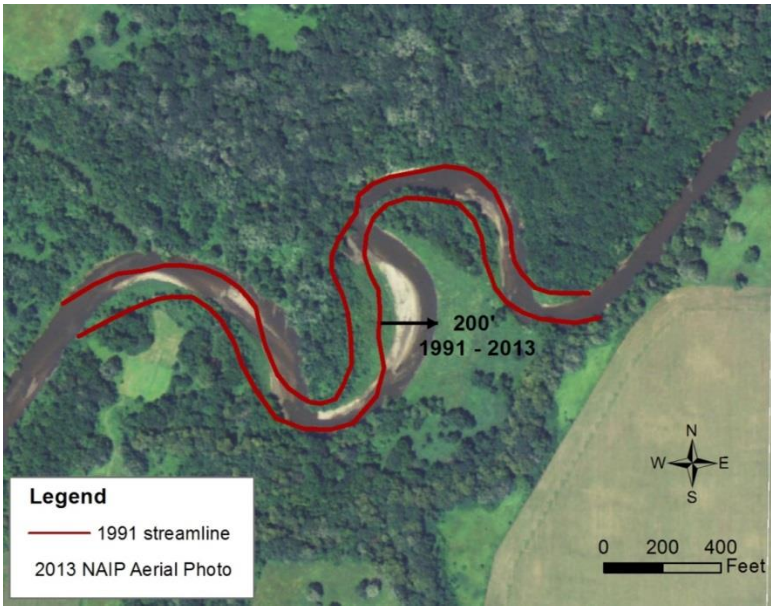


Figure 65. Depiction of an actively eroding meander bend within the lower reaches of the Watonwan watershed.

Channel Changes via GIS Investigation

GIS analysis of the Watonwan River watershed indicates extensive changes to the natural hydrology of the watershed. Figure 66 shows the relative proportion of channelized stream miles within the Watonwan watershed. Subwatersheds in red indicate the highest relative proportion of channel alteration while those watersheds in green represent the least amount of channel alteration. When streams are ditched or straightened, as much as half of the stream length can be lost. Nearly 1/3 of Minnesota streams are ditched (*i.e.* 27,000 of 90,000 stream miles). Land-use changes and resulting changes in stream shape lead to excessive streambank or streambed erosion while degrading stream health. These impacts, in addition to climate change, lead to increased erosion and deposition, altered hydrology, more frequent and destructive flooding, degradation of aquatic and riparian habitat, and decrease in species diversity (MNDNR 2014a).

Comparing a range of historical aerial photographs provides one way to identify accelerated channel changes and/or potential reference sites. Typically, an area where widening or loss of sinuosity is occurring faster than another indicates an unstable reach and high sediment loading. However, there may be situations where natural geologic or soil conditions cause uncommon responses compared to other reaches. Channels that have maintained their pattern, profile, and dimensions for decades are often signs of channels with reduced watershed disturbance or vegetation or bedrock control. Figure 67 provides an example of channel changes from 1991 to 2011. The area of the Watonwan River near Madelia has experienced obvious changes over the past 20 years. The following Figure 68 provides an example of anthropogenic channel cutoff in the watershed. The old ‘sinuous’ channel measures out to be 4,506 feet, while the current channel measures out at 1,751 feet; a difference in 2,755 feet or 0.5 miles. Restoring the stream from the ditch back into the old sinuous channel would achieve additional water storage, increase stream stability, and provide for greater environmental benefits.

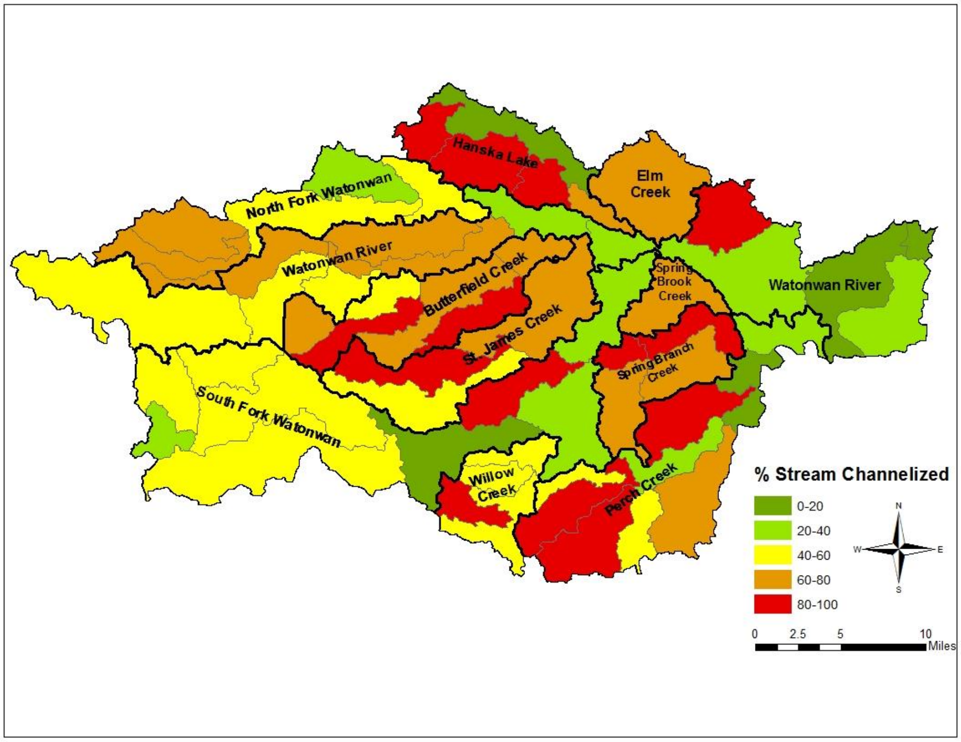


Figure 66. Relative proportion of channelized stream miles within the minor subwatersheds of the Watonwan River watershed.

