Crow Wing River Watershed Stressor Identification Report

Determination of stress factors affecting aquatic biological communities

Minnesota Pollution Control Agency

April 2014

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Acronyms, abbreviations, and term definitions

AUID - Assessment Unit (Identification Number) MPCA's a pre-determined stream segments used as units for stream/river assessment – each has a unique number.
CALM - Consolidated Assessment and Listing Methodology - The protocol used in MPCA's assessment of designated use attainment for surface waters.
CR - County Road
CRP - Conservation Reserve Program
CSAH - County State Aid Highway
CWRW - Crow Wing River Watershed
DO - Dissolved Oxygen
DS - Downstream
GIS - Geographic Information System
HUC - Hydrologic Unit Code (a multi-level coding system of the US Geological Survey, with levels corresponding to scales of geographic region size)
IBI - Index of Biological Integrity – a multi-metric index used to score the condition of a biological community
IWM - MPCA's Intensive Watershed Monitoring, which includes chemistry, habitat, and biological sampling.
LWH/LWD - Large Wood Habitat or Large Woody Debris
m - The abbreviation for meter
mg - Milligrams per liter
µg/L - Micrograms per liter (1 milligram = 1000 micrograms)
Macrophyte - Macro (= large), phyte (= plant) - These are the large aquatic plants, such as Elodea and Coontail.
MDNR - Minnesota Department of Natural Resources
MSHA - Minnesota Stream Habitat Assessment
M&A Report - MPCA Monitoring and Assessment Report for the Crow Wing River Watershed
MS4 - Municipal Stormwater Plan, Level 4
NPDES - National Pollutant Discharge Elimination System
Natural background - an amount of a water chemistry parameter coming from natural sources, or a situation caused by natural factors
N:P - Nitrogen to Phosphorus Ratio
OP - Orthophosphorus (a form of phosphorus that is soluble)
OHW - Ordinary High Water lake level – a surveyed elevation
PJG - Professional Judgment Group – a multi-agency staff group which met to verify assessments
SID - Stressor Identification – The process of determining the factors (stressors) responsible for causing a reduction in the health of aquatic biological communities.
Sonde - A deployable, continuous-recording water quality instrument that collects temperature, pH, DO, and conductivity data and stores the values which can be transferred to a computer for analysis.
TALU - Tiered Aquatic Life Uses, a new process of setting standards for different categories of streams. MPCA plans to implement this approach around 2015.
Taxa - Plural form - refers to types of organisms; singular is taxon, may refer to any level of the classification hierarchy (species, genus, family, order, etc.). In order to understand the usage, one needs to know the level of biological classification being spoken of. For MPCA fish analyses, taxa/taxon usually refers to the species level, whereas for macroinvertebrates, it usually refers to genus level.
TP - Total Phosphorus (measurement of all forms of phosphorus combined)
US - Upstream
EPA - U. S. Environmental Protection Agency

WMA - Wildlife Management Area (owned by MDNR)
WRAPS - Major Watershed Restoration and Protection Strategy, with watershed at the 8-digit Hydrological Unit Code scale.
1X - One time (chemistry samples collected on 1 date)
10X - Ten times (chemistry samples collected on 10 dates)
2X - Two times (chemistry samples collected on 2 dates)
303(d) list - The official EPA-accepted list of impaired waters of the state.

Executive summary

This report documents the efforts that were taken to identify the causes, and to some degree the sources of those causes, of the impairments to aquatic biological communities in the Crow Wing River Watershed (CWRW). Much information on the Stressor Identification (SID) process can be found on the U.S. Environmental Protection Agency (EPA) website http://www.epa.gov/caddis/.

The CWRW is situated along a line of landscape transition between the mostly forested north central and northeastern parts of the state, and the mostly agricultural western areas. As such, it contains a blend of land uses. The agriculture is primarily livestock-oriented, as the soils in the CWRW are very sandy and do not produce a significant crop without irrigation. Pastures are typically large, and most non-pastured open uplands are used for hay production. There are two locations in the northern part of the watershed that have dense irrigation systems and grow corn, potatoes, and soybeans. There are large tracts of managed forest, owned by a large forest products company, and forest harvest is common. These tracts typically are kept in forest cover. There are several broadly scattered smaller towns in the watershed, with the largest being the city of Park Rapids. With these landscape attributes, the primary anthropogenic stressors in the CWRW are most likely to be from livestock agriculture, and in a few areas, the more intensive row crop agriculture. Forest harvest may have some influence on hydrologic patterns, and the original, wide-ranging clearcutting of the virgin pine forests here may have some legacy effect on stream channels and habitat; however, these forestry influences, particularly the historic ones, are hard to determine. Stressors associated with denser human communities (e.g., stormwater runoff, impervious surfaces, wastewater discharges) are not likely to play a significant role in this watershed. One stressor that can occur anywhere roads are present is barriers to fish migration caused by the structures used to place a road over a stream. Culverts in particular are fairly commonly found to be at least partial barriers to fish passage.

A very important natural feature of the landscape is its geological setting, which here was highly influenced by historic glacial activity. A long terminal moraine (an elevated ridge of glacial debris) forms the eastern boundary of the watershed, and a large drumlin field lies across the center of the watershed. Both of these features play a significant role in the hydrologic flow paths in the CWRW, especially the groundwater component of those paths. The sandy soil also provides for the development of a significant surficial aquifer (the Pineland Sands Aquifer), and in many parts of the watershed, the water table is within a foot or two of the ground surface. These areas of lower topographical elevation have formed extensive sedge meadows with a surficial layer of peat soil, and typically occur in the riparian corridor of CWRW streams. Spring seeps in these wet areas are extremely common, and most of the smaller streams have cool water as a result of this groundwater input. The shallow groundwater moves through these peatlands and into the streams, and thus these organic soil areas can have significant influence on stream water chemistry.

The common factors causing stress to or limiting the biological communities in the CWRW are first and foremost, low dissolved oxygen (DO) and secondly the finding of elevated phosphorus concentrations, which are not problematic in themselves, but which can lead to excess plant growth and resulting loss of DO if certain other conditions are present. The challenge here has been to determine if these findings are due to natural sources, or whether they are at least partially due to human activities. Habitat is another factor that seems to be limiting the biological communities in a number of streams. This is a natural factor here related to the extremely sandy conditions and lack of both rock substrate and large wood, both of which create important habitat diversity in stream channels, and which many species require. Some of the biologically-impaired streams also have high levels of iron, about two times the concentration of the EPA's recommended aquatic life use standard. This may be an additional natural factor limiting the biological community in some of the CWRW streams.

Initially, eight streams were brought into the SID process because they were determined to have substandard biological communities via the 2010 Intensive Watershed Monitoring and Assessment phase of this Watershed Restoration and Protection Strategy (WRAPS) project. Upon review of the data collected during the SID process and detailed review of the landscape, some of these streams appeared to have natural landscape factors that were causing the substandard biological communities. These cases were brought before a Minnesota Pollution Control Agency (MPCA) committee designated to consider additional, post-assessment data for judgments regarding the degree of natural and/or anthropogenic factors responsible for the substandard biological conditions. Situations deemed to be due to natural factors are placed in a different impairment category and not given rehabilitation attention. The SID process resulted in changes to the assessment decision for some of the eight investigated streams. The sites listed below are shown on Figure 1.

One stream was determined to have limited biological condition due to natural factors.

- **Bender Creek** (AUID 07010106-691) - Low DO due to heavy wetland influence, coupled with a high level of beaver activity (dam building) causing potential migration barriers for fish.

One stream that was first determined to be impaired by natural factors is now assessed as "insufficient information" due to late-breaking information that Minnesota Department Natural Resources (MDNR) has previously managed water levels in the reach for wild rice production, which may have influenced the channel habitat. MDNR physically excavated within the channel in 2012 to remove sediment deposition and remove an earthen dam.

- **Unnamed tributary to Shell River** (AUID 07010106-553) - Low DO due to heavy wetland influence, though area managed as a wild rice/waterfowl production area.

Two streams are still undetermined as to the stressor. New data from 2013 will be presented to appropriate MPCA committees for a determination of impairment status.

- **Unnamed tributary to the Crow Wing River** (AUID 07010106-687) - One set of culverts appears to be a barrier to site 10UM103, yet locations downstream of this site also showed sparse numbers of fish. As of the publishing date of this report, the stream is in the impairment class 4E, possibly anthropogenically impaired.
- **Tower Creek** (AUID 07010106-528) - This stream is undergoing continuing study to gain further insight into the high phosphorus concentrations and low DO found in the stream. This situation is curious because other evidence of eutrophication is not present; there is no abundant algae and macrophyte growth, and concentrations of nitrogen-based nutrients (nitrate and ammonia) are extremely low. Dissolved oxygen levels also do not have the strong daily fluctuation typical of streams undergoing eutrophication. This stream is currently listed as impaired, though it will probably undergo another natural background review in late 2014, utilizing additional data.

Three streams are considered anthropogenically impaired.

- **Upper Shell River** (AUID 07010106-537) - Numerous culvert road crossings are at least partial barriers to fish migration. The river also lacks diverse habitat, such that even if barriers are corrected, a fish community meeting the scoring threshold may not develop. The near-absence of these important habitat features can be explained by natural landscape factors. This Assessment Unit Identification Number (AUID) is in impairment category 4C, meaning a non-Total Maximum Daily Load (TMDL) solution is needed.
- **Swan Creek** (AUID 07010106-527) - This AUID shows both impaired and excellent biological communities, depending on location. Thus, there are not systemic stressors acting on the stream. The anthropogenic factors affecting the channel and habitat can be explained by local land use related to livestock production. Local, non-TMDL solutions can likely solve these issues.

- **Farnham Creek** (AUID 07010106-522) - This creek is extensively channelized. It also experiences the same chemistry phenomena as Tower Creek. Because channelized streams will have lower scoring thresholds for meeting their use support, this stream will await that threshold determination before rehabilitation is attempted. This stream is for much of its length a designated coldwater (trout) stream. Because of that special status, a reconnection to its original sinuous channel may be justified. That would likely need to be a MDNR decision.

Lastly, one stream was determined to have been sampled at a location that ended up being quite anomalous with regard to habitat compared to the general character of the whole AUID.

- **Indian Creek** (AUID 07010106-569) - The impairment of the fish community was reversed because the rocky substrate at the sample reach was not representative of the whole AUID and thus the fish community may not have been appropriately represented in this sample. The AUID is currently assessed as supporting its aquatic life use.

The intensive watershed monitoring (IWM) and assessment, and SID phases of the WRAPS have allowed for a much better understanding of the condition of the aquatic biological communities and the fairly unique hydrologic characteristics of the CWRW. Some of these characteristics are not fully understood at this point. It is hoped that in the intervening period between now and the next CWRW IWM effort (in 2020), some additional time can be spent to continue to understand the interactions of some of the interesting landscape factors and the water resources of the CWRW. One example is that with the new resources given to MDNR to monitor groundwater more extensively, there will likely be a better understanding of the groundwater dynamics of the area, and the groundwater/surface water interactions within the CWRW.

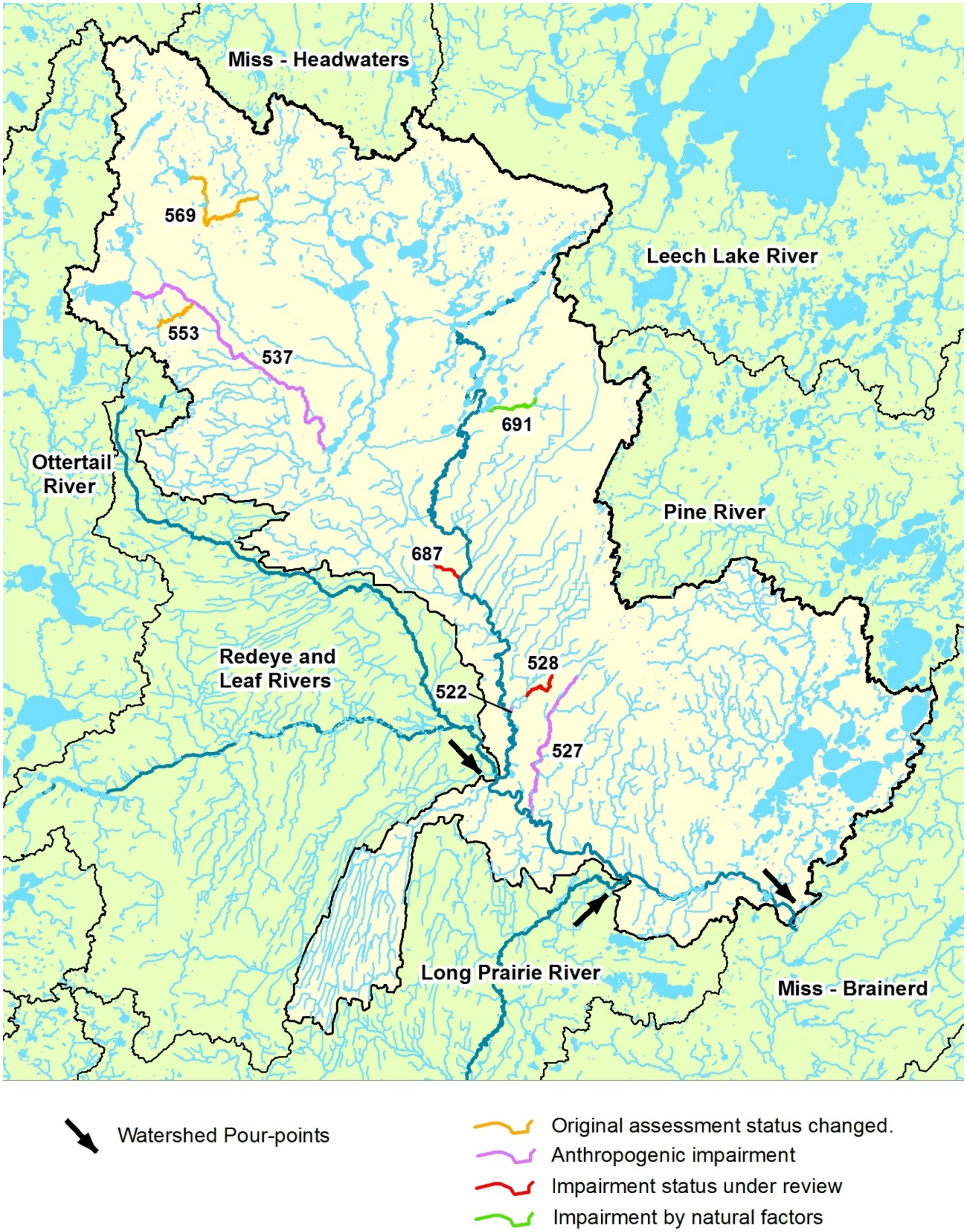


Figure 1. Stream reaches discussed in this report. Label numbers are the last three digits of the AUID number.

Introduction

The Minnesota Pollution Control Agency (MPCA), as a continuation of its past water quality programs, and in special response to the Clean Water Legacy Act, has developed a strategy for improving water quality of the streams, rivers, wetlands, and lakes in Minnesota's 81 Major Watersheds, each known as Watershed Restoration and Protection Strategy (WRAPS). This document reports on the second step of the multi-part WRAPS for the Crow Wing River Watershed (CWRW), located in the Upper Mississippi River Basin. This report builds on the first step of the WRAPS, the biological and chemical monitoring and assessment of the CWRW's streams and rivers, also conducted by the MPCA with assistance from other state and local government agencies.

The purpose of this second step of the WRAPS, stressor identification, is to find and evaluate factors, either natural or anthropogenic, which are likely responsible for the impaired condition of the fish and/or macroinvertebrate communities, as found in the monitoring and assessment study. An important first step in the identification of potential stressors is to understand the natural features and processes occurring in the watershed, as well as gaining an understanding of the extent of various human activities going on in the watershed that have potential to degrade water resources.

The watershed

The CWRW is located in north central Minnesota, with its headwaters to the north and west of Park Rapids, and its confluence with the Mississippi River just southeast of Brainerd. The watershed contains many well-known water resources, including the lakes of the Akeley/Nevis area, those of the Park Rapids area, and the Brainerd Lakes area. One of Minnesota's best trout streams, the Straight River, runs near Park Rapids. The Crow Wing River itself provides a very large volume of water to the Mississippi River. Many other details and statistics about the watershed and its hydrological setting can be found on the MPCA's Crow Wing watershed webpage http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/crow-wing-river.html and in the Crow Wing River Watershed Monitoring and Assessment Report (MPCA, 2014). The watershed details that follow here are those that relate specifically to water resource quality and factors that have potential to degrade the stream and river quality of the region.