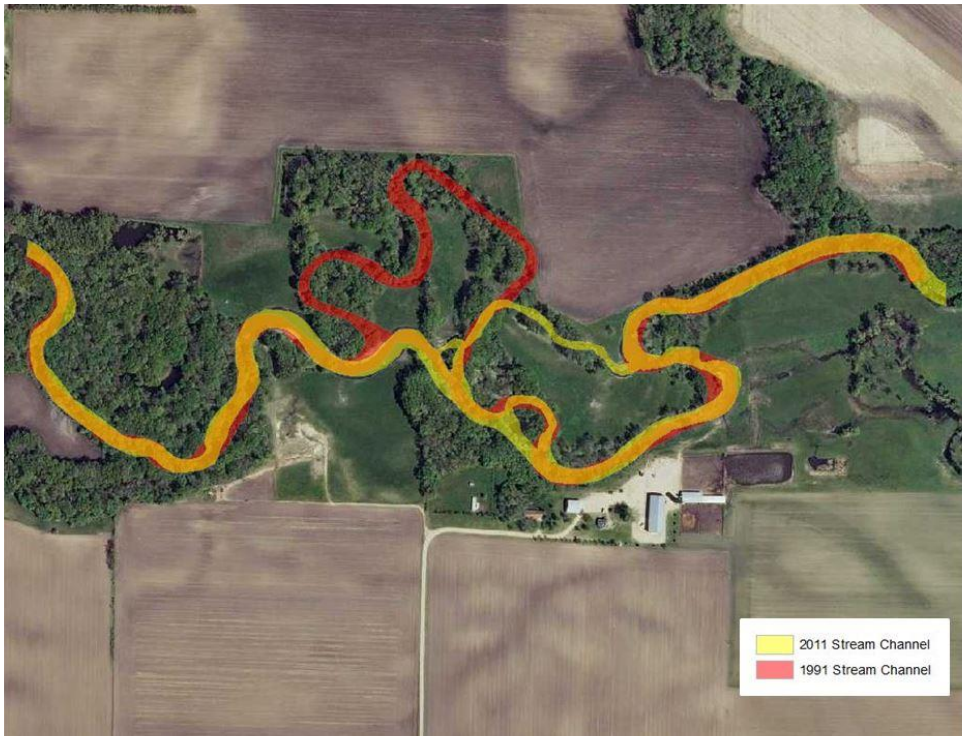


Figure 67. Channel area as delineated by aerial photography indicates accelerated rates of change within the pattern and profile of the Watonwan River near Madelia, MN.

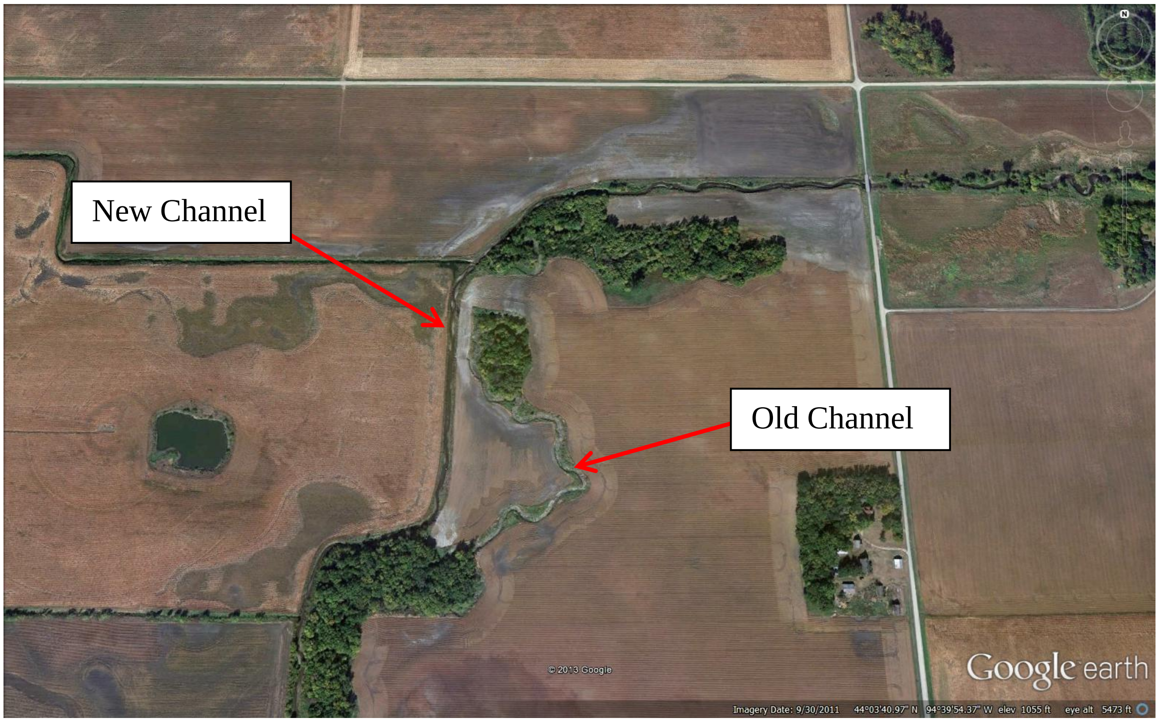


Figure 68. Channel cutoff on the Watonwan River.

Conclusions

Hydrology, connectivity, and geomorphology are three essential components of a healthy watershed. If any of these components depart from natural or stable conditions, one or more of the other components will be impacted and potentially have negative impacts on biology and water quality within the watershed. The soils and geology of the watershed have resulted in highly productive lands, but significant portions of the river and its tributaries have been straightened and altered to provide for drainage of farmland and flood reduction. In addition, enhanced drainage practices, fragmented riparian zones, and land use changes have resulted in an increase in flows and channel instability at many surveyed sites. Due to past or present channel modifications, successional processes were apparent at the majority of sites surveyed. While streambank erosion is a natural process, acceleration of this natural process due to changes in land use and hydrology lead to a disproportionate sediment supply, stream channel instability, and a loss of land, aquatic habitat and other adverse effects (Rosgen 2006).

Discharge and precipitation data collected from the Watonwan River indicate the amount and timing of water delivered per inch of precipitation has increased over time. This rapid rate and increased volume of water delivered can further destabilize the system and is a contributing factor to the geomorphic response in the watershed.

Historically, there has been widespread channelization in the watershed. Channelized systems have limited floodplain connectivity and are often sized incorrectly (*i.e.* cross sectional area to drainage area); therefore, not allowing the base flow channel to handle sediment competency and capacity.

Naturally meandering river systems are working to adapt to the changing hydrologic regime and frequently show symptoms of instability. Bankfull features were difficult to identify, which is typical in unstable systems. Therefore, locally developed regional hydrology curves were used as guidance to determine bankfull elevations.

The majority of the sites assessed had adequate floodplain connectivity (*i.e.* accessing their floodplain at 2x bankfull flows). Four of the 11 sites were classified as entrenched and did not have floodplain access during bankfull and higher flows. However, the degree of channel incision, or BHR, at each riffle indicates 9 of the 11 sites are slightly incised to deeply incised. Streams with high BHR values generally contribute disproportionate amounts of sediment from banks and bed due to high shear stress (Rosgen 2006). One additional indication of channel instability is when the width-to-depth (w/d) ratio is high compared to a reference condition. Increases in w/d ratios and channel capacity are generally associated with accelerated streambank erosion rates, excess deposition/aggradation processes, and over-widening due to direct mechanical impacts (Rosgen 2006). Overall, w/d ratios below 12 are considered low. However, high ratios, for example above 15 or 20 for a C channel, indicate a sediment transport disequilibrium, or excessive siltation, which may result in high water temperatures and loss of habitat (Appendix II). South Fork Watonwan, Lower Perch Creek, and Watonwan gage have w/d ratios >20.

Less disturbed upper watershed sites, such as upper Perch Creek, show more resilience to the hydrology changes taking place in the watershed because of deep-rooted perennial vegetation in the riparian corridor, floodplain connectivity, and water storage in the upper watershed. Riparian buffers and/or filter strips are very important for stream stability, especially for low gradient, sinuous E channel types that are typical of the historic prairie pothole landscape.

Stream stability for the Watonwan River is also linked to maintaining a vegetated corridor with an intact floodplain due to the geologic conditions of the watershed. Sites with larger drainage areas and mature floodplain forests have resiliency built in to a certain degree; however, upstream channelization and land use alterations increase downstream flows and result in channel widening. Over wide channels reduce lateral connectivity and eventually systemically impact the dimension, pattern, and profile.

Using the Bank Assessment for Non-point source Consequences of Sediment (BANCS) evaluation procedures for streambank sediment contributions on the lower 25 miles of the low gradient Watonwan River indicated roughly 9,342 tons of sediment per year (*i.e.* ~934 dump truck loads) are being contributed to the river by streambank erosion. The highest sediment contribution rate is occurring in the stream reach between CSAH 20 and the gage near Garden City (CSAH 13).

The complex road network in this watershed results in 331 stream crossings in total (0.38/mi^2). With this many road crossings, it is likely that a number of perched culverts exist that may seasonally impact longitudinal connectivity within the system. Disconnects within the longitudinal connectivity of river and stream systems impact the capacity of fish assemblages to makes annual or seasonal migrations. Furthermore, with a road crossing density of 0.38 mi^2, many bridge and culverts are likely improperly sized. Bridges and culverts that are not properly sized in accordance with bankfull flows create flood flow confinement, which in turn changes flow dynamics in a manner that erodes and deposits sediment in an irregular manner. Furthermore, flood flow confinement can cause catastrophic failure of road crossings or bridges and impose an economic burden upon local municipalities.

Restoration and Protection Strategies

Throughout the Watonwan River watershed, there are multiple opportunities for restoration as well as protection. It is important to restore rivers with the watershed (system) in mind, instead of installing practices that reduce bank erosion on a small number of banks and transfer energy downstream. When stream restoration is the most feasible option, the goals need to be to preserve or restore streambank stability while maintaining benefits to habitat, biota, water quality, and connectivity.

The following strategies are recommended, but not limited to:

- Establish, maintain, and/or protect the deep rooted perennial vegetation in the riparian corridor.
- Increase water storage by targeting projects providing additional floodplain/lateral connectivity and/or water retention.

  - Future projects for habitat restoration and nutrient treatment could include grade control to build up the channel bed and allow frequent oxbow recharge, or similar projects increasing access to the floodplain.
  - Conservation practices, such as: cover crops, conservation tillage, wetland restoration, and waterways, have the ability to slow down the water, allow for greater infiltration, and/or reduce excess sediment and nutrient contributions to watercourses.
- Consider targeting a subwatershed, for instance Perch Creek or South Fork Watonwan, and partner with local government units, landowners, and agencies to further develop science-based, measurable prioritization strategies and implementation efforts.
- Design future ditch improvement projects for multiple purpose drainage management.
  - Correctly design the channel to handle flows and sediment with floodplain connectivity to provide adequate drainage for agricultural producers and maintain a healthy river system with natural riffles, runs, glides, and pools.
  - Implement conservation practices on the landscape to mitigate downstream impacts and improve water quality.
- When new road crossing projects are designed, consider resizing culverts and bridges to allow water and sediment movement throughout the watershed. As shown previously, oversizing of culverts or undersizing of bridges can affect the river channel downstream. This can lead to excess sediment supply and habitat degradation, as well as block passage for riparian animals making them cross busy highways to migrate upstream or downstream. See Zytkovicz and Murtada (2013) for further guidance.
- Recognize current valley and stream type and identify the probable stable form for the stream under the present hydrology and sediment regime before engaging in any stabilization or restoration measures.