Important natural features

There are a number of landscape features within the CWRW that come into play in determining the water quality of its streams. One interesting and fairly unique feature of the watershed relates to the glacial history of the area. The eastern edge of the watershed, what is now the Foothills State Forest, is a major glacial end moraine, named the St. Croix Moraine. It is a north-south running hilly ridge, which is riddled with tiny lakes. This high ridge provides some of the groundwater-driven aspects of the watershed's hydrologic pathways. To the west of this moraine is another glacially-formed feature, an area known as a drumlin field, in particular the Wadena Drumlin Field. It is composed of a set of linear, parallel ridges, and here, they lie in a perpendicular direction to the St. Croix Moraine. These are particularly evident in the area east of Nimrod, and in the spur that is the Partridge River subwatershed, south of Highway 210 (Figure 2). These too add interesting groundwater/surface water interactions to the CWRW system. Between these parallel ridges lie parallel valleys which are covered by sedge meadows that contain stream channels (Photos 1 and 2). These valleys have very high water tables which keep their soils nearly saturated. This prevents woody plants from growing in these riparian areas, with the exception of willow shrubs and alders where there is a bit less saturation. These valley soils are completely organic (peat), formed by the centuries of slow decay of the sedge grasses. Based on descriptions by Boelter and Verry (1975), these wet meadows would be classified as fens, and also as minerotrophic (fed by high iron-content groundwater). The extensive riparian wetland (sedge meadow type) is a common landscape feature in north central Minnesota streams, but is much more extensive than in other areas of Minnesota (Figure 3). These landscape features play a significant role in the characteristics of the water found in much of the CWRW, especially the non-lake areas, and will be discussed more in following sections.

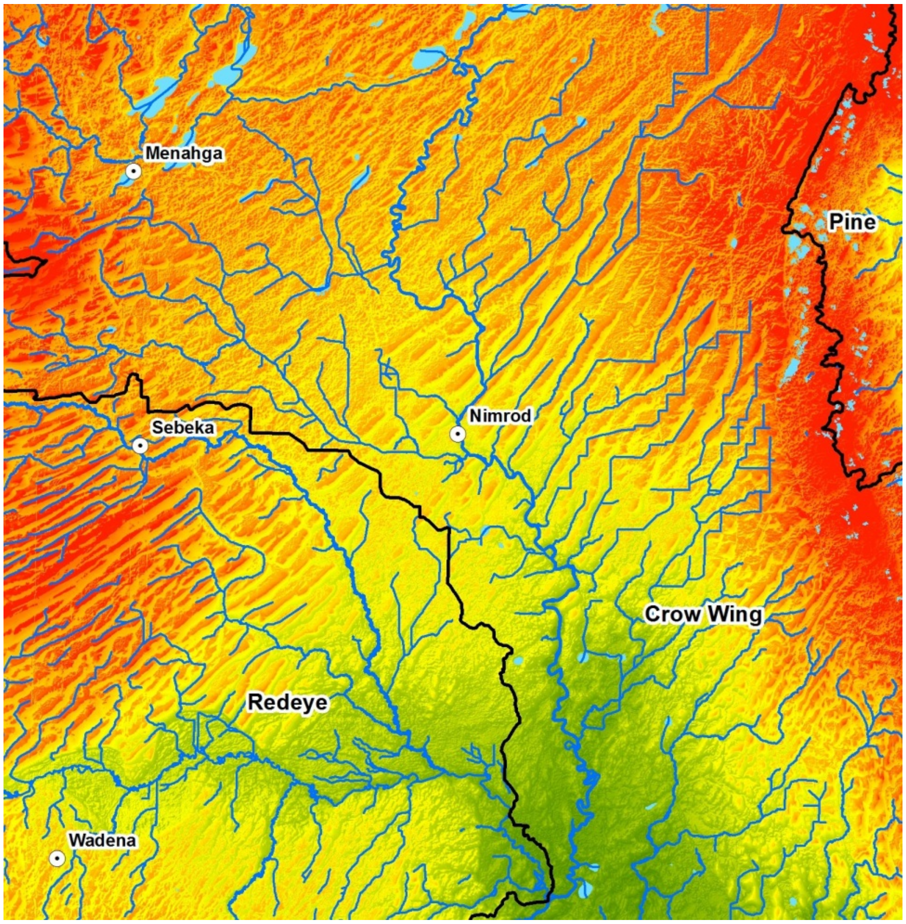


Figure 2. Glacial landscape features. Map shows the central portion of the CWRW, as well as parts of the Redeye and Pine watersheds. Colors show elevation, with red being high and green low. Note the northeast to southwest oriented ridges, which are the drumlins. Also, the St. Croix Moraine can be seen as the wide, dark red ridge running north-south on the right side of the image. This forms the boundary between the Crow Wing River and Pine River watersheds, and is the headwaters area for many Crow Wing River tributaries.

Another important natural feature related to the region's glacial history is the watershed's surficial geology. An easily-seen dominant aspect of this geology is the very sandy soils that cover much of the watershed. These areas are outwash plains formed when the glaciers melted, and the sands can be tens of feet deep, with no or little gravel contained within the sand. The Natural Resources Conservation Service (NRCS) has created a map of the surficial geology regions of the state called Major Land Resource Areas (MLRA). The CWRW contains parts of two of these MLRA units, the Northern Minnesota Gray Drift and the Central Minnesota Sandy Outwash. The boundaries of these areas within the watershed are shown in Figure 7 of the CWRW Monitoring and Assessment Report. The Northern Minnesota Gray Drift is somewhat hilly terrain, with some coarse material such as gravel, cobble and boulders. The NRCS description of this area states: "The Central Minnesota Sandy Outwash MLRA is more level with less gradient changes. This region also is comprised of many areas of poorly drained organic soils which are conducive to anaerobic (low oxygen) soil conditions." These organic soils are sedge peat, and these areas are very common along the riparian corridors of the area's streams, which will be addressed later as an important factor in some of the observed water quality measurements.

Yet another feature associated with the region's glacial history and surficial geology is the extensive surficial groundwater aquifer lying beneath much of the CWRW, named the Pineland Sands Aquifer (Figure 4). Only the southeast corner of the CWRW and the Partridge River spur are not underlain by this aquifer. Nice maps and discussion of this aquifer are provided in Reppe (2005). This aquifer has a shallow water table that feeds the surficial waters in much of the CWRW. Spring seeps are extensive within low-lying areas of the topography and often emerge within sedge meadows and along stream borders (Photo 3). An area of high iron-content shallow groundwater is found along the whole length of the western side the Pineland Sands Aquifer (and also the CWRW) in an arcing band from the Staples/Motley area all the way north to near the town of Ponsford (Figure 6). The streams on the west side of the Crow Wing River in the central part of the CWRW show high iron content in their waters and become a turbid orange color in mid-summer, due to these high levels of iron (Photo 4). This will be elaborated on further along in this report. In order to put the nutrient (phosphorus and nitrogen) chemistry data into context, it is important to know what is naturally typical within a given area.

Photo 1. Blueberry River at Cty Highway 16 (384th St.)

Photo 2. Iron Creek at 79th Ave SW

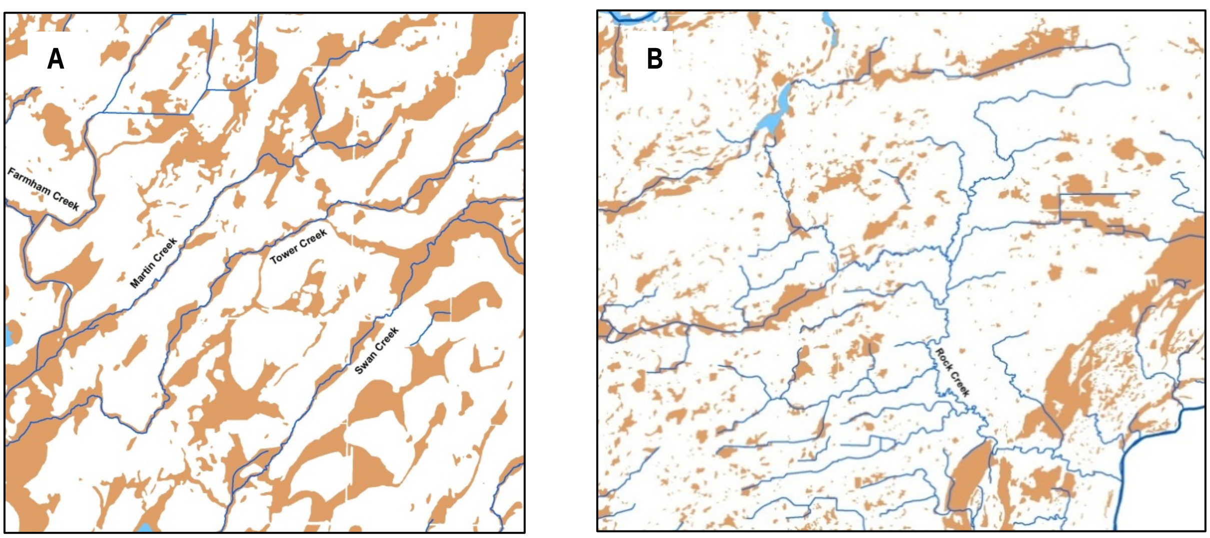


Figure 3. A contrast of the landscape-scale wetland/stream linkages in the CWRW with another northern Minnesota watershed. Orange areas are wetland soils. A. Several Creeks in the Central CWRW showing how wetland areas are connected, and are directly associated with stream channels. B. The Rock Creek watershed in the upper St. Croix Basin, Pine County. Many of the wetlands here are isolated, and the majority of the stream corridor is not wetland soil.

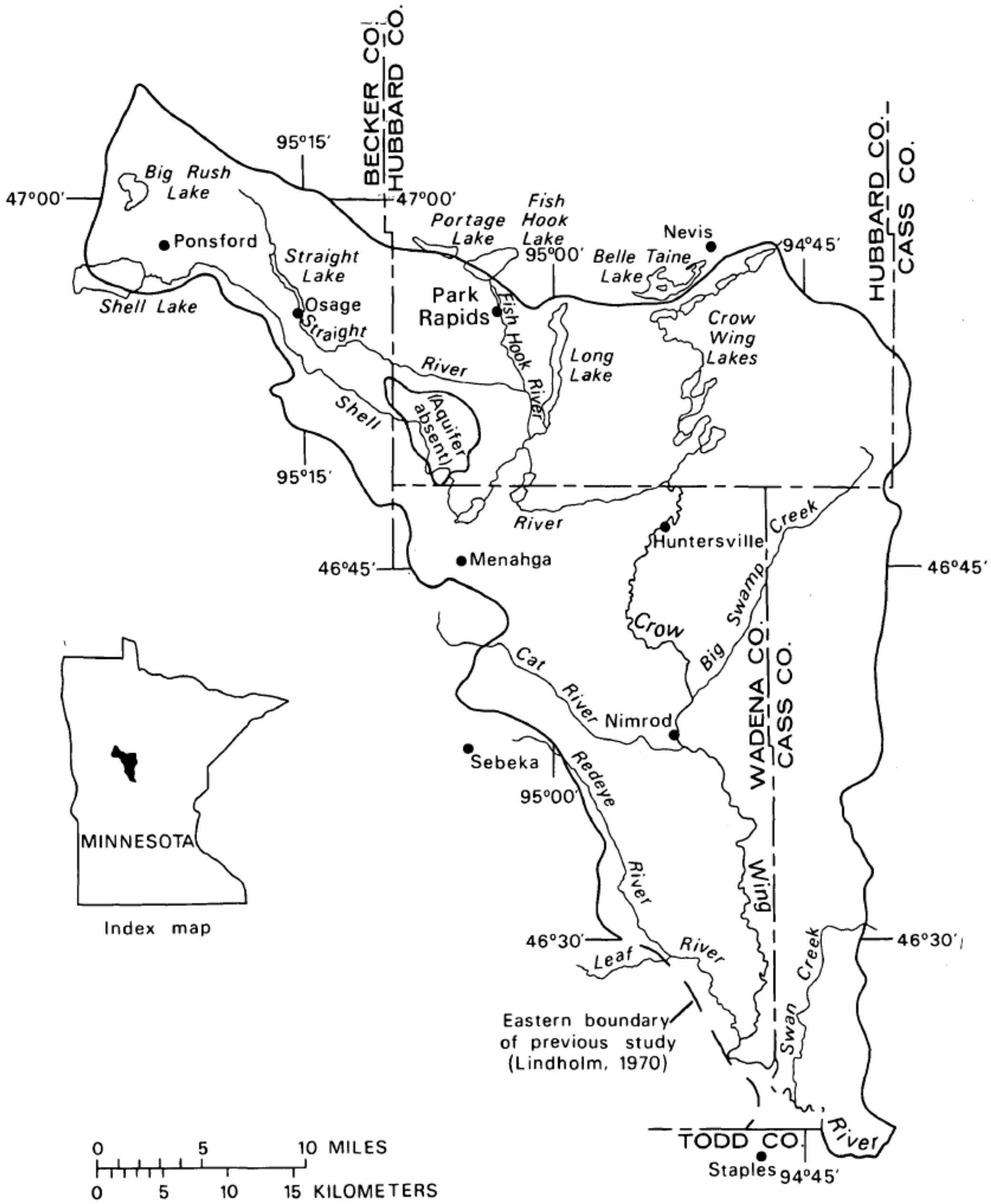


Figure 4. Pineland Sands Aquifer boundaries. The primary rivers within the aquifer area are the Fish Hook, Straight, Shell, and Crow Wing. The eastern border is formed by the St. Croix Moraine (a ridge that is now the Foothills State Forest). Map taken from USGS, 1977. A later map extends the northern border (Figure 5).

Expectations for river phosphorus concentrations, based on a number of landscape and climate factors, differ within the CWRW. The MPCA has developed nutrient regions geographically, and there are three; northern, central, and southern (MPCA [Heiskary, Bouchard, and Markus], 2013). The CWRW contains two of these, the northern and central (Figure 7). This situation adds yet another somewhat unique natural factor to this watershed and the analysis of its waters. The central part of the watershed will naturally have somewhat higher levels of phosphorus than the northwestern and southeastern parts of the watershed, which are within the North Nutrient Region. The draft standard for total phosphorus (TP) in the northern region is 0.050 mg/L, and in the Central Region, 0.100 mg/L.

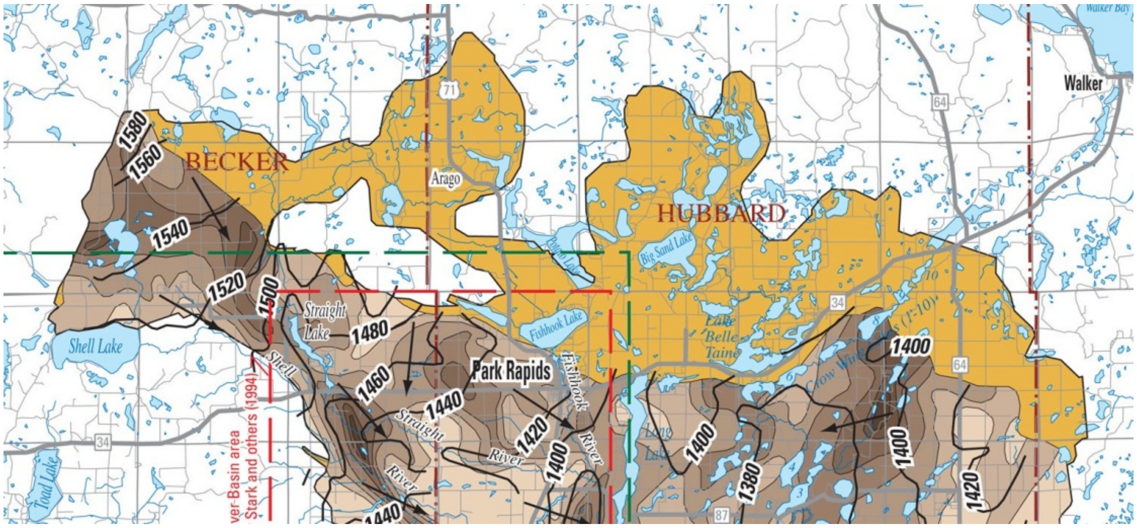


Figure 5. Northern extent of Pineland Sands Aquifer. The orange area is the extension onto the boundary shown in Figure 3. Map taken from Reppe (2005).

Photo 3. Farnham Creek groundwater seeps. The circled area shows shallow groundwater seeps emerging within the sedge meadow and entering Farnham Creek. Also note the orange color seen in many places along the channel due to iron inputs from groundwater.

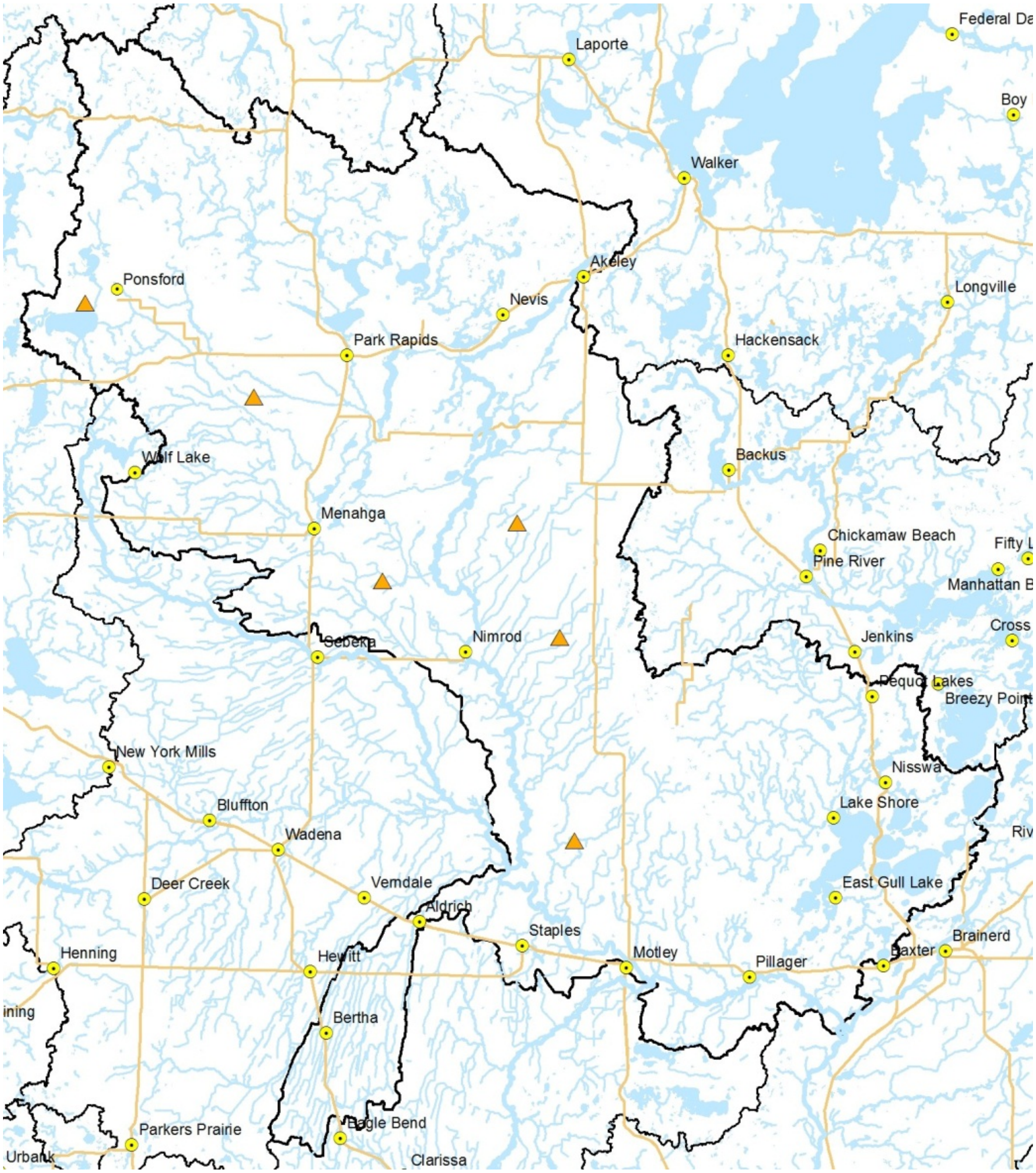


Figure 6. Map of the CWRW showing the six highest iron-content shallow wells (5.8 to 13.0 mg/L) found in the study by Helgeson (1977). Well locations are marked by orange triangles. The other 23 Pineland Sands Aquifer wells ranged between zero (below detection) to 3.3 mg/L iron, with 16 of those at < 1.0 mg/L.

Photo 4. Iron Creek, a tributary to Swan Creek, north of Staples, MN. The water is turbid orange from the high iron content. Note the oily sheen on the surface, which is commonly seen in these high-iron waters.

Figure 7. The CWRW and its nutrient regions

Minnesota Department of Natural Resources Watershed Health Assessment Framework

MDNR has created a new web-based tool called the Watershed Health Assessment Framework that can be useful in the early stages of the evaluation of possible stressor candidates in a major watershed. The framework provides an overall score at the 8-digit HUC scale, as well as numerous sub-scores relating to biology, hydrology, water quality, geomorphology, and connectivity. This tool gives the CWRW a score of 61 of 100. For a regional perspective, scores from adjacent 8-digit HUC watersheds can be compared to determine a watershed's health in relative terms. There are seven adjacent watersheds that border the CWRW. Of these seven, three score lower than the Crow Wing, and four score higher (Figure 8). The higher scoring watersheds are generally those north and east of the CWRW, while those scoring lower are generally to the south and west (the exception being the Redeye River Watershed). These scores likely reflect the regional change in land use, which transitions within the CWRW. To the east and north, lands are primarily forested (less altered), whereas to the south and west, the predominant land use is agricultural (more altered).

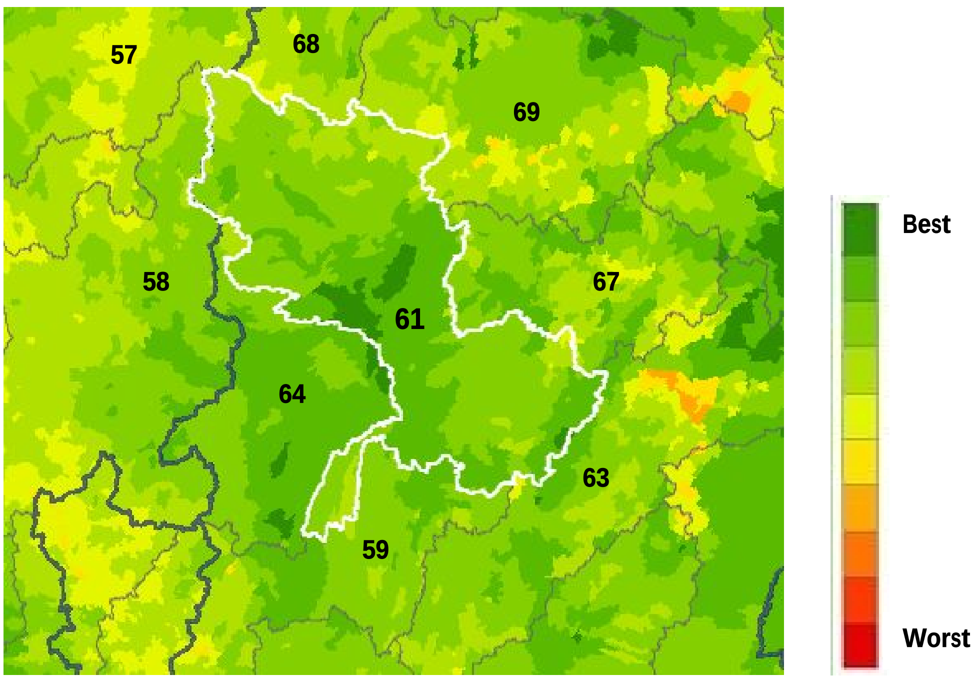


Figure 8. Overall watershed scores and soil erosion susceptibility in CWRW and surrounding watersheds. Note the CWRW has no yellow/orange areas (significant erosion potential), and has significant darker green areas (very little erosion potential).

Identification of aquatic stressors in the CWRW

Initial steps

Desktop analyses

The first step in determining stressors to streams on a broad scale is to become familiar with the natural landscape features and human activities occurring in the watershed. Previously, that would have required driving throughout the watershed, and while that is still a useful, valuable, and indeed necessary effort, new technologies allow one to learn much without leaving the office. An early evaluation of possible stressor candidates involved looking at aerial photography (of various ages) as well as a variety of Geographic Information System (GIS) layers that relate to potential stressors (e.g. National Pollutant Discharge Elimination System (NPDES) discharger locations, land use/cover types, agricultural crop information, proximity of various activities to stream channels), or other readily available data (e.g. demography statistics, soil type maps). Again, the MDNR Watershed Health Assessment Framework Tool is helpful here (Figure 9).

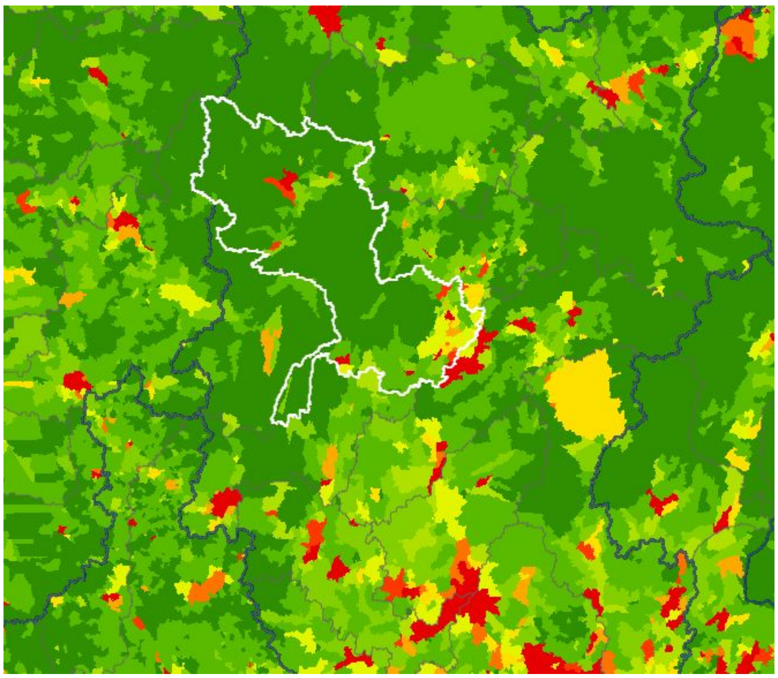


Figure 9. Impervious surface for Central MN, with CWRW outlined in white. A majority of the CWRW is dark green, meaning little impervious surface coverage. Relative to most other surrounding watersheds, there is less imperviousness in the CWRW. Color key is same as in Figure 8.

Land use/cover

Land use has consistently been shown to have significant influence on the quality of water resources (Allan *et al*., 1997, Allan *et al*., 2004, Schlosser, 1991). Therefore, an analysis of land use patterns can provide insight into areas that may warrant further investigation as candidate stressors of streams and lakes. This information can be obtained from aerial photography and numerous GIS layers that depict activity locations (e.g. industry discharge locations) and landscape features (e.g. soil types).

The CWRW contains a wide variety of land uses, perhaps more than the average Minnesota watershed. The watershed is situated along the state's east to west transition from forest to farmland, and so has areas of each of these land uses. Overall, rowcrop agriculture occurs in a few pockets; a corridor along the Straight River west of Park Rapids, a circular patch of about 27,500 acres just east of Long Lake (southeast of Park Rapids), and in the southwest spur of the CWRW - the Partridge River subwatershed. The first two of these regions have significant center-pivot irrigation, watering fields of potatoes and corn. Much of the previously-farmed land which isn't irrigated is or has recently been enrolled in the Conservation Reserve Program (CRP). The southern half of the watershed has significant pasture and/or hay field acreage, with occasional row crop plots. Forestry is also a significant activity in the CWRW, on private, corporate, county, and state lands. A large amount of land is held and managed by a forest products company.

The CWRW has significant acreage of state-owned lands (Figure 10). The largest amount is in State Forest, including the Badoura, Huntersville, Pillsbury, and Two Inlets, and significant parts of the Foot Hills, Paul Bunyan, Lyons, Smoky Hills, and White Earth. There are also numerous MDNR Wildlife Management Areas (WMA), including the Meadow Brook WMA at approximately 5,772 acres and a small portion of Itasca State Park.

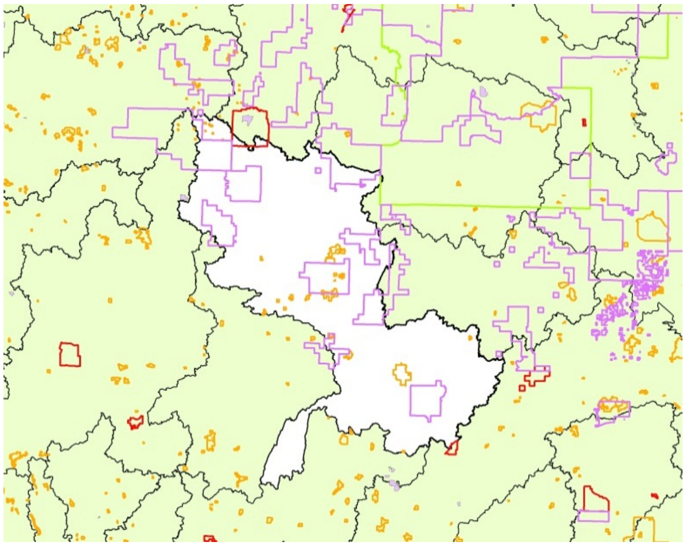


Figure 10. State lands in the CWRW. Purple is State Forest, red is State Park, orange is Wildlife Management Area, green is National Forest. Note that State Forest land is absent south and west of the CWRW.

As with farmland, the distribution of lakes is very patchy, occurring in two primary clusters. One is in the northernmost part of the watershed, from Park Rapids and north, while the other is in the extreme southeast, the Brainerd Lakes area. The central part of the watershed contains almost no lakes, except for the many tiny lakes located in a narrow north-south band on the eastern edge of the watershed, in the Foothills State Forest.

The CWRW has only a small percentage of its land area in non-farm development, with about 4.0% of land area considered developed at any intensity level, and approximately 1.0% of land area in medium or high-level intensity (as defined by the National Land Cover Designations). Residential development is primarily in several small towns and along the shoreline of the areas numerous lakes. There are 13 incorporated towns/cities, which each have relatively low populations (2009 Census estimate data): the larger are; Park Rapids - 3,634, Staples - 2998, Nisswa - 2,125, Pequot Lakes - 1,936, Menahga - 1,191, Lakeshore - 1,056, and East Gull Lake - 1,014. None of these are large enough to require an MS4 Stormwater plan/permit. Akeley and Nevis are located in a lake-rich/stream poor portion of the watershed, and little monitoring of streams occurred there. Park Rapids is the primary urbanized area of the watershed potentially of impact to CRWR streams, due to its proximity to the Fishhook River. Other towns do not have streams running through them.

Given this low level of non-farm developed land, stressors linked to urbanization are likely to be a minor contributor to stream water quality issues and ecological degradation in the CWRW. Therefore, candidate stressors involving urbanization (chemical pollution, impervious surfaces, stormwater issues, etc.) were removed from further consideration as stressors to the stream biological communities of the CWRW. Additionally, parts of the watershed would also not be at higher risk of non-point pollution from farming activities, while some areas have definite potential to be impacted by agriculture.

Candidate stressors

After familiarization with the watershed via travel and observation in the field, as well as the desktop tools mentioned above, one can start to formulate hypotheses as to the more likely situations that may be causing an ecological problem to the streams and rivers. The EPA has provided a very comprehensive list of potential stressors/activities that can negatively impact water resources (USEPA, 2010). Based on the initial efforts discussed above, the long list of potential stressors documented by EPA was greatly reduced for the CWRW simply due to the fact that activities producing many of those pollutants are not occurring in this rural watershed (e.g., acid mine drainage, major urban stormwater generation).

The predominant human activities occurring in the CWRW are agriculture (both crop and animal), forest harvest, and residential development. Therefore, stressors associated with those activities were the focus of investigation.

Given the predominant human activities in the CWRW, one of the most likely stressors would be **nutrients**, which can come from failing septic systems, crop fertilization, animal agriculture, or residential runoff. Both nitrogen (as nitrate and ammonia) and phosphorus are natural elements in the landscape, but elevated levels can be problematic for streams because, they (particularly phosphorus) stimulate plant growth to abnormal levels. This excess plant growth uses oxygen from the water column at night during respiration, and oxygen is also removed from the water by bacteria as they work to break down this plant material when it dies. Thus, phosphorus additions to surface waters can become a stressor to aquatic biological life through its effect of causing **reduced oxygen** availability. This process is called **eutrophication**. In addition to reducing oxygen, nitrogen, both in the common form of nitrate, and also ammonia, can be directly toxic to aquatic organisms at higher concentrations. **Altered hydrology**, and its follow-on effects of **channel instability, bank erosion, and excess sediment** are possible stressors almost everywhere in the state to some degree. In many places in Minnesota, the alteration involves faster runoff of rainfall, meaning higher peak flows in stream channels, resulting in damage to the physical channel and habitat features. In some places, the alteration is a reduction in flow, due to aquifer drawdown from water withdrawals. This can also damage habitat through changes in water temperature, insufficient transporting of natural sediment inputs, or reduction of habitat space in general. In the CWRW, both excess and reduced water levels are possible. Excess water in channels is possible due to trenching within the extensive wetlands found in the CWRW and the historic conversion of forest to field. Surface runoff from fields or developed areas is mitigated significantly in the CWRW due to the flat topography, and the extremely sandy soils, which allow easier infiltration of precipitation. Flow reductions have potential to occur in some locations in the CWRW due to the significant amount of groundwater withdrawal for irrigated cropland, and the continuing increase in irrigation currently underway in the Pinelands Sand Aquifer area.