In the long run, it is beneficial (from economic and environmental perspectives) for watershed professionals to adopt a systemic approach and address sources (*e.g.*, altered hydrology or landuse practices) of water quality issues as opposed to the symptom (e.g., bank erosion) when looking at restoration opportunities. Appendix III provides guidance on stream restoration practices, as appropriate for given current stream stability and channel type.

Protection opportunities may seem sparser than areas to restore; however, options and opportunities do exist. Lands providing multiple ecosystem services, or environmental benefits, should have highest priorities for protection. Critical habitat areas, wetland\upland complexes, and natural areas not only provide quality habitat, but sequester carbon, provide a home for rare species, produce clean water, and offer many recreational opportunities.

As a watershed, it is also important that practices are not put on the land that would increase stress on these systems. In order to realize the healthy watershed objective, it is important that everyone plays a part in holding some water on the landscape to allow for aquifer recharge, flood reduction, and water quality protection.

There are many scenarios and opportunities for restoration and protection. Suggestions throughout this report are merely opportunities within or near survey reaches, and have been identified through technical office and field methods. Continuing to build watershed knowledge and partnering efforts will help pinpoint instability and the highest sediment contributors.

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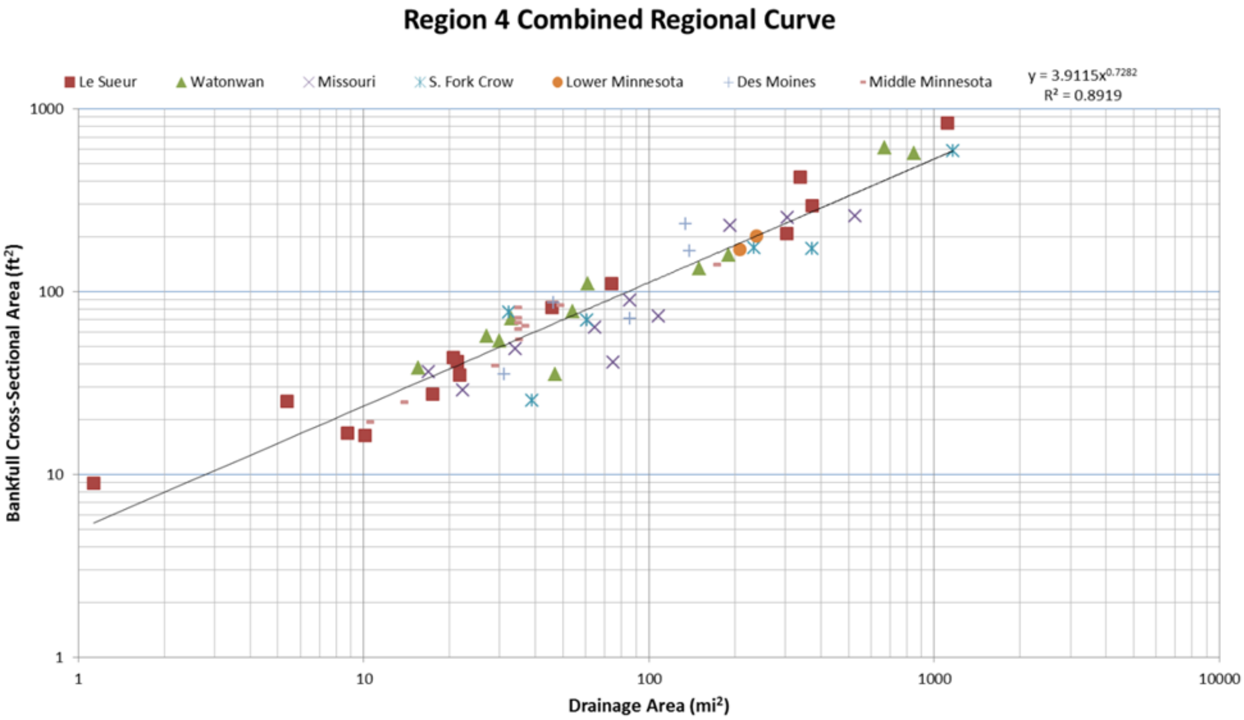
Appendix I

Appendix I. Southern Minnesota regional curve by stream type; developed through MNDNR geomorphology surveys. Bankfull cross sectional area was taken at the representative riffle cross section at each site. This is a draft regional curve and subject to change.