One very widespread stressor (nationally) of streams is **excess sediment** inputs, from erosion of exposed soil or when stream banks erode due to the funneling of excess water to streams. Sediment can be either suspended in the water column and cause turbidity, or settle out onto the stream bed where it smothers important habitat features. This stressor is less of an issue in the CWRW than in many other locations in Minnesota, because much of the watershed's land is quite flat and the soils very sandy (Figure 8). As mentioned above, both of these factors reduce the amount of surface runoff, which is the mechanism that transports the fine sediment to stream channels. Streams within the CWRW are typically quite clear. The cloudiness seen in some CWRW streams is not from sediment, but from iron, which is transformed from its dissolved form which enters streams via groundwater inflow into extremely small particulates that are too small to settle out and thus stay in suspension and add some cloudiness to the water. Some smaller CWRW streams become a turbid orange color in mid-summer due to this phenomenon. An example is the aptly-named Iron Creek, a tributary to Swan Creek, north of Staples.

Stream channel crossings have potential to become **physical barriers** to fish movement. Crossings can either be culverts (metal corrugated tubes or concrete boxes) or bridges. The crossings can become barriers when they are not installed properly, either due to incorrect sizing for the site or at the wrong elevation and/or slope. Bridges generally do not become barriers because they are wider and the channel can adjust its bed elevation to accommodate the situation. Culverts are the crossing type that more likely will become a migration barrier if not engineered properly. If culverts are too small, the passing water will increase in velocity. The velocity can become too fast for smaller fish species to move through (Warren and Pardew, 1998). Improper slope of the culvert will also lead to high velocity. If culverts are installed at an incorrect elevation, they can be "perched" at the outlet end, meaning the base of the culvert is above the water level of the stream. Minnesota's native fish species are not capable of doing the leaping and surging required for migrating through these situations in the way that salmon for instance can navigate ledges in streams. The denser the road network, and the older the crossing constructions, the more opportunity there is for barriers to be found. Parts of the CWRW do have a dense road network, typically in the areas with more agriculture.

The initial SID efforts judged that these factors have fair possibility of occurrence, and were then further examined at the locations where data from the monitoring and assessment phase of the WRAPS was judged to show an impaired fish or macroinvertebrate community. The goal is to determine the stressor(s) that are negatively affecting the biological community so that sources may be found, and steps taken to modify the activity to reduce or eliminate the particular stressor. This process can be likened to the examination, testing, and prescribing performed by physicians to improve human health. The next section describes the examinations and results for the biological impairments found in several streams in the CWRW.

Investigations organized by impaired stream

The streams initially assessed as impaired are discussed from this point on. The general format will be a section to review and discuss the data that was initially available at the start of the SID process, including the stressors that were deemed possible given the initial data. That will be followed by a section discussing the data that was collected during the SID process. The third section will discuss the conclusions for that stream based on all of the data.

Unnamed tributary to Shell River (AUID 07010106-553)

Impairment: The creek was assessed as impaired for not meeting macroinvertebrate community expectations at 10UM054 (Guyles Road). Fish were not sampled as it appeared in the mid-June visit to not have a defined channel (a criterion for sampling). Later in summer, a defined channel existed. Much later in the SID process, it was learned that there was a cryptic old cross-channel berm just upstream of the sample reach, used to regulate upstream water levels for optimizing wild rice production for waterfowl usage. In 2013, MDNR removed the berm, cleaned out fine sediment in the channel of the sample reach and changed the elevation of the culvert at the downstream end of the sample reach. Because of the lack of knowledge as to how the old berm may have been affecting the flow and DO regime, and the lack of a fish sample, this reach was moved to an assessment of "Insufficient Information".

Review of the subwatershed

Aerial photography review showed little potential here for human disturbance, with only a couple residential parcels at the extreme headwater end of the subwatershed. The great majority of this small subwatershed is in the Smokey Hills State Forest. There are several significant flow-through wetlands along the stream path above the sampled site.

Review of initial data

No water chemistry grab samples were collected during IWM in 2010. The DO during the macroinvertebrate sampling was 1.3 mg/L and the transparency was excellent (> 100 cm).

Targeted investigation and results

The DO measurement on October 5, 2011, showed a very low oxygen level (2.73 mg/L) despite the cold water temperature of 13.8^{o}C. Water clarity was excellent. Due to the natural setting of this stream, and its downstream location from several wetlands on the channel, the low DO was considered to be due to natural causes.

Conclusion

The argument of naturally-low DO as the stressor was originally presented to the MPCA's Natural Background Committee, which agreed with the line of evidence provided, and the stream was determined to not be anthropogenically degraded, and its poor macroinvertebrate community caused by natural factors (low DO due to wetland influences). Detailed information used in the natural background review is archived at MPCA and is available upon request. Subsequent knowledge of the old berm has created a question as to whether the low DO is natural here, and thus the current assessment standing of "insufficient information". MDNR has done restoration work on this AUID in 2013 as described above, and the stream will be resampled at the next scheduled CWRW IWM effort (2020).

Bender Creek (AUID 07010106-691)

Impairment: The creek was assessed as impaired for not meeting both fish and macroinvertebrate community expectations at 10UM070 (Bender Creek Road). Diversity in the fish community was very low and the invertebrate community was dominated by one taxon, the moderately-tolerant crustacean species Hyalella azteca, commonly called scuds or sideswimmers.

Review of the subwatershed

Analysis of aerial photography showed the majority of this subwatershed to be in a relatively natural state. The uppermost part of this watershed contains some irrigated agriculture. The nearest cultivated fields are 3.5 miles from 10UM070, and there are no stream channels from near these fields feeding into Bender Creek. The soil is extremely sandy, and likely explains why agriculture is not practiced here in a major way. This sandy soil factor also reduces surface runoff, and thus reduces the potential for surface transport of soil or chemicals. Also in this headwaters area is a chain of lakes that form the uppermost part of Bender Creek. Below the lake chain, the subwatershed is managed forest, and clearcut patches and newer pine plantations are present. The riparian corridor is very natural, and is dominated by wet meadow or beaver-created wetland. There are many beaver dams in the section of the creek downstream of Tripp Lake. Monitoring results show that water quality in the lakes supplying Bender Creek is very good.

Review of initial data

The MPCA Human Disturbance Score for site 10UM070 is quite good (69.1 of 81.0) and confirms the relative natural state of this site's watershed. The stream is wide and shallow, in places just an inch or two deep. The substrate is nearly all sand, with a small amount of pea gravel. A moderate amount of quite small diameter wood (probably mostly from beaver activity) is present in the channel. The sub-scores from the Minnesota Stream Habitat Assessment (MSHA) regarding riparian condition also confirm the land use is natural (5/5). The sub-scores for in-channel attributes suggest habitat may be a limiting factor here. The in-channel scores, composed of Substrate (14/27), Cover (11/17), and Channel

Morphology (9/36) sum to a total of 34 of 80 possible. Adding the shade component (1/5), the score becomes 35 of a possible 85**.** None of these metrics has an anthropogenic cause here (such as riparian vegetation disturbance or sediment excess from erosion).

Targeted investigation and results

Information via vehicle travel through the watershed revealed useful information. Each of the three road crossings on this AUID were inspected as to being possible migration barriers. The lowest crossing has a culvert that is undersized and is at an incorrect elevation. It appears to contribute to ponding of water upstream, and its small size causes water to have significant velocity within the culvert (Photo 5). It is a barrier to fish migration upstream. The uppermost culvert (Brayton Road) is apparently consistently blocked by beavers (Photo 6). The culvert at Bender Creek Road was found to be newly and partially plugged by beaver in summer 2012. Numerous beaver dams were also found on the recent aerial photos on more remote locations of the creek.

Photo 5. Upstream entrance to the Aspen Lane culvert. The culvert elevation is not correct, and it is also undersized, causing the flow to be quite swift.

Other observations found excellent water clarity at two visits with no evidence that either sediment inputs or turbidity are an issue here at all. No soil erosion was seen in ditches or other near-stream areas.

The initial TP sample from 2010 was elevated (0.148 mg/L), though nitrate was quite low (0.081 mg/L). Excess plant growth was not evident. Source water from the lake chain is low in nutrients, and given the relatively natural landscape here as discussed above, this high TP is likely due to the riparian wetlands, as in other streams in the CWRW just south of here. Additional water chemistry samples were collected and results of both nutrients showed much lower levels (Table 1). In 2012, there was much filamentous algae at 10UM070, but this may have been due to the dry period occurring at that time. The stream is wide and shallow here and receives much sun exposure, and the very low flow conditions may have helped the algae thrive. No water-column (sestonic) algae were evident here.

Additional DO sampling was performed in 2012. Longitudinal sampling (Table 2) revealed some low early morning DO levels. A Sonde was also deployed at the 10UM070 site for approximately 13 days. It also revealed that DO regularly dropped below the state standard (Figure 11). Water temperatures were fairly cool to even cold (Table 2, Figure 12). Nightly, the temperature dropped to 16^{o} C or less.

Photo 6. Outlet of Tripp Lake wetland, blocked by a mud beaver dam. There was evidence here of repeated attempts to maintain open flow in this culvert (debris pile, stakes over culvert opening).

Table 1. Longitudinal, synoptic nutrient sampling on August 21, 2012

Site	Stream name	Location	Time	TP	Nitrate
S007-171	Bender Creek	Brayton Rd	9:50	0.012	< 0.05
S007-170	Bender Creek	Bender Cr. Rd	9:20	0.066	< 0.05
S007-169	Bender Creek	Aspen Drive	9:05	0.063	< 0.05

Table 2. Longitudinal, synoptic DO sampling on August 21, 2012

Site	Stream name	Location	Time	Cond.	Temp.	pH	DO	Notes
S007-171	Bender Creek	Brayton Rd	8:05	181	16.63	7.77	1.33	1
S007-170	Bender Creek	Bender Cr. Rd	8:35	257	13.68	7.63	4.70	2
S007-169	Bender Creek	Aspen Drive	8:56	239	17.40	7.97	5.97	--

Note 1: The upstream side of the culvert was completely sealed off with mud by beaver. The sample was collected on the downstream side of culvert, where water was deep but not flowing, so apparently another dam exists downstream somewhere.

Note 2: There was a beaver dam here in the culvert, and this location is normally impounded per aerial photos. Flow could be heard in the culvert. Sample was taken at the culvert inlet in the impoundment. The water temperature was quite cold here. Springs were observed just downstream, and likely also occur within this impounded area.

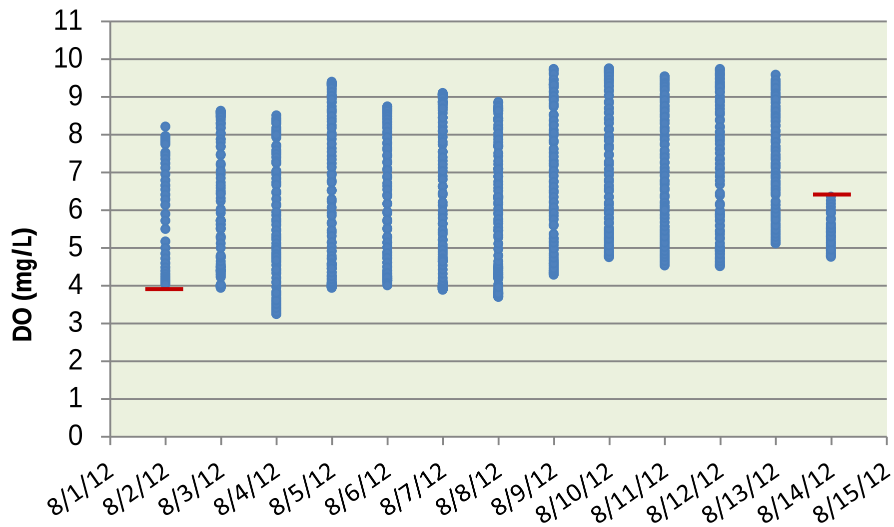


Figure 11. DO readings from the Sonde at Bender Cr. Rd

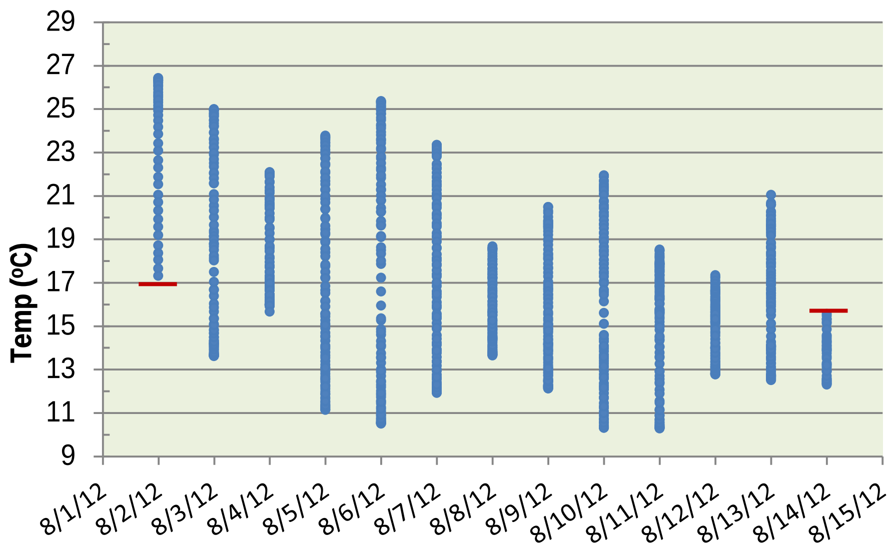


Figure 12. Temperature readings from the Sonde at Bender Cr. Rd

Conclusion

The fact that the incoming water from the lakes is good quality, that the land area surrounding the sample site is natural, and yet the in-channel habitat assessment score was very low, suggest that a significant part of the reduced biological communities is due to a naturally-occurring poor diversity of habitat. Another natural attribute of this reach that may be contributing to the low fish score is the abundance of beaver activity. There are numerous dams on this reach, which may be impediments to fish migration along the reach.

A meeting of MPCA's Assessment Consistency Technical Team and biological and watershed staff was held in May 2013 to discuss the information above, and its bearing on the original impairment decision. The group determined that the fish and invertebrate impairments should be considered due to natural causes, summarizing the decision with the following comments: The Committee reviewed the additional information collected in summer 2012 and determined that the appropriate Consolidated Assessment and Listing Methodology category for this site is 4D. The natural factors contributing to the lower fish and macroinvertebrate (Index of Biological Integrity (IBI) scores are a combination of riparian wetlands and beaver dams/impoundments. Macroinvertebrate habitat in the AUID is limited by the wetland dominance and lack of hard substrates, and fish movement is likely restricted by the numerous dams. Based on several observations, beaver seem to be a persistent blocker of the culvert emptying the Tripp Lake wetland. In addition, these factors are also likely contributing to the reduced oxygen levels found at some locations. The culvert near the mouth may restrict the movement of fish into the stream from First Crow Wing Lake due to being undersized (increases velocity), but just upstream is a large, deep wetland that likely provides some overwintering habitat for fish. Detailed information used in the natural background review is archived at MPCA and is available upon request.

Unnamed tributary to the Crow Wing River (AUID 07010106-687)

Impairment: The creek was assessed as impaired for not meeting fish community expectations at 10UM103 (294th Street). The original 2010 sample collected only three individuals, and a subsequent sample in 2012 collected only 6 individuals. Reaches with fewer than 25 individuals generally fail to meet the fish community expectation as some of the IBI metrics score zero in these cases. This stream is certainly large enough to hold significant numbers of fish. The macroinvertebrate community meets expectations.

Review of the subwatershed

The subwatershed has mixed land use. In the headwaters area of the creek are a group of fields of a sod farm operation. There is a network of small ditches within this field area that drain together into the main channel. The channel flows through significant wet meadow habitat. There are a few scattered residential parcels in the subwatershed, and three road crossings on the main part of the creek. Part of the riparian land below 294th Street, including the stream, is wooded pasture. The human activity within the watershed suggests the main potential human disturbances would be nutrient addition to the stream, sediment from banks within pastured areas, or barriers to fish passage at the road crossings.

Review of initial data

The water temperatures in the stream are quite cool. The sample on July 10, 2012, during late afternoon was only 20.7^{o}C, nearing the level that streams are considered coldwater and able to support trout. The chemistry samples collected at the fish visits (Table 3) showed nitrate levels that are somewhat elevated from what is found in many of the small creeks in this area of the CWRW, but well below concentrations which can be toxic to aquatic life. Ammonia was a bit elevated in one sample as well, but the unionized ammonia fraction, which is toxic to aquatic life, was well below the state standard of 0.04 mg/L. The TP levels were slightly above the proposed state TP standard, which is 0.100 mg/L at this location. It should be noted that many small streams in this part of the CWRW that flow through sedge meadows have phosphorus levels equivalent to or greater than those measured here. Dissolved oxygen was fine in the two late-afternoon fish sampling efforts (Table 3), though the daily minimum isn't known here. These samples were taken at the daily peak period, and being in the 7-8 mg/L range, are good daily maximum levels, and suggest that eutrophication is not occurring here. The cool water temperatures also suggest that DO should less likely be a problem.