Appendix II

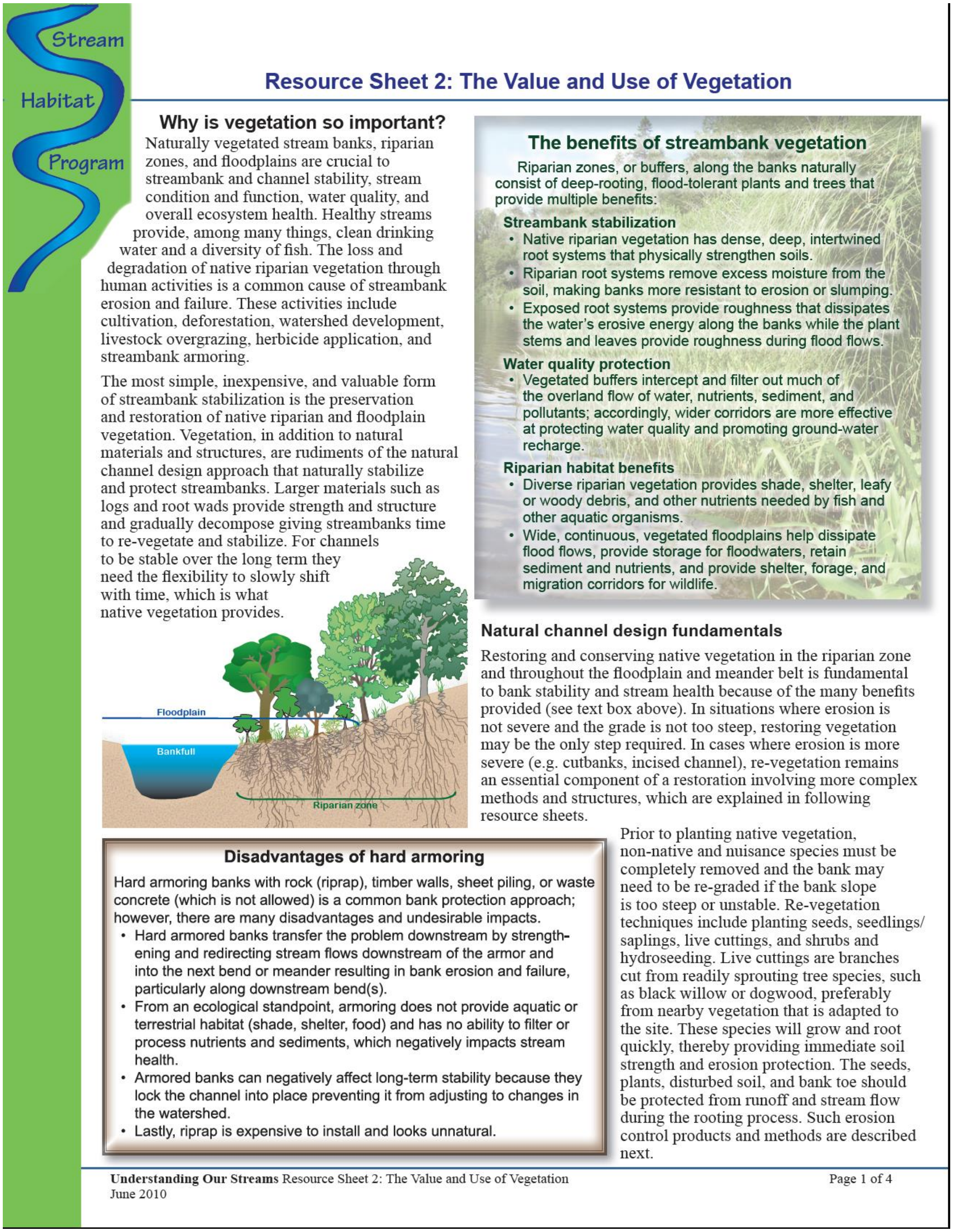
Appendix II. Management implications for individual stream types (Rosgen 1994).

Stream Type	Sensitivity to Disturbance [a]	Recovery Potential [b]	Sediment Supply [c]	Streambank Erosion Potential	Vegetation Influence [d]
A1	Very Low	Excellent	Very Low	Very Low	Negligible
A2	Very Low	Excellent	Very Low	Very Low	Negligible
A3	Very High	Very Poor	Very High	Very High	Negligible
A4	Extreme	Very Poor	Very High	Very High	Negligible
A5	Extreme	Very Poor	Very High	Very High	Negligible
A6	High	Poor	High	High	Negligible
B1	Very Low	Excellent	Very Low	Very Low	Negligible
B2	Very Low	Excellent	Very Low	Very Low	Negligible
B3	Low	Excellent	Low	Low	Moderate
B4	Moderate	Excellent	Moderate	Low	Moderate
B5	Moderate	Excellent	Moderate	Moderate	Moderate
B6	Moderate	Excellent	Moderate	Low	Moderate
C1	Low	Very Good	Very Low	Low	Moderate
C2	Low	Very Good	Low	Low	Moderate
C3	Moderate	Good	Moderate	Moderate	Very High
C4	Very High	Good	High	Very High	Very High
C5	Very High	Fair	Very High	Very High	Very High
C6	Very High	Good	High	High	Very High
D3	Very High	Poor	Very High	Very High	Moderate
D4	Very High	Poor	Very High	Very High	Moderate
D5	Very High	Poor	Very High	Very High	Moderate
D6	High	Poor	High	High	Moderate
DA4	Moderate	Good	Very Low	Low	Very High
DA5	Moderate	Good	Low	Low	Very High
DA6	Moderate	Good	Very Low	Very Low	Very High
E3	High	Good	Low	Moderate	Very High
E4	Very High	Good	Moderate	High	Very High
E5	Very High	Good	Moderate	High	Very High
E6	Very High	Good	Low	Moderate	Very High
F1	Low	Fair	Low	Moderate	Low
F2	Low	Fair	Moderate	Moderate	Low
F3	Moderate	Poor	Very High	Very High	Moderate
F4	Extreme	Poor	Very High	Very High	Moderate
F5	Very High	Poor	Very High	Very High	Moderate
F6	Very High	Fair	High	Very High	Moderate
G1	Low	Good	Low	Low	Low
G2	Moderate	Fair	Moderate	Moderate	Low
G3	Very High	Poor	Very High	Very High	High
G4	Extreme	Very Poor	Very High	Very High	High
G5	Extreme	Very Poor	Very High	Very High	High
G6	Very High	Poor	High	High	High

[a] Includes increases in streamflow magnitude and timing and/or sediment increases.
[b] Assumes natural recovery once cause of instability is corrected.
[c] Includes suspended and bedload from channel derived sources and/or from stream adjacent slopes.
[d] Vegetation that influences width/depth ratio-stability.