Table 3. Unnamed Creek chemistry data from three fish sampling visits - values in mg/L.

Date	Time	TP	Nitrate	Ammonia	Unionized ammonia	DO
6/28/10	5:55 PM	0.144	0.288	0.221	0.0043	7.4
7/10/12	4:07 PM	0.111	0.320	< 0.100	--	7.5
9/11/13	10:20 AM	0.047	0.320	< 0.05	--	8.8

Habitat here, as measured by the MSHA was at about the middle of the scoring range considered to be "Fair", in the MPCA's good-fair-poor rating system. The sub-scores which were lowest were those for Substrate and Channel morphology.

Targeted investigation and results

Chemistry

Because the initial 2010 IWM water chemistry results did not signal water quality problematic for aquatic life, no additional samples were collected specifically to investigate the stream's water chemistry. However, two additional chemistry grab sample sets were collected during subsequent, post-assessment fish sampling visits (Table 3). The values for nutrients were similar, except ammonia was much lower in the subsequent data. Total Phosphorus also was significantly lower in the September sample, and the pattern with these three samples looks similar to that of other CWRW sites, where TP is elevated in mid-summer, and then declines as the season changes to late-summer and fall, suggesting this stream too has its phosphorus controlled by redox chemistry in the subwatershed's soils, a natural phenomenon. Observations from road crossings as well as a walk in the channel for a long distance found no noticeable filamentous algae, and a minimal amount of aquatic plants, further evidence against eutrophication. Therefore, nutrient pollution was ruled out as a stressor.

Habitat

Most of the channel from 294th Street to the mouth at the Crow Wing River was walked in October 2013. This included the pastured area (forested pasture), and allowed an assessment of the domestic animals' influence on the stream. There was little bank erosion, isolated to two relatively small areas, and it appeared that the animals do not traverse the banks much along most of the pasture. The riparian area has significant alder brush, which may be deterring the animals from spending time in the riparian corridor. The level of erosion seen would not be responsible for the lack of fish. The channel did not show signs of significant physical alteration (incision or excess sediment). Downstream of the site, the channel runs through in a very natural riparian setting, and the physical channel appears to be in a natural condition. It is a sand-dominated channel, as are many of the streams in the CWRW, which is responsible for its low MSHA substrate score. The MSHA channel development score was also poor because of the sandy nature of the stream; such streams do not form good riffle-pool sequences.

Connectivity

A survey of the three road crossings was conducted to discern whether any may be blocking upstream fish migration. All of the crossings downstream of site 10UM103 are culverts. One culvert did appear to be a likely barrier, or at least a periodic barrier (depending on creek water levels) - that one being at the crossing immediately downstream of site 10UM103 on 294th Street. During low flow, the culverts (a pair) are perched at or above the water level, while at high flows, the velocity is very high (Photos 7 and 8). These culverts are set at too high an elevation. The high velocity has created a sizeable scour pool at the outfall. The culvert on Highway 14 is not problematic at all – the flow is slow, and the water is deep through it. The furthest downstream culvert is on a private drive. It is set at an appropriate elevation, however it is somewhat undersized and as such, the passing water has elevated velocity. It may reduce movement of fish upstream, particularly the smaller individuals, but it doesn't seem to be a complete barrier. At high water, it likely precludes most non-game species from passing due to high velocity. A deep scour pool at the outfall reveals that high velocities do occur here.

A third fish sampling effort was conducted on September 11, 2013, to better determine the effect the 294th Street culvert was having on the fish community in the 10UM103 reach. A sample was collected both upstream and downstream (13UM184) of this culvert. The results did not show a strong upstream/downstream difference. Seven species were collected below the culvert, while six of these species were collected above. The number of individuals collected was 24 downstream and 18 upstream. Based on observations, this culvert is still considered problematic, but there appears to be additional factors causing overall low numbers of fish in the stream. The private culvert mentioned previously could be a partial factor or two beaver dams seen on a recent aerial photo may be partial barriers.

To investigate the barrier issue further, on October 16, 2013, the author and an MPCA fish biologist traversed the stream down from 294th Street to the mouth at the Crow Wing River, and also walked in the Crow Wing River channel from the creek mouth downstream to the bridge in Nimrod. The intent was to look for any other barriers, look at the beaver dams, and do some exploratory fish sampling below the two sample sites described above. Some backpack electrofishing gear was taken along, and fish sampling was conducted periodically along the way, including above and below the last downstream culvert. Based on what was collected in this screening fish effort, there did not seem to be much difference above and below this private culvert either. One would expect fish to be utilizing the scour pool at the moderate flow level occurring on this date. However, few fish were gathered there. There was no evident current beaver activity, and the dams did not seem to be currently maintained. They were partially breached, and probably allow for fish passage currently. In general, fish were sporadic and few along most of this distance down to the mouth. The most common species captured were sculpin and johnny darters. Others which were infrequent were northern pike, common shiners, mimic shiners, black-nosed dace, and creek chubs. Near the mouth, fish were more abundant, consisting of schools of very small mimic shiners. Larger specimens were no more frequently caught than upstream.

Photo 7. Culvert outfall at 294th Street, fall 2012. The algae here is not representative of the stream in general - this is just a warm, full sun exposure, damp microhabitat.

Photo 8. Outfall of right-bank culvert, May 2013. Note that even at high water, the lip of the culvert is only a few inches below the water surface. The arrow points to standing wave, a sign of high velocity.

Conclusion

Based on the above discussion, there is no evident anthropogenic stressor acting to suppress the fish abundance in this creek, aside from some passage issues at some culverts. But again, fish were not abundant downstream of these culverts either. It is noteworthy that one of the primary fish in the creek, and which was collected in all four sampling events, was mottled sculpin. This species is regarded as being fairly sensitive to human-caused disturbance to streams. This makes it less likely that an unknown chemical constituent is responsible for the low fish abundance throughout the stream.

Nutrients are elevated at times, but not at alarming levels. It appears that the phosphorus is elevated due to the same phenomenon that is occurring at other streams in this area – leaching of phosphorus from riparian peat soils during mid-summer during anoxic soil conditions (see the Tower Creek section for more discussion). Nitrate is elevated compared to what is typically found in these same streams, where normally it is below the detection limit. This nitrate is plausibly coming from sod production areas in the headwaters of this subwatershed. This nitrate is not at levels that are known to be toxic to aquatic life, and there does not appear to be significant eutrophication occurring due to excess nutrients.

Given the close proximity of the Crow Wing River, which in 2010 was sampled only about a half mile downstream of the confluence with Unnamed Creek, and determined to be healthy, one would expect the stream to have a nice source of fish to migrate into it. One hypothesis is that the cool temperatures of the stream make it less desirable for warmwater species, and that they are generally avoiding it. It was also observed during the trek in the Crow Wing River near the creek mouth, that there was very poor habitat in the river at this location. It was extremely sandy and very shallow, and without any type of protective cover (rocks, wood, or pools). Some exploratory fish sampling was done right along the bank below the mouth in the only heterogeneous habitat present in the river here, and few fish were caught here either. However, about 300 meters further downstream, the river's habitat changes significantly and there is a very mixed substrate – with much gravel, cobble, and boulder material and lots of protective cover. Perhaps there is a general fish avoidance of the area of the Crow Wing River near the mouth of Unnamed Creek due to the river's poor habitat there, and the very good habitat a short distance downstream in the river (meaning the local fish congregate there), combined with the colder water of Unnamed Creek. These factors may mean that there are a relatively few fish in the Crow Wing River near the mouth of Unnamed Creek to immigrate into the creek in spring. At this time, there is no known stressor to pursue for remediation. The 294th culvert could be considered for replacement; however, this option should be discussed further with MPCA and MDNR staff to determine if the correction is worth the cost, since it cannot be considered responsible for the low fish abundance all through the creek. And, prior to considering requesting a change of the private culvert, a MDNR hydrologist should evaluate it to determine the degree of under-sizing, and whether replacement is justified. One option there may be to place objects inside the culvert to provide current breaks to improve fish passage. In 2014, a temperature logger will be placed in a couple locations in Unnamed Creek to further investigate the hypothesis that temperatures in the creek may be lower than most warmwater fish prefer.

Tower Creek (AUID 07010106-528)

Impairment: The creek was assessed as impaired for not meeting macroinvertebrate community expectations at 10UM078 (87th Avenue southwest).

Review of the subwatershed

The stream lies in a quite natural landscape setting. There are some animal agricultural operations along the stream, primarily in the very headwaters. These areas are large pasture parcels primarily. There is one registered feedlot in the subwatershed. Other agricultural land use is primarily non-alfalfa hay fields, with a very small amount of row crop acreage. The other dominant land use is forest, and particularly managed forest, owned by a large, national paper company. There are forest patches in many different stages of regrowth, much of it in red pine plantation, while there is also much natural second growth hardwood/pine forest.

An overall GIS quantification of land use types based on the National Land Cover Dataset, 2006 version, showed 31.6% of watershed area is covered by un-natural land uses (urban + agriculture + rangeland). The breakdown of land area in cropland vs. rangeland is heavily weighted to rangeland - only 1.2% of the watershed is cropped, while 27.9% is rangeland. Forest covers 51.2% of the land area in the subwatershed.

As with other subwatersheds in this part of the CWRW, there is much wet meadow area, particularly lying along the stream corridors. This area was quantified using two buffer widths along the stream, first with a 20 m buffer (= 40m width corridor), and a 50 m buffer (= 100m width corridor) with results shown in Table 4.

Review of initial data

Chemistry

Because the stream lies in a fairly natural landscape setting, determining whether there is an anthropogenic stressor is not obvious. The DO measurements taken at the biological sampling dates were below the state standard. On June 17, 2010 the DO was 4.70 mg/L, and on September 21, 2010, was 4.04 mg/L. The nutrient grab samples from June 17 showed significantly elevated TP (0.211 mg/L), but low nitrate (0.091 mg/L) and low ammonia (< 0.1 mg/L).

Habitat

The author conducted the original macroinvertebrate sampling, and felt from general observations made while traversing the stream, that the habitat here for macroinvertebrates was mediocre. This is a sand-dominated system, and there was no hard mineral substrate, not even any gravel. The other potential hard substrate, wood, was present only as small diameter alder branches reaching into the water, with much of that material above the water line during base flow conditions. There was very minimal large diameter wood present in the channel. Flow was slow as well, which is unfavorable to most of the sensitive macroinvertebrates.

Review of the MSHA scores showed that while this stream has great riparian habitat (in natural condition), this stream reach has only fair instream habitat at best. Component scores from the MSHA are presented in Table 5, with the percent of the total score also shown.

It was considered helpful to compare data from the adjacent stream to the north, Martin Creek, to data from Tower Creek, because Martin Creek biological data were above the impairment threshold. Visual interpretation of the aerial photo suggests that they should have very similar biological communities, because the landscape and stream size are very similar. Though there was significantly more chemistry data collected at Martin Creek (a 10X site), the chemistry data appears quite similar for nutrients (high TP at both, minimal nitrates/ammonia), but different (and better) for DO (Table 6).

Regarding habitat, the MSHA in-stream score for Martin Creek was actually lower than Tower Creek's (37 and 41 respectively). However, this habitat assessment is somewhat more geared toward assessing fish habitat. The author made a note on the original macroinvertebrate visit form that there was nice wood habitat for macroinvertebrates present in Martin Creek, and wood was reported as one of the two dominant macroinvertebrate habitats in Martin Creek, which was not so in Tower Creek. However, wood habitat was sampled in both streams. Gradient is an important determinant of macroinvertebrate communities because many the species require moving water, and many do best in swift waters. The overall slope of the stream channel of Tower Creek was 0.00204 (ft/ft), and that of Martin Creek is a very similar 0.00194 (ft/ft). So, at a large scale, gradient does not seem to explain a difference in habitat and with this very low gradient, neither one of these can have much swift-flow habitat. The gradient at the specific reach however apparently is greater at Martin Creek; based on the notes on the macroinvertebrate visit forms, the MSHA, and fish sampling photographs, there is more flow velocity evident in Martin Creek than in Tower Creek.

Biology

In comparing the biological communities between the two streams, the fish communities are quite similar. However, the macroinvertebrate communities are quite different, and an analysis of the taxa present or absent may hold some clues as to how these streams differ and whether anthropogenic factors might be at play. First, the diversity is much higher in Martin Creek, which may translate into a more-diverse habitat present there. The taxa list from Martin Creek suggests that flow velocity and/or hard substrate are more favorable or abundant at Martin Creek, as there were more mayfly and caddisfly taxa present (Table 7). Many of the representatives of these insect orders prefer some velocity to the water, and are adapted to cling to hard substrates in swifter, more oxygenated waters. Also, many of the caddisflies are filter feeders, capturing organic particulate material carried by the current. Many of the mayfly and caddisfly species are gatherers, and more of these taxa were present in Martin Creek. Taxa from the families Hydropsychidae, Heptageniidae, and Baetidae were present in Martin Creek, but missing from Tower. All three of these families are very common where water is moving with at least moderate velocity.

The macroinvertebrate data is consistent with the observations that there is better hard substrate habitat and somewhat swifter water velocity in Martin Creek. Because the variation of neither of these two factors have an anthropogenic explanation here, this is most likely a simple difference in natural habitat between the two reaches, with Tower Creek being naturally habitat-limited.

Table 4. Percent of riparian area of stream corridor that is Palustrine wetland (hydric soils), based on the National Wetland Inventory GIS layer.

	Percent riparian area within:	
	20 m buffer	**50 m buffer**
Headwaters "AUID"		
Wetland area (m^2)	83.4	74.3
Upland area (m^2)	16.6	25.7
Channel length (m)	10834.8	
Channel length (mi)	6.73	
Middle AUID		
Wetland area (m^2)	90.3	74.3
Upland area (m^2)	9.7	25.7
Channel length (m)	12191.4	
Channel length (mi)	7.58	
Lower (Impaired) AUID - 528		
Wetland area (m^2)	**86.3**	**76.4**
Upland area (m^2)	13.7	23.6
Channel length (m)	12309.6	
Channel length (mi)	7.65	
Total Tower Creek System		
Wetland area (m^2)	**86.8**	**75.0**
Upland area (m^2)	13.2	25.0
Channel length (m)	35335.9	
Channel length (mi)	21.95	

Table 5. MSHA scores at 10UM078.

Habitat feature	Score	Total possible	Percent of total
Out-of-channel habitat	20	20	100
Instream habitat	41	80	51.3
Substrate	9	27	33.3
Cover	10	17	58.8
Channel morphology	22	36	61.1

Table 6. Select 2010 fish sample 2010 10X chemistry statistics from Martin Creek – values in mg/L.

2010, 10X	TP	Nitrate	Ammonia	Unionized ammonia	DO
Maximum	0.237	< 0.03	--	--	9.85
Minimum	0.069	< 0.03	--	--	5.84
Average	0.118	< 0.03	--	--	8.02
Fish sample					
6/17/10	0.132	0.082	0.104	.0017	7.3

Table 7. Select metrics to compare Tower Cr. and Martin Cr.

Stream	# of Filterer taxa	# of Gatherer taxa	% Filterers	# of Clinger taxa
Tower	4	12	23.6*	7
Martin	7	15	34.1	14

*Almost all were a single taxon, *Simuliium*.

Targeted investigation and results

Since elevated phosphorus and depressed DO are common stressors resulting from anthropogenic changes in the watershed, further investigation into their causes was conducted. Because of the generally natural condition of the landscape, the extremely low measurements of nitrate and ammonia, in combination with observations of groundwater input (springs), low water temperatures (another sign of groundwater input), and an unusual amount of wetland riparian area (Figure 3) due to the glacial drumlin field landscape here, the hypothesis became that the higher TP and low DO were naturally-occurring conditions.

To investigate this hypothesis, many visits were made to the stream in 2012 and 2013 to monitor the TP, nitrate, ammonia, temperature and DO levels. Measurement of iron and orthophosphorus (OP) was also initiated in 2012 and 2013 respectively. These visits were conducted all across the non-frozen season and at numerous longitudinal sites along the stream course, from headwaters to near the confluence with Farnham Creek. This sampling will continue into the future, in order to better define the dynamics and sources of phosphorus and gain further insight into why the DO is low.

Because water chemistry parameters can be influenced by factors such as flow volumes, height of the water table (Hill and Devito, 1997), etc., it is good to understand the current moisture conditions when stream water samples are collected, so that the results can be interpreted within proper context. Most data utilized in this report are from 2010-2013. For the area within the central part of the watershed, an IWM flow monitoring station at Farnham Creek (at County Road (CR) 30), which also collected precipitation data (Table 8), will be helpful in understanding data from Tower and Swan Creeks. It can be seen that 2011 was a much drier season than 2010 or 2012, and that later summer 2010 was quite wet, while 2012 was extremely wet in early summer and extremely dry later on (Figure 13).

Table 8. Monthly precipitation data (inches) at Farnham Creek at CR 30. Seasonal totals for various periods are also shown.