Appendix III

Appendix III. MN DNR Stream Habitat Program Resources Sheets.
http://www.dnr.state.mn.us/eco/streamhab/about.html



Resource Sheet 2: The Value and Use of Vegetation

Why is vegetation so important?

Naturally vegetated stream banks, riparian zones, and floodplains are crucial to streambank and channel stability, stream condition and function, water quality, and overall ecosystem health. Healthy streams provide, among many things, clean drinking water and a diversity of fish. The loss and degradation of native riparian vegetation through human activities is a common cause of streambank erosion and failure. These activities include cultivation, deforestation, watershed development, livestock overgrazing, herbicide application, and streambank armoring.

The most simple, inexpensive, and valuable form of streambank stabilization is the preservation and restoration of native riparian and floodplain vegetation. Vegetation, in addition to natural materials and structures, are rudiments of the natural channel design approach that naturally stabilize and protect streambanks. Larger materials such as logs and root wads provide strength and structure and gradually decompose giving streambanks time to re-vegetate and stabilize. For channels to be stable over the long term they need the flexibility to slowly shift with time, which is what native vegetation provides.

The benefits of streambank vegetation

Riparian zones, or buffers, along the banks naturally consist of deep-rooting, flood-tolerant plants and trees that provide multiple benefits:

Streambank stabilization

- Native riparian vegetation has dense, deep, intertwined root systems that physically strengthen soils.
- Riparian root systems remove excess moisture from the soil, making banks more resistant to erosion or slumping.
- Exposed root systems provide roughness that dissipates the water's erosive energy along the banks while the plant stems and leaves provide roughness during flood flows.

Water quality protection

- Vegetated buffers intercept and filter out much of the overland flow of water, nutrients, sediment, and pollutants; accordingly, wider corridors are more effective at protecting water quality and promoting ground-water recharge.

Riparian habitat benefits

- Diverse riparian vegetation provides shade, shelter, leafy or woody debris, and other nutrients needed by fish and other aquatic organisms.
- Wide, continuous, vegetated floodplains help dissipate flood flows, provide storage for floodwaters, retain sediment and nutrients, and provide shelter, forage, and migration corridors for wildlife.

Natural channel design fundamentals

Restoring and conserving native vegetation in the riparian zone and throughout the floodplain and meander belt is fundamental to bank stability and stream health because of the many benefits provided (see text box above). In situations where erosion is not severe and the grade is not too steep, restoring vegetation may be the only step required. In cases where erosion is more severe (e.g. cutbanks, incised channel), re-vegetation remains an essential component of a restoration involving more complex methods and structures, which are explained in following resource sheets.

Prior to planting native vegetation, non-native and nuisance species must be completely removed and the bank may need to be re-graded if the bank slope is too steep or unstable. Re-vegetation techniques include planting seeds, seedlings/saplings, live cuttings, and shrubs and hydroseeding. Live cuttings are branches cut from readily sprouting tree species, such as black willow or dogwood, preferably from nearby vegetation that is adapted to the site. These species will grow and root quickly, thereby providing immediate soil strength and erosion protection. The seeds, plants, disturbed soil, and bank toe should be protected from runoff and stream flow during the rooting process. Such erosion control products and methods are described next.

Disadvantages of hard armoring

Hard armoring banks with rock (riprap), timber walls, sheet piling, or waste concrete (which is not allowed) is a common bank protection approach; however, there are many disadvantages and undesirable impacts.

- Hard armored banks transfer the problem downstream by strengthening and redirecting stream flows downstream of the armor and into the next bend or meander resulting in bank erosion and failure, particularly along downstream bend(s).
- From an ecological standpoint, armoring does not provide aquatic or terrestrial habitat (shade, shelter, food) and has no ability to filter or process nutrients and sediments, which negatively impacts stream health.
- Armored banks can negatively affect long-term stability because they lock the channel into place preventing it from adjusting to changes in the watershed.
- Lastly, riprap is expensive to install and looks unnatural.

Resource Sheet 2: The Value and Use of Vegetation

In choosing suitable native plant species, consider local habitat type (e.g. forest, prairie, wetland) and habitat components such as shade, soil type, moisture, and climate. Resources available to identify plant species suitable for various habitat types and desired purposes, such as erosion control, aesthetics, and wildlife habitat include: local nurseries, extension offices, soil and water conservation districts, the "Restore Your Shore" CD-ROM (info at http://mndnr.gov/restoreyourshore) and MN DNR website http://mndnr.gov/gardens/nativeplants. Vegetative stabilization has all the benefits of restoring native vegetation (strengthen and stabilize stream banks, runoff buffer, provide habitat, aesthetic value) in addition to low cost, low maintenance, lack of structural complexity, and endurance. Below is a list of plant species native to Minnesota that are recommended for streambank restorations.