Month	2010	2011	2012
April 20-30	0.37	0.87	0.64
May	2.87	4.38	7.91
June	3.47	2.41	4.19
July	7.01	3.97	4.79
August	3.62	2.29	1.77
September	3.51	0.79	0.32
October	1.88	1.69	1.12
Total thru July	**13.7**	**11.6**	**17.5**
Total thru August	**17.3**	**13.9**	**19.3**
Total thru September	**20.9**	**14.7**	**19.6**
Total thru October	**22.7**	**16.4**	**20.7**

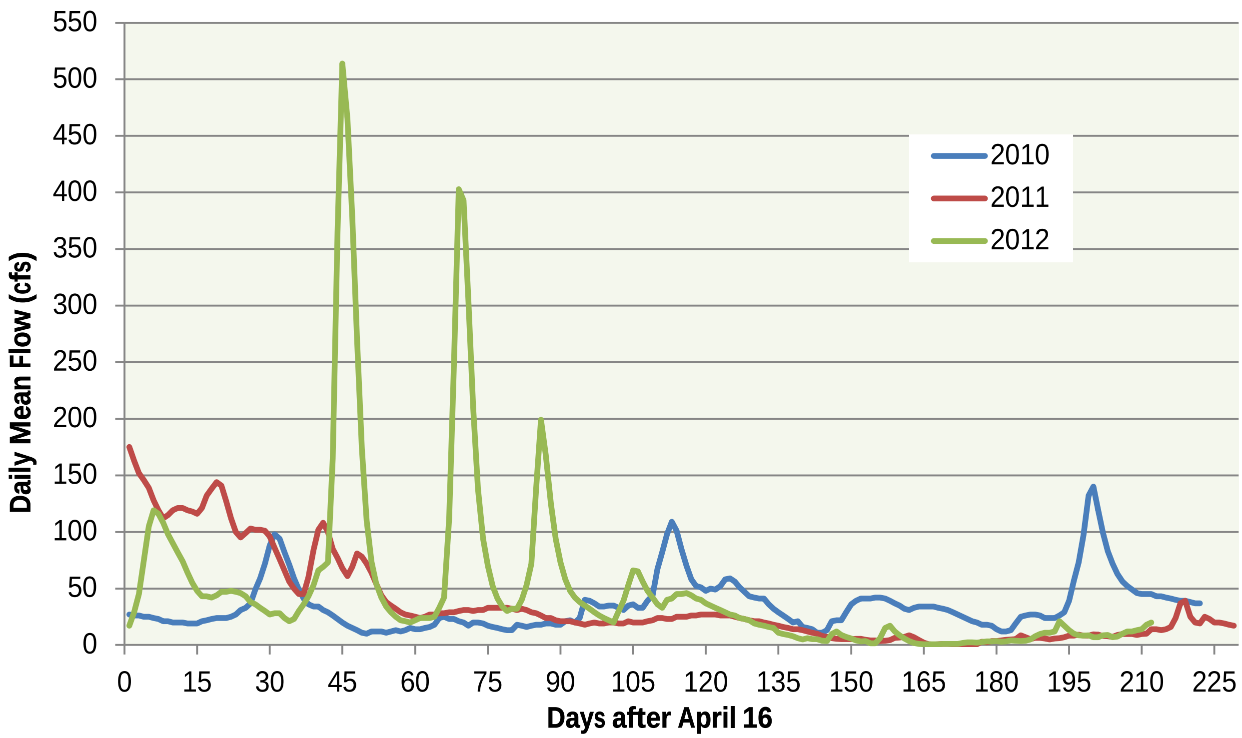


Figure 13. Flow in Farnham Creek at CR 30, 2010 – 2012

Chemistry

Phosphorus

As mentioned, numerous phosphorus samples (both TP and OP) were collected in 2012 and 2013 in Tower Creek at several locations along its path (Figure 14). Some of these samples confirmed the high TP values that were found during the IWM biological sampling. It was also revealed that TP concentration has a somewhat bell-shaped seasonal pattern, over which the concentration varies greatly, and where generally the peak concentrations occur in mid-July or the immediately adjacent few weeks. That is the period when the combined factors of water table height and soil/water temperatures peak (the time when reducing conditions are greatest, that is, when soil and water oxygen are low). Orthophosphorus does not follow this pattern – the concentrations were highly similar throughout the season. In many areas, one primary way that phosphorus enters streams is from surficial, eroded soil because phosphorus strongly adsorbs to mineral particles. Because suspended mineral material in stream water is not very significant in this area due to flat topography and sandy soils that reduce land erosion, and that the low gradient nature of the area's streams would not carry suspended mineral material for long, it is suspected that the high TP collected here is related to colloidal iron compounds in the stream water to which phosphorus becomes bound as the groundwater entering the stream (and carrying both soluble phosphorus and soluble iron) becomes more oxygenated. This relationship of colloidal iron binding phosphorus is discussed in (Liu *et al.*, 2011). They concluded that "colloids act as the intermediate and buffer in the dynamically balanced transfer of P from the truly dissolved phase to the large particulate phase, having a significant role in the size distribution of P." These colloidal iron particles are likely the cause of the turbid, orange coloration of the stream water shown in the photos earlier in this report.

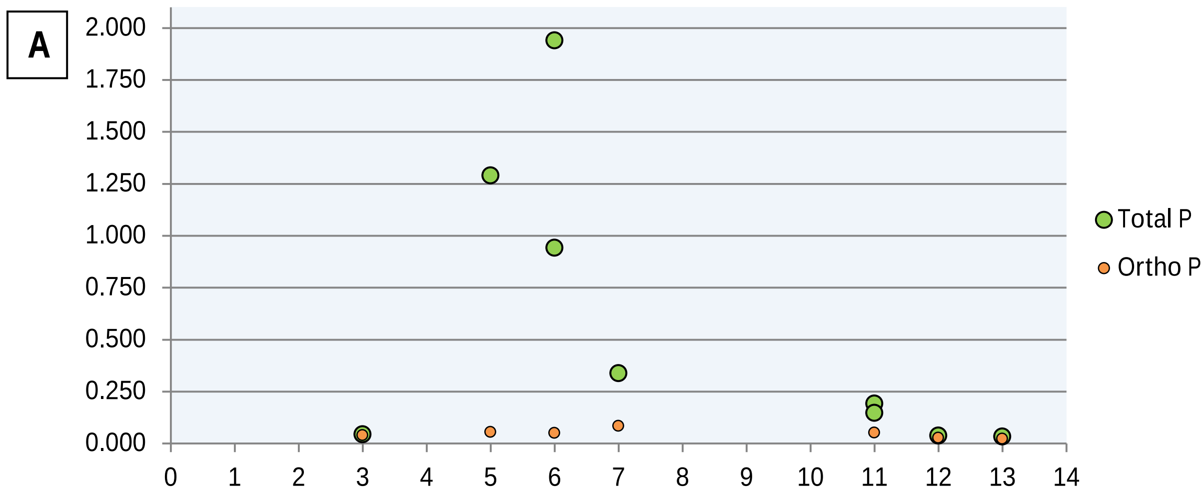
The phosphorus at various points along the creek's longitudinal profile shows high phosphorus at most locations. In general, TP is highest near the headwaters and in the middle reaches, and then decreases downstream near the biological site (Table 9), though in mid-summer, the TP is still elevated significantly there. The highest level on any given date consistently is at the Highway 24 (S007-131) crossing. There is a very large beaver dam and impoundment about 150 meters upstream. The organic sediments are likely more anoxic here due to the impoundment (flooded riparian area) and its extensive exposure to the sun adding warmth. Anoxic, saturated organic soil will export soluble phosphorus. There is an animal farm (cattle and sheep) adjacent to the impoundment, but animals have not been seen in the stream or impoundment above this sample site. A high phosphorus reading has been collected above the impoundment in the headwater reach. On July 10, 2013, TP and OP were 0.228 and 0.086 mg/L respectively. These were not as high as the Highway 24 crossing, but are still quite elevated relative to the proposed state river phosphorus standard.

Nitrogen (nitrate and ammonia)

Numerous measurements of nitrate and ammonia were collected at various times during 2012 and 2013 at S007-130, S007-131, and S007-132 (Table 9). These nitrogen compounds were consistently found in extremely low concentration, with site averages less than 0.06 mg/L.

Dissolved oxygen

A Sonde was placed for a week at 10UM078 in early August and DO dropped below 5 mg/L on a nightly basis. Early morning DO minimums were between 3-4 mg/L. The daily DO flux was fairly low, between 2.5 - 3 mg/L (Figure 15). Tower Creek is right on the border between these two regions. A synoptic-longitudinal collection was done to provide insight into the DO regime throughout the subwatershed (Figure 16). Dissolved oxygen is low throughout Tower Creek, which is very low gradient throughout, and its slow velocity reduces the opportunity for mixing and picking up atmospheric oxygen. The best DO level was at the biological sampling site, where there is more observable flow velocity, though still slow.



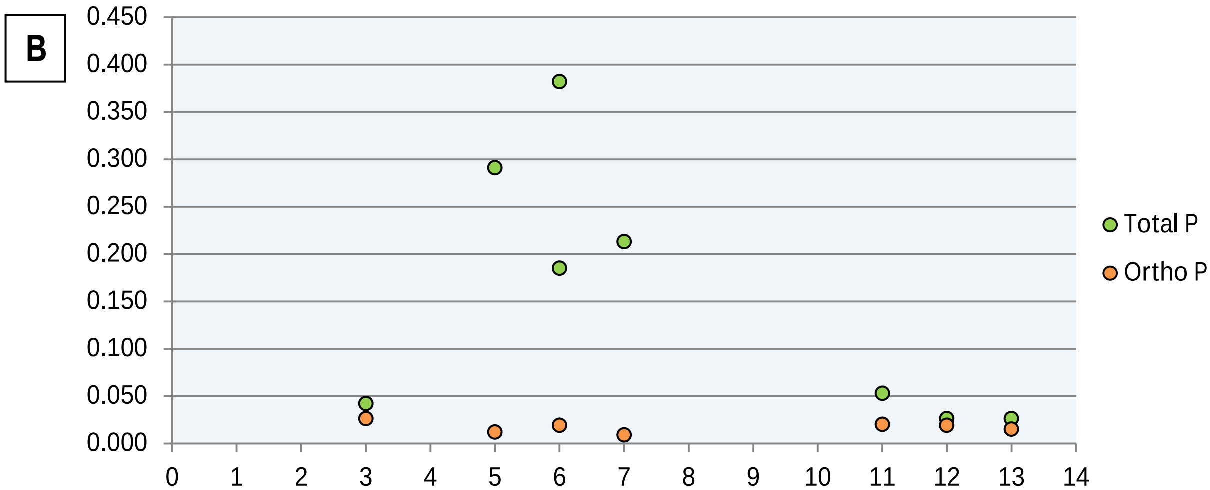
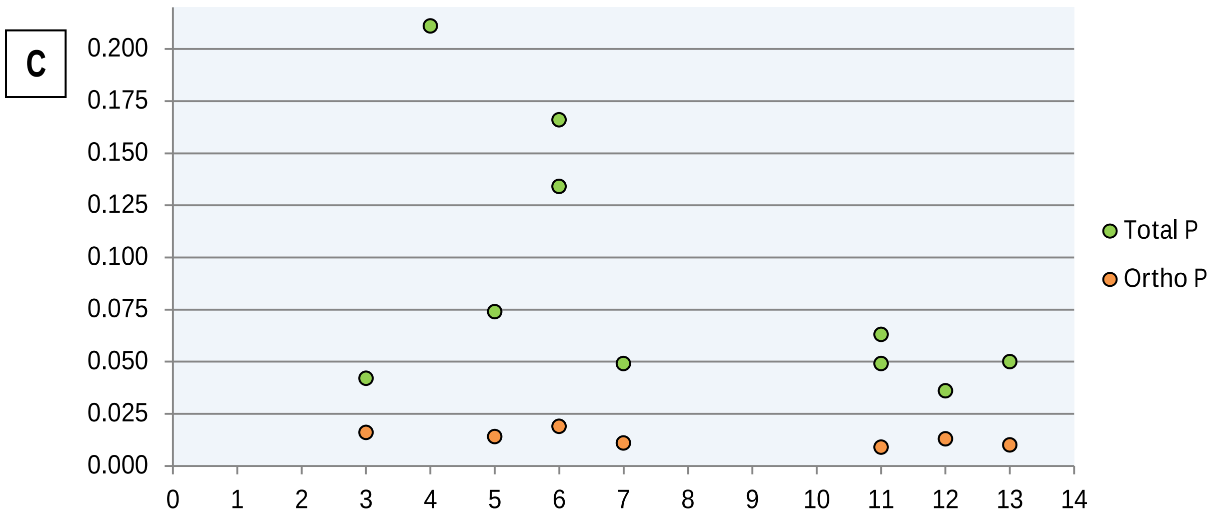


Figure 14. Phosphorus values for: 1) Tower Creek (2010-2013) - A S007-131 B S007-130 C S007-132 (= 10UM078), 2) Martin Creek (2010 – 10X) D S006-247, and 3) Farnham Creek E S004-065. Values are mg/L and the ranges differ somewhat on the graphs. The x-axis numbers for A-C represent 2-week intervals - the number 1 is May 1 – May 15, 2 is May 16 - May 31, 3 is June 1 - 15, and so on, through mid-November. This figure set is continued on the next page.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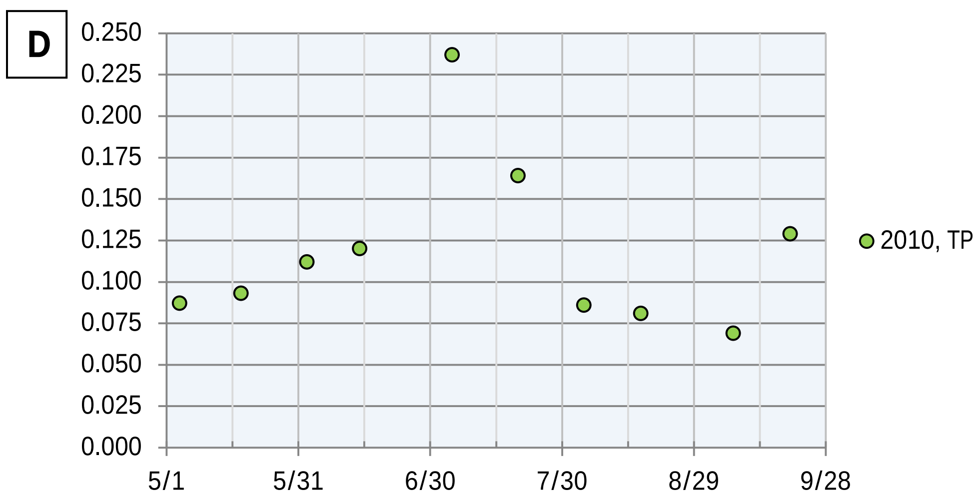
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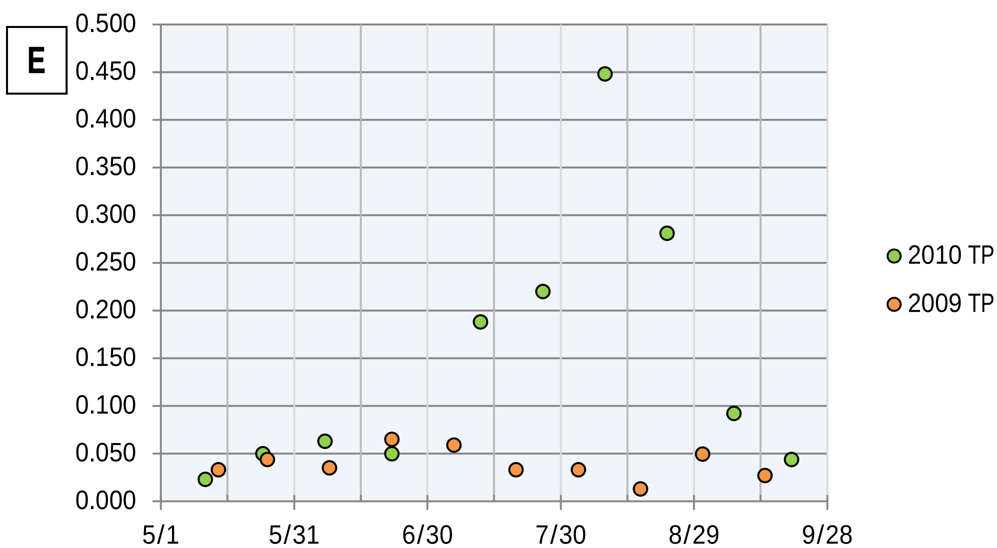
2010, TP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5/31
6/30
7/30
8/29
9/28
2010 TP
2009 TP

Table 9. TP, OP, nitrate, and ammonia results (all in mg/L) from Tower Creek sites, US to DS. Blue numbers denote a single sample.