Common name	Scientific name	Life form	Habitat
Blue vervain	*Verbena hastata*	F	W, UM
Canada anemone	*Anemone canadensis*	F	W, UM
Golden alexanders	*Zizia aurea*	F	W, UM
Grass-leaved goldenrod	*Euthamia graminifolia*	F	W, UM
Monkey flower	*Mimulus ringens*	F	W
Obedient plant	*Physostegia virginiana*	F	W, UM
Swamp milkweed	*Asclepias incarnata*	F	W, UM
Fowl manna grass	*Glyceria striata*	G	W
Fox sedge	*Carex vulpinoidea*	G	W, UM
Hardstem bulrush	*Scirpus acutus*	G	A, W
Porcupine sedge	*Carex hystericina*	G	W
River bulrush	*Scirpus fluviatilis*	G	A, W
Softstem bulrush	*Scirpus validus*	G	A, W
Tall manna grass	*Glyceria grandis*	G	W
Virginia wild-rye	*Elymus virginicus*	G	W
Basswood	*Tilia americana*	T	UM, UD
Black willow	*Salix nigra*	T	W
Red-osier dogwood	*Cornus sericea (stolonifera)*	T	W, UM, UD
Silver maple	*Acer saccharinum*	T	W, UM

Native Minnesota plant species recommended for stream bank restorations throughout the state (sorted by Life form then Common name).
***F**: forb (flower)*   ***G**: grass or grass-like*   ***T**: woody vegetation*
***A**: aquatic*   ***W**: wet/transitional*   ***UM**: upland moist*   ***UD**: upland dry*

Natural materials and structures

Natural materials and structures can be used in addition to native vegetation to:

- ☆ protect seed & plantings from overland and stream flows,
- ☆ protect the toe of the streambank,
- ☆ prevent erosion on slopes,
- ☆ promote trapping of sediment,
- ☆ quickly develop dense roots and sprouts, & provide habitat.

The following six techniques are effective on small to medium streams. They are of moderate cost and can be installed by most landowners with a bit of direction. Landowners should consult an area hydrologist as project approval or a permit is required by the DNR and other agencies.

Biodegradable erosion control blankets (ECBs)

» Biodegradable ECBs are made of: jute (a vegetable fiber) mesh (*in photo*), coconut/coir fiber, straw, or excelsior (fine wood fiber) that are woven into a fiber matrix. ECBs are designed to temporarily provide erosion protection and assist with vegetation establishment as they degrade over 1-3 years leaving a vegetated bank. Products with polypropylene materials are not recommended because they do not degrade and can entangle wildlife in the rigid knitting.

× ECBs are placed over re-graded and re-seeded streambanks (use more durable netting for steeper banks). Wood stakes or live cuttings are used to secure the fabric in place (instead of metal anchor pins). Blankets should be installed promptly after the restoration to provide immediate erosion protection.

Resource Sheet 2: The Value and Use of Vegetation

Broadcast seeding and hydroseeding

» Broadcast seeding is the scattering of native seed mixes by hand or mechanically over prepared soil. Good seed to soil contact, protection (ECBs, mulch, oats or rye as a cover crop), and watering are important.

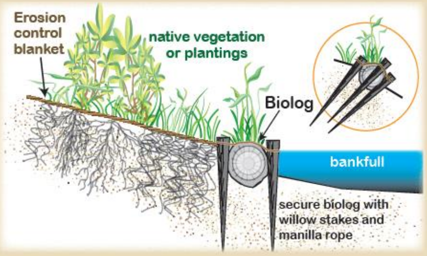
» Hydroseeding is a planting process that uses a mixture of water, seed, fertilizer, mulch, and tackifiers that is sprayed over renovated banks or slopes. Native seeds that are suitable to the habitat should be used in the mix. This mixture can be applied to the upper slopes, even on steeper slopes. The mixture should not be applied too close to the channel to avoid fertilizer from polluting the stream or seed from being washed away.

Staking and live cuttings

» Stakes and live cuttings from readily sprouting, local, healthy tree species such as black willow, dogwood, and alder are used to quickly vegetate restored streambanks. Staking can be applied on all types of banks and in addition to other techniques.

× The cuttings or stakes (branch sections without twigs or leaves) are cut and planted while dormant, late fall through early spring. Stakes are 2'+ in length and ½ - 3" in diameter with one end cut at a 45° angle. Stakes are planted 1 - 2' deep in soft soils or into a pilot hole in harder soils ensuring the stake is deep enough to reach permanently wet soils. Stakes are planted 1 - 2' apart depending on the size of the stakes to ensure successful survival and sufficient cover.

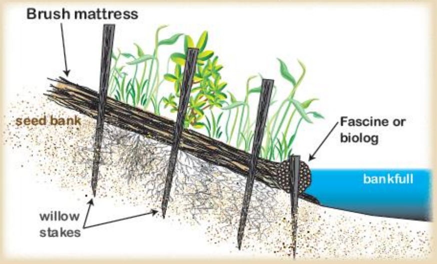
Biologs, coir fiber rolls, wattles, fascines



» Biologs and coir fiber rolls are made of coconut fiber, straw, or excelsior fiber. Wattles and fascines are cylindrical bundles of wheat or rice straw or cuttings. They are strong, flexible rolls (8-10' long, 8-12" diameter) of biodegradable material used to protect the toe of banks and to stabilize slopes . These structures work best where scour is not too severe and where flows will infrequently flow over the toe protection.

× The logs, rolls, or bundles are staked and tied into a shallow trench along the toe of the streambank to deflect flows and wave energy, retain sediment, and provide a stable structure for plant growth (substrate). Native vegetation is planted on and around the structures, then as the vegetation or cuttings becomes established, the natural materials will degrade in 2 to 6 years leaving a vegetated bank.

× Additional rows can be installed (placed in shallow trenches secured by wood stakes) upslope parallel to the toe of the bank for additional bank stabilization.

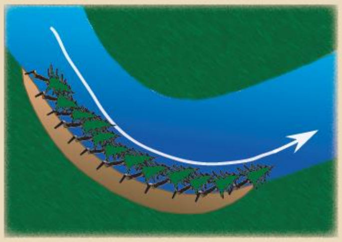


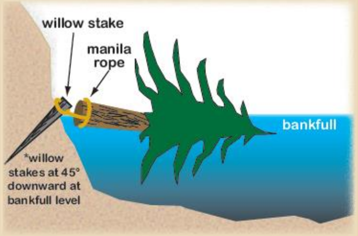
Brush mattresses

» Brush mattresses consist of a layer of interlaced dormant cuttings (e.g. willow, dogwood, alder) that are laid perpendicular to the toe and staked over a gently sloped streambank, often with a fascine or biolog at the base as toe protection.

× These structures work on most banks. They require good soil contact to support brush growth; base flows to keep the basal ends of the cuttings moist; and installation during the non-growing season, preferably early spring.

Tree revetments





» Tree revetments involve anchoring coniferous (such as Christmas trees) or hardwood trees along an outside bend where erosion is excessive.

× The trees are tied by the trunks with natural filament rope to wooden stakes placed at the bankfull level with the treetops pointing downstream. Tree revetments dissipate outside meander flows and collect sediment, thereby reducing erosion and promoting deposition.

× Tree revetments work best in small to medium streams with high sand or gravel loads because sediment deposition is important to the long-range goal of rebuilding and protecting the bank.

➪ These structures provide habitat and as they degrade and accumulate sediment they become a natural, structural part of the bank.

Resource Sheet 2: The Value and Use of Vegetation

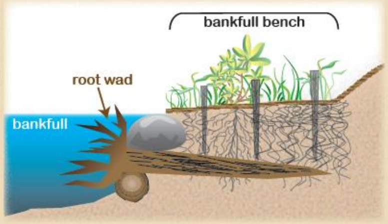
Root wad revetments

» Root wad revetments are more complex structures built into exposed cutbanks where erosion is actively cutting away the bank. These revetments commonly involve the construction of a bankfull bench to help accommodate and dissipate flood flows. This design is especially useful where there is infrastructure on the bank that needs to be protected from bank loss or slumping. These revetments can be scaled to the size of the stream (e.g., root wads can be stacked in large streams). They are not recommended in sandy soils where it is difficult to drive the trunks into the bank and the sand is more erodible.

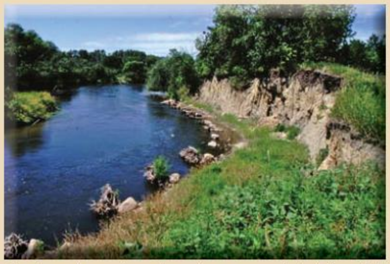
× Large tree trunks with root wads are driven into a renovated cutbank so that the trunks angle upstream and the root wads are positioned below bankfull level directed into the flow. The trunks are secured with large boulders and a matrix of logs. Live cuttings are staked, natural vegetation planted or seeded, and erosion control fabric is staked on the bankfull bench and restored bank.

⇨These revetments protect the banks over a range of flows, provide substrate for invertebrates and refuge for fish, and will slowly degrade while becoming a natural part of the streambank.

**Variations of this design have been used through the years. For more specific design details see Applied River Morphology by Dave Rosgen, 1996.*

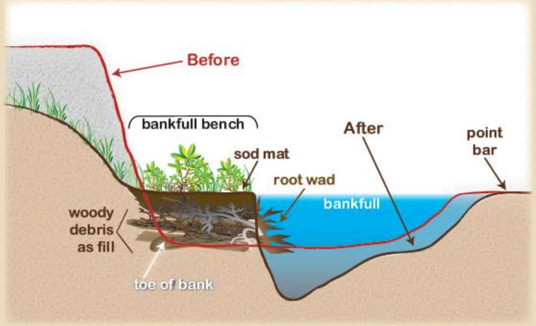


Installation of root wads using an excavator to drive tree trunks into the bankfull bench (looking upstream).



Root wad revetment and a revegetated bankfull bench built to stabilize a cutbank encroaching on Interstate 94, two years after construction (looking downstream).

Toe wood-sod mats *(see fact sheet for more details)*



» Toe wood-sod mats involve similar design elements to the root wad revetments. This approach can be scaled to all stream sizes.

× Cutbanks are renovated with a bankfull bench consisting of layers of logs, branches, brush, roots, and fill. Root wads can be incorporated to provide additional roughness and habitat. These layers are then covered with sod mats, willow cuttings, and transplants set at bankfull stage.

⇨ This structure design restores the connection to the floodplain with a bankfull shelf, restores channel dimensions, protects a once vulnerable and unstable cutbank, provides habitat (both aquatic and terrestrial), and is relatively inexpensive.

**Variations of this design have been used through the years. General design details are credited to Dave Rosgen of Wildland Hydrology.*

Review and advanced restoration designs

Bank restorations utilizing vegetation, erosion-control blankets, biologs, wattles, revetments, and mats or combinations thereof, can effectively protect and rebuild banks if properly placed and established. These approaches utilize all natural materials that do not artificially confine the channel, they are relatively inexpensive, and can be applied to all stream varieties (forested, prairie, steep, gentle, rocky, sandy). As explained in Resource Sheet #1, the cause(s) of stream instability and future watershed conditions should be considered. Most projects will need permits and professional assistance.

In some cases in-channel structures can also be used to protect restored or unstable banks. These include rock structures such as rock vanes, J-hooks, and riffles that are effective at properly slowing and deflecting flows from the streambanks. Installation of these structures requires professional assistance because proper placement is absolutely essential for successful streambank protection and restoration. This requires stream and watershed monitoring and assessments. These in-channel structures are explained in more detail in the following resource sheets.

Contact Information

DNR Ecological Resources:
Stream Habitat Program
Ecosystem Restoration
500 Lafayette Road, Box 25
St. Paul, MN 55155
(651) 259-5900

DNR Waters:
Public Water Permit Requirements
500 Lafayette Road, Box 32
St. Paul, MN 55155
(651) 259-5700

DNR website:
http://mndnr.gov

Appendix IV

Appendix IV. Various stream type succession scenarios representing actual rivers (Rosgen 2006).

Figure 11–15 Various stream type succession scenarios