Site	EQuIS #	Avg. TP	Highest TP	Avg. OP	Avg. nitrate	Avg. NH_4
60th St SW x 71st "North Br."	S007-678	0.070	0.228	0.052	< 0.05	< 0.05
71st Ave SW "South Br."	S007-677	0.056	0.083	0.013	< 0.05	< 0.100
Hwy 24	S007-131	0.552	1.940	0.047	< 0.05	< 0.128
68th St SW	S007-130	0.152	0.382	0.017	< 0.05	< 0.098
87th Ave SW (10UM078)	S007-132	0.087	0.211	0.013	< 0.058	< 0.065
87th Ave SW wetland spring	NA	0.146	--	--	< 0.05	--

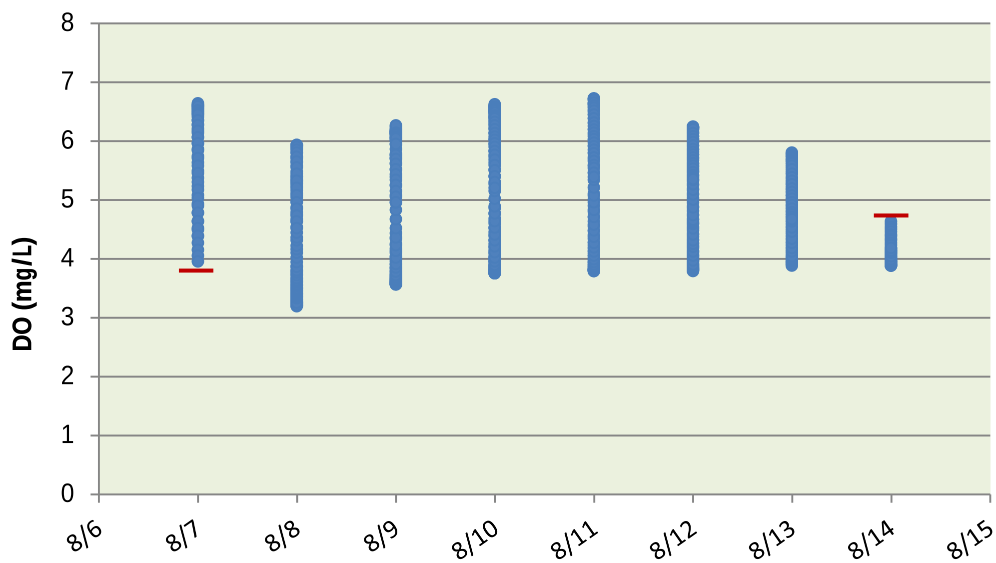

Figure 15. DO readings from the Sonde at 87th Ave. SW (10UM078)

Iron

Iron is known to be significantly related to the dynamics of phosphorus chemistry and its movement in the environment (Morris and Hesterberg, 2010; Liu *et al*., 2011; O'Brien *et al*., 2013). Iron in and of itself can be an aquatic life stressor at certain concentrations (Vuori, 1995). The routine IWM monitoring does not include iron among the parameters that are collected. Routine water monitoring by local government units also does not normally collect stream iron concentration either. Thus, no pre-existing iron data was available to review going into the SID phase of the WRAPS.

Because of the easily-observable iron deposits in many streams of this area of the CWRW, and its common occurrence in groundwater, a few stream iron samples were collected in 2012. After review of several published research studies, it became clear that more iron data should be collected due to the relationship of iron and phosphorus. Additional samples were collected in fall 2013, and more will be collected in 2014. Table 10 presents the iron data currently in hand for Tower Creek. Based on known iron dynamics in the environment, it is anticipated that iron concentrations will be highest in mid-summer and into early fall. The data in the table show a dramatic decline in iron levels between October 2 and October 22 in 2013, with values declining by at least 100 percent at all sites, and much more at some sites.

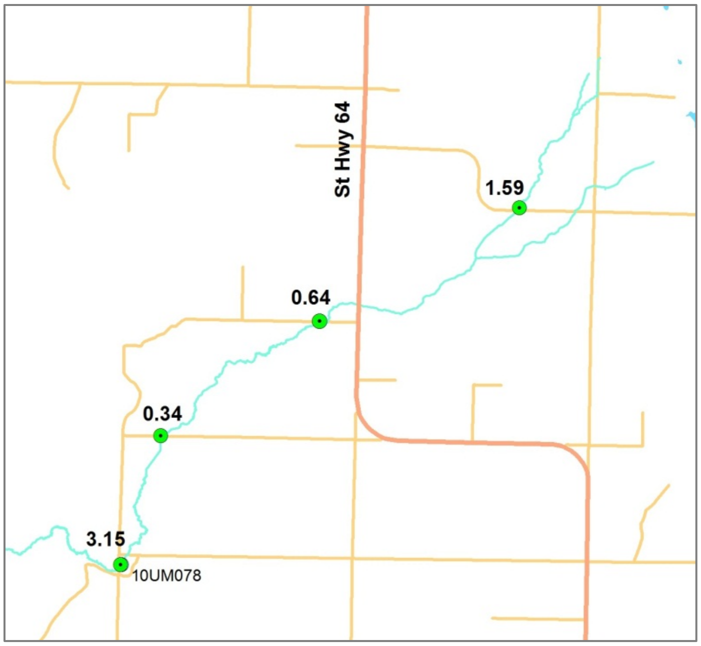

Figure 16. Longitudinal DO readings (in mg/L), collected July 17, 2012. Collection times (DS to US): 7:53, 8:04, 8:54, and 9:15 am.

Because iron changes form and mobility based on oxygen levels in the soil and water, samples from other times of the year will provide more insight into how iron is interacting with phosphorus. This will be accomplished in 2014. However, the current data does yield two important pieces of information.

1) The whole stream length, except the headwater site, has iron concentrations over 1000 µg/L. At the biological site, it is over twice that level. The EPA has determined a threshold concentration above which iron may become toxic to aquatic life, with that level being 1000 µg/L (USEPA, August, 2013). A discussion of the toxic effects of iron on fish and invertebrates is found in the review paper by Vuori (1995). The complete range and cause of iron toxicity is not known, but the paper discusses evidence of toxicity involving gill (and therefore oxygen exchange) interference in fish (brown trout). Intra-cellular damage is also a suspected mechanism of toxicity to cells. Iron often precipitates from the water column, and Vuori presents evidence of the smothering effect of iron deposits on fish and macroinvertebrate gill tissues, as well as egg membranes. Iron deposition on stream substrate surfaces have also been shown to reduce periphyton abundance and community diversity (Vuori, 1995). Periphyton is an important food source for numerous macroinvertebrates. Thus, there are a variety of ways that iron may be detrimental of various aquatic biological life forms.

2) Iron concentrations drop drastically in mid-October at some sites, but not at others (Table 10). This is likely due to a change in redox conditions in the soil and water. At this time of year, ground and water temperatures cool significantly. More oxygen dissolves into colder water, shifting these environments to a more oxidizing state. Also, bacterial breakdown of organic material slows, meaning bacteria are using less soil and water oxygen, again contributing to a more oxidized state. Iron converts to an insoluble oxide state, and phosphorus binds to the oxidized iron compounds. This means that iron and phosphorus are locked up until the following summer, when reducing conditions return.

Table 10. Iron concentration levels along Tower Creek, from headwaters down to the biological site, 10UM078. Note that the highest concentration was found in a streamside spring emerging from a riparian wet meadow at 10UM078, and that iron levels are highest in the lower area of the stream, which is where the biological samples were taken.

Site (US to DS)	Date	Iron (µg/L)
S007-678	10/3/12	103
S007-678	10/22/13	48
S007-678	11/6/13	58
S007-677	11/6/13	1810
S007-131	10/2/13	1610
S007-131	10/22/13	204
S007-131	11/6/13	156
S007-130	10/2/13	1060
S007-130	10/22/13	221
S007-130	11/6/13	309
S007-132 (10UM078)	9/5/12	2070
S007-132 (10UM078)	10/2/13	2080
S007-132 (10UM078)	10/22/13	1050
S007-132 (10UM078)	11/6/13	1790
S007-132 - Lateral spring	9/5/12	2500
Lateral spring pool (DS of S007-132)	11/6/13	912

Conclusions

The findings through 2012 were brought before the MPCA's Natural Background Committee for discussion and a decision as to whether the elevated phosphorus and low DO levels could be overwhelmingly attributed to natural factors, or whether human activities might be playing a role in the levels of these two chemistry parameters. Due to the close proximity of a small number of animal farms to the stream channel upstream of the sample site (10UM078), it was decided that human contribution to these findings couldn't be ruled out at this time.

Because of the relatively unusual landscape factors contributing to the movement of water through this subwatershed, both above and below ground, further sampling and analyses will be done in this subwatershed to try to better understand the phosphorus and DO levels found in the stream, and thus determine whether these concentrations are essentially completely natural, or whether there is an anthropogenic contribution. The water chemistry dynamics that have been observed here are quite complex and some aspects of these dynamics are still only partially understood by the scientific community (Liu *et al.*, 2011; Dillon and Molot, 1997). MPCA will continue to collect additional data in 2014. Based on the results through 2013, some refinement in sampling, in terms of timing, and collection of addition of related parameters (e.g. dissolved organic carbon and more iron samples), will shed further light on why the phosphorus and oxygen levels are high and low respectively. This phenomenon is being studied on a broader scale than just in Tower Creek, because similar phosphorus, nitrate, and oxygen patterns have been found in a number of streams in the CWRW (including Swan Creek subwatershed, discussed in this report), the Leech Lake River Watershed, and the Pine River Watershed. It is likely that some streams in other north central Minnesota watersheds, including in the

Mississippi - Headwaters, Mississippi-Grand Rapids, and Mississippi - Brainerd watersheds will show similar chemistry patterns, because they too have extensive riparian peat wetlands. Educators at North Carolina State University (Bartenhagen *et al*., 1995) sum up the effects of phosphorus on freshwater systems well:

> "Generally, phosphorus (as orthophosphate) is the limiting nutrient in freshwater aquatic systems. That is, if all phosphorus is used, plant growth will cease, no matter how much nitrogen is available. The natural background levels of total phosphorus are generally less than 0.03 mg/L [varies by region, however]. The natural levels of orthophosphate usually range from 0.005 to 0.05 mg/L (Dunne and Leopold, 1978).
>
> Many bodies of freshwater are currently experiencing influxes of phosphorus and nitrogen from outside sources. The increasing concentration of available phosphorus allows plants to assimilate more nitrogen before the phosphorus is depleted. Thus, if sufficient phosphorus is available, elevated concentrations of nitrates will lead to algal blooms. Although levels of 0.08 to 0.10 mg/L orthophosphate may trigger periodic blooms, long-term eutrophication will usually be prevented if total phosphorus levels and orthophosphate levels are below 0.5 mg/L and 0.05 mg/L, respectively (Dunne and Leopold, 1978)."

Currently, it appears that the substandard DO, and thus a likely primary stressor to the impaired macroinvertebrate community, is the result of natural causes. Reasons for this conclusion include:

1) Extremely low levels of nitrogen-based nutrients (nitrate and ammonia) in Tower Creek. Excess phosphorus is only a problem if there is enough nitrogen also present for excess plant growth to occur. Plants need both nutrients simultaneously to grow.
2) Much professional scientific literature support detailing the natural, wetland-based source of stream phosphorus in landscapes with similar riparian peat wetlands (O'Brien, *et al*., 2013; Fristedt, 2004; Carlyle and Hill, 2001; Banaszuk *et al*., 2005).
3) The bell-shaped seasonal pattern of TP, meaning a redox control of phosphorus dynamics in riparian soils (O'Brien *et al*., 2013; Fristedt, 2004; Dillon and Molot, 1997; Banaszuk *et al*., 2005).
4) Relatively low OP levels in Tower Creek. Liu *et al*. (2011) discuss that with OP samples which used a 0.45 µm membrane filter (the standard protocol) a portion of what is considered to be OP (soluble) is actually colloidal, because the range of colloidal particles is from 0.2 to 1.0 µm. Thus the standard protocol, used in collecting the data in this MPCA study, overestimates the concentration of OP.
5) High levels of iron in the stream water and wetland soils (iron interacts with phosphorus and behaves similarly to phosphorus under various redox conditions - Morris and Hesterberg, 2010; Carlyle and Hill, 2001). Iron is also potentially toxic to aquatic life at levels above 1000 µg/L (USEPA, 2013), such as occurs in Tower Creek in mid-summer and early fall. Orthophosphorus is the form of P that is available for plant uptake. Because OP stays about the same concentration all season, not as much is available for plant growth as might be suspected by looking only at TP values, which is the parameter most studies sample and correlate to poor DO. It may be that the iron in the stream water is sequestering a large amount of the dissolved OP. This will be studied further.
6) Low abundance of plant life in the stream, either macrophytes or algae.
7) Low daily maximum DO concentrations and low daily DO flux.
8) Extensive natural riparian conditions along the longitudinal course of the stream.
9) Fish were sampled in mid-June when the water temperature was still seasonally low (15.9°C) and thus their metabolic needs were less than would occur later in the season (e.g. August) when water temperatures were warmer. This may explain why the fish did not show effects of low DO (less need in June), though macroinvertebrates did. Fish can move out when habitat requirements are insufficient, while macroinvertebrates cannot.

In addition to the low DO levels in Tower Creek, there are other natural factors which appear to be limiting the macroinvertebrate community. There is poor macroinvertebrate habitat here due to the natural geologic and hydrologic conditions. It is quite likely that the combined effects of poor habitat, slow flow, high iron concentrations, and low DO levels are responsible for the poor macroinvertebrate community found in Tower Creek.

When the understanding of these processes and factors is more complete, particularly the chemistry, the new data will again be presented to the MPCA's Natural Background Committee to review, and at that time a decision will be made to either attribute the phosphorus and oxygen levels wholly to natural factors, or to proceed with implementation of some best management practices to minimize any human contribution to the substandard oxygen levels, and thus benefit aquatic life. If the MPCA or county Soil and Water Conservation District (SWCD) is able to determine that there are animal farming practices that are not fully following the feedlot/shoreland rules, those should be addressed, whether or not this impairment is natural. Otherwise, no additional efforts toward stream rehabilitation or best management practices (BMP) implementation are recommended at present.

Upper Shell River (AUID 07010106-537)

Impairment: This AUID was assessed as impaired for not meeting fish community expectations at 10UM053, 10EM133, and 10UM055 (a channelized reach). The macroinvertebrate community was assessed as sufficiently healthy at all three sites.

Review of the subwatershed

This subwatershed is a mix of forest, wetlands, fallow fields, and active cropland. As with much of the CWRW, soils here are very sandy, and the topography flat. One exception regarding the topography is the Smokey Hills State Forest, which is an abruptly hilly area in the northwest part of the subwatershed. The river's source is 3147 acre Shell Lake, which has not been assessed for water quality, but its shores are mostly undeveloped. The MPCA's 2012 assessment of CWRW lakes included the following comment for Shell Lake; "TP meeting threshold, Chl-a is at the threshold and Secchi exceeds the threshold. Insufficient information for assessment." The large sedge meadow riparian corridors found elsewhere in the CWRW are also present here (Figure 17). The great majority of this AUID has a significant natural riparian buffer.

The Shell River subwatershed is one part of the CWRW where there is substantial row crop agriculture occurring, and most of the active acres are irrigated. Much of the irrigated acreage is at the upstream portion of the subwatershed, above Shell Lake. The extremely sandy soil and flat topography of agricultural fields here mean rainfall has low potential to become overland flow and erode field soil into the river. Many fields are currently in CRP since, with the extremely sandy soil, irrigation is required to obtain a crop. A large part of the watershed's land area is within the Smokey Hills State Forest, which is a combination of mature forest and patchy harvested areas in various stages of re-growth. The above landscape features are shown in Figure 18. CRP and crop percentages are shown in Table 11. This is a completely rural subwatershed, with only one extremely small town. It contains no NPDES-permitted feedlots and has eight smaller, registered feedlots, and none are adjacent to the main channel. This is a large subwatershed, and so feedlots are quite sparse. Channelization of the river is very minimal here as only a very short reach at the extreme downstream end of AUID has been straightened (near Highway 71). There is no coarse substrate in the upper 50+ feet of surficial geology in most of this area (based on well boring information). The numerous beaver dams in the AUID are potential fish barriers.

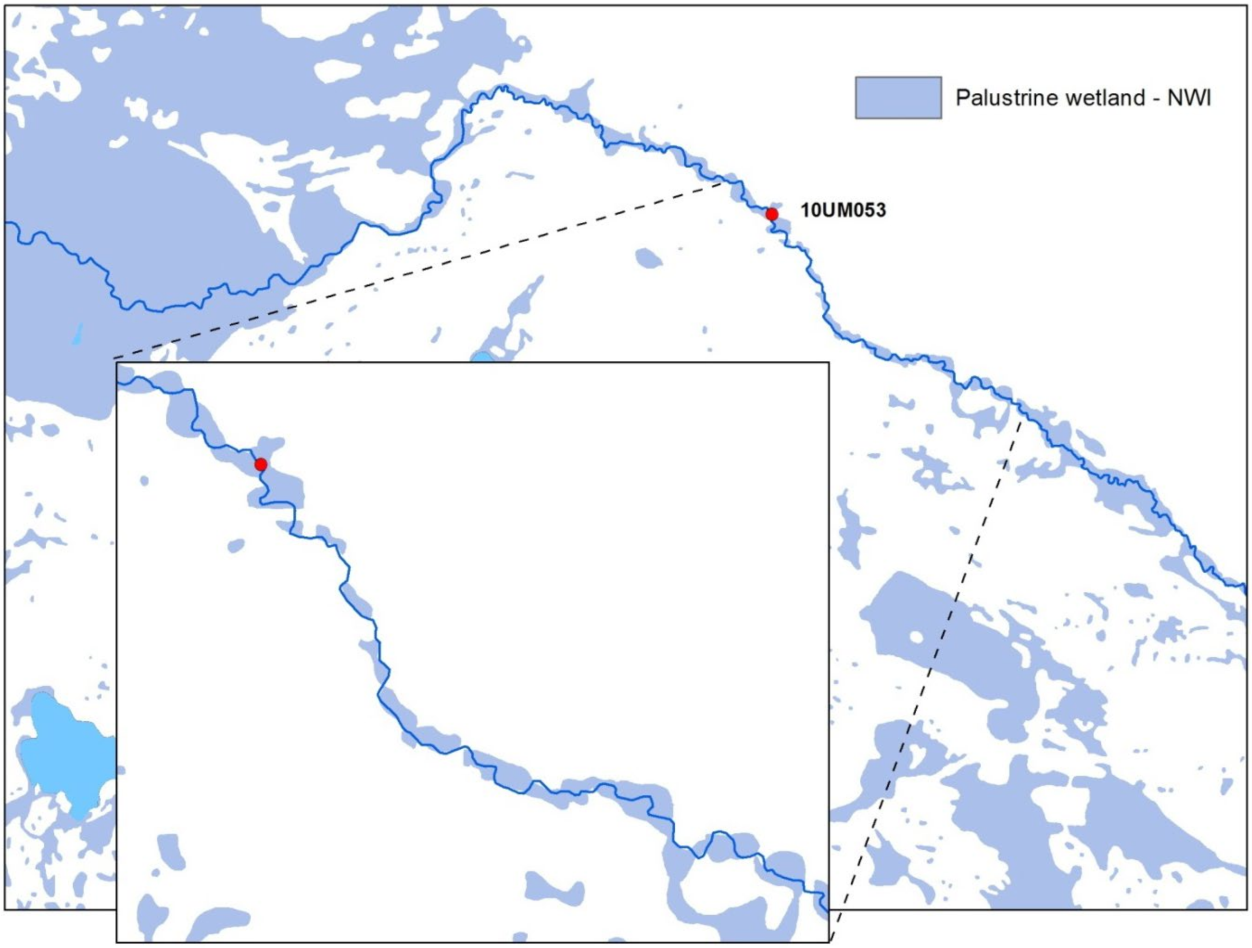

Figure 17. Upper section of AUID 537 showing extent of Palustrine wetlands along the riparian corridor. Note the huge wetland area the river flows through. This large wet area starts just below the outlet of Shell Lake.

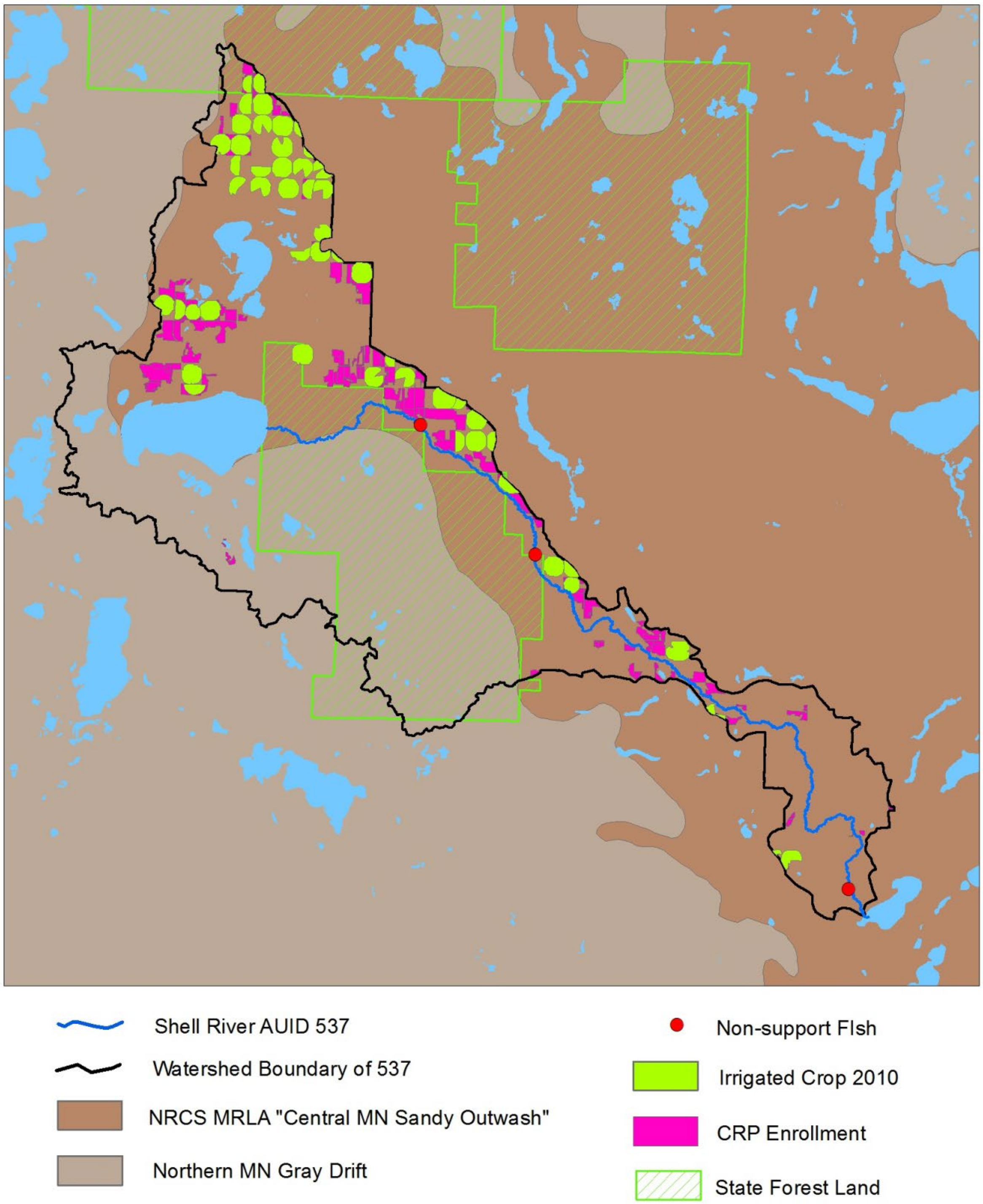

Figure 18. NRCS MRLA areas, irrigated acreage, CRP lands, and state forest boundaries in the AUID 537 (Upper Shell River) subwatershed.

Table 11. Various statistics for the Upper Shell subwatershed

- AUID Drainage Area‡ (DA) = **113.7 mi^2**
- Area of DA Irrigated Agric. in 2010*** = 4552 acres = 7.1 mi^2**
- Percent of DA irrigated in 2010 = **6.3 percent**
- Percent of DA in CRP 2008 = **6.32 mi^2** = **5.6 percent**
- Gradient of AUID (Shell Lake to Blueberry Lake)
    - § MDNR Lake Level Shell Lake (dammed outlet) = **1519.1** (min/max average)
    - § LiDAR Lake Level Shell Lake = 463.3 m = **1520.0 ft**
    - § MDNR Lake Level Blueberry Lake = **1369.5 ft** (OHW)
    - § Stream miles of AUID δ = 56192 m = **34.92 miles**
    - § Gradient = 150.5 ft drop over 34.92 river miles = **4.3 ft/mi = 0.814 m/km** (This is very similar to the gradients calculated for sites 10UM053 and10EM133, so those sites should be quite representative of the AUID).
    - § Slope = 4.3 ft/mi = 4.3 ft/5280 ft = **0.000814** (note, this slope puts this AUID in the Rosgen c-subcategory, meaning the Shell River has lower slope than typical for the Class C stream type.
    - § Generalized AUID-wide Rosgen class = **C5c-**
- In the 20m buffer of the Upper Shell AUID, 69.4 percent of that land area is wetland.Φ

‡Calculated using a web-based watershed delineation tool of USGS, "StreamStats"
*Irrigated fields digitized from 2010 FSA aerial photography by the author.
δ The author hand-digitized the channel of the AUID for more accurate length measurement than using the National Hydrography Dataset (NHD) GIS linework.
ΦCalculated using GIS and the National Wetlands Inventory coverage

Review of initial data

Habitat

Though the riparian conditions along the Shell River are quite natural and healthy, the instream habitat is poor to fair (Table 12). There are relatively few macrophytes, no rock, and a minimal amount of large wood pieces (Photos 9, 10, 11). Deep pools are not common due to low gradient combined with lack of large woody debris to cause local scouring, though in those areas where riparian forest exists, significant wood is present (Photo 12). Most riparian areas along the Upper Shell however have no tree canopy, as soils are too wet. These missing channel features and the channel habitat they create have been recognized by MDNR as limiting fish populations in the adjacent Straight River. The MDNR is importing large trees and placing them such that they will create a narrower, deeper, more sinuous channel (Photos 13 and 14).

Table 12. Substrate and cover scores from the MSHA.

Site ID	Location	Substrate	Instream cover	Riparian – shade	Channel morphology	Total
10UM053	Smokey Hills Road	18 of 27	8 of 17	1 of 5	14 of 36	41 of 85
10EM133	Adjacent to CR 47, 10 mi. E of Park Rapids	16 of 27	12 of 17	1 of 5	26 of 36	55 of 85

Photo 9. Mid-reach photo from 10EM133. Photo depicts the typical sandy, shallow, uniform depth, exposed, canopy-lacking, non-woody riparian condition common (and natural) throughout this AUID. Large pieces of downed wood are uncommon in this AUID.

Photo 10. Aerial photo showing 1) the common, riparian sedge-meadow habitat along the river, 2) the extremely homogenous, cover-poor fish habitat – this isn't turbid water, it is the sand substrate - the black along the edge is thin organic detritus deposited on the sand, 3) the near-absence of wood debris or macrophytes.

Photo 11. Shell River channel immediately DS of photo 10 (110th St.) showing poor instream and riparian cover, sand-dominated substrate, and homogenous channel habitat. Also shows the ubiquitous palustrine riparian habitat.

Photo 12. Large wood in the channel adds habitat complexity. In the areas where forest can exist in the riparian corridor (due to elevated topography), a more heterogeneous habitat (shade, cover, scour pools, food production, flow refugia) can be found. These forested riparian areas are uncommon however, due to saturated riparian soils.

Note how shallow it is
in mid-channel area

Photo 13. MDNR deemed that parts of the adjacent Straight River needed habitat enhancement due to the absence of structural habitat/cover and channel forming materials. Trees were imported and carefully placed to enhance the naturally bland, homogeneous channel morphology. *MDNR Photo*

Photo 14. Placement of imported trees intended to deepen the thalweg, narrow the channel, add sinuosity, and add cover for fish. Again note the natural wide sedge meadows that occur in this region. *MDNR Photo*

Irrigation and other agricultural effects

No analysis of irrigation effects to the groundwater levels immediately adjacent to the Shell River is available and the Upper Shell River is not gaged. However, a cursory review by Andrew Streitz (MPCA) found no evidence of long-term flow modification trends due to irrigation and municipal water withdrawals in the adjacent Straight River watershed (Figure 19), where there is actually more irrigation and the Park Rapids municipal wells near that river. During the assessment process meeting, where numerous stakeholders may attend, no comments were received regarding observations of declining stream flows, though that does not rule out the possibility. This area, being a location of significant groundwater withdrawal, is currently planned to become a pilot project of MDNR, which may more actively manage it as an "Aquifer Management Area". More data on the aquifer dynamics and interaction with area streams will be available from the MDNR efforts in the coming years.

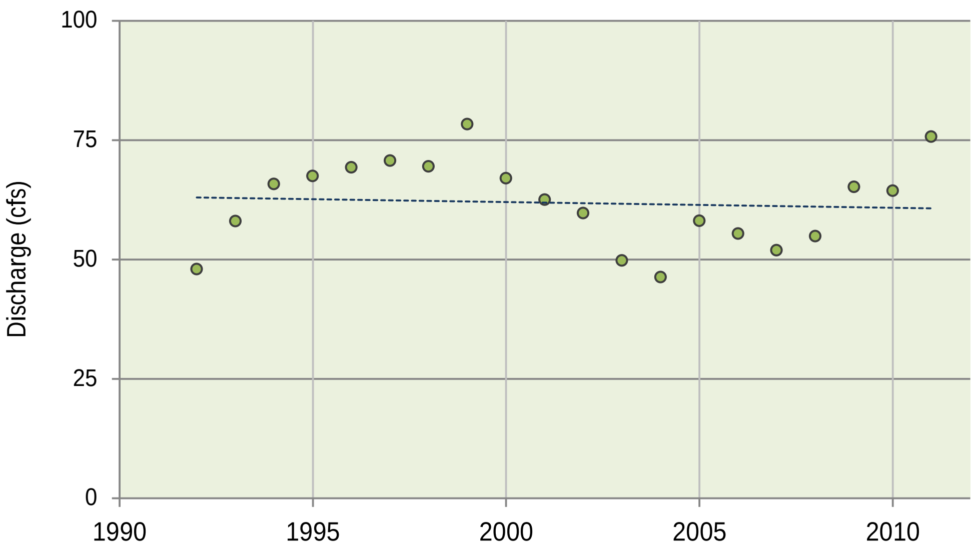

Figure 19. Straight River discharge for past 20 years. The Straight River watershed has more irrigation occurring than in the Shell, and does not have the adjacent high elevation natural area for groundwater input. Graph provided by Andrew Streitz – MPCA

Chemistry

Nutrients

Measured TP concentrations were between 0.048 and 0.081 mg/L. Nitrate concentrations were very low. The maximum nitrate measurement was 0.079 mg/L, and the values from the other two sites were less than the reporting limit of 0.05 mg/L. These low levels of nitrate would not be sufficient to promote significant aquatic plant growth. They are also far below values where nitrate becomes toxic to aquatic life. Ammonia was less than the reporting limit of 0.1 mg/L at all three sites. Thus, unionized ammonia cannot be calculated, but would be much lower than the state unionized ammonia standard. Typically only a very small percent of the ammonia is in the unionized state.

Oxygen

Intensive watershed monitoring DO values looked good, though instantaneous readings provide only limited insight into the overall picture of the DO regime (Table 13). These however are in the range for a healthy stream during the mid-day hours.

Table 13. IWM DO values (mg/L) in the upper Shell River, 2010

Site	Date	Time	DO
10UM053	6/9/2010	18:03	9.01
10UM053	8/31/2010	13:59	7.59
10EM133	8/26/2010	13:00	8.38
10UM055	6/9/2010	14:57	9.48
10UM055	8/30/2010	19:14	8.39

Targeted investigation and results

Agricultural influences

Soil erosion is not noticeable as one drives throughout the watershed. One does not observe farming to the edge of the stream bank in this area. Streams typically have a significant natural buffer along their riparian areas. Buffers are more effective at trapping phosphorus and sediment. Nitrate is soluble and can be transported into streams by groundwater. Given the nitrate and ammonia samples taken from the Shell River, it does not appear that agricultural nitrate is significantly entering the Shell River.

Connectivity

The author checked road crossings for problematic fish passage while collecting other data. A subsequent, more-quantitative inventory of road crossings was conducted by MDNR. As a result of both efforts, at least four human-placed infrastructure elements appear to be at least partial barriers to fish migration, that is, at certain time periods or for certain fish species (Figure 20). These occur at wide ranging locations within the AUID. The outlet of Shell Lake has a low weir blocking fish access to/from the lake (Photos 16, 17). The author observed geomorphological and flow alterations at the crossing on the downstream end of biological reach 10UM053, and the next crossing downstream (DS), only a short distance away. MDNR staff completed a detailed geomorphology study of the culverts and stream channel from upstream (US) of Smokey Hills Road to a ways DS of Guyles Road using survey gear, which verified that the set of culverts at these two close-proximity crossings is problematic (Appendix 1). The Guyles Road crossing culvert has extremely high velocity (Photo 18). Further downstream, an old bridge on an abandoned road significantly constricts flow and accelerates velocity (Photo 19). The culvert at 520th Ave. is undersized, resulting in high water velocity in the culvert, and a large scour pool in the stream (Photo 20). A float trip would be helpful to verify that there are no other old structures that may be barriers. A review of aerial photography showed a possible barrier at coordinates 46.879652, -95.229093. (Photo 15).

Photo 15: Possible barrier with turbulent overflow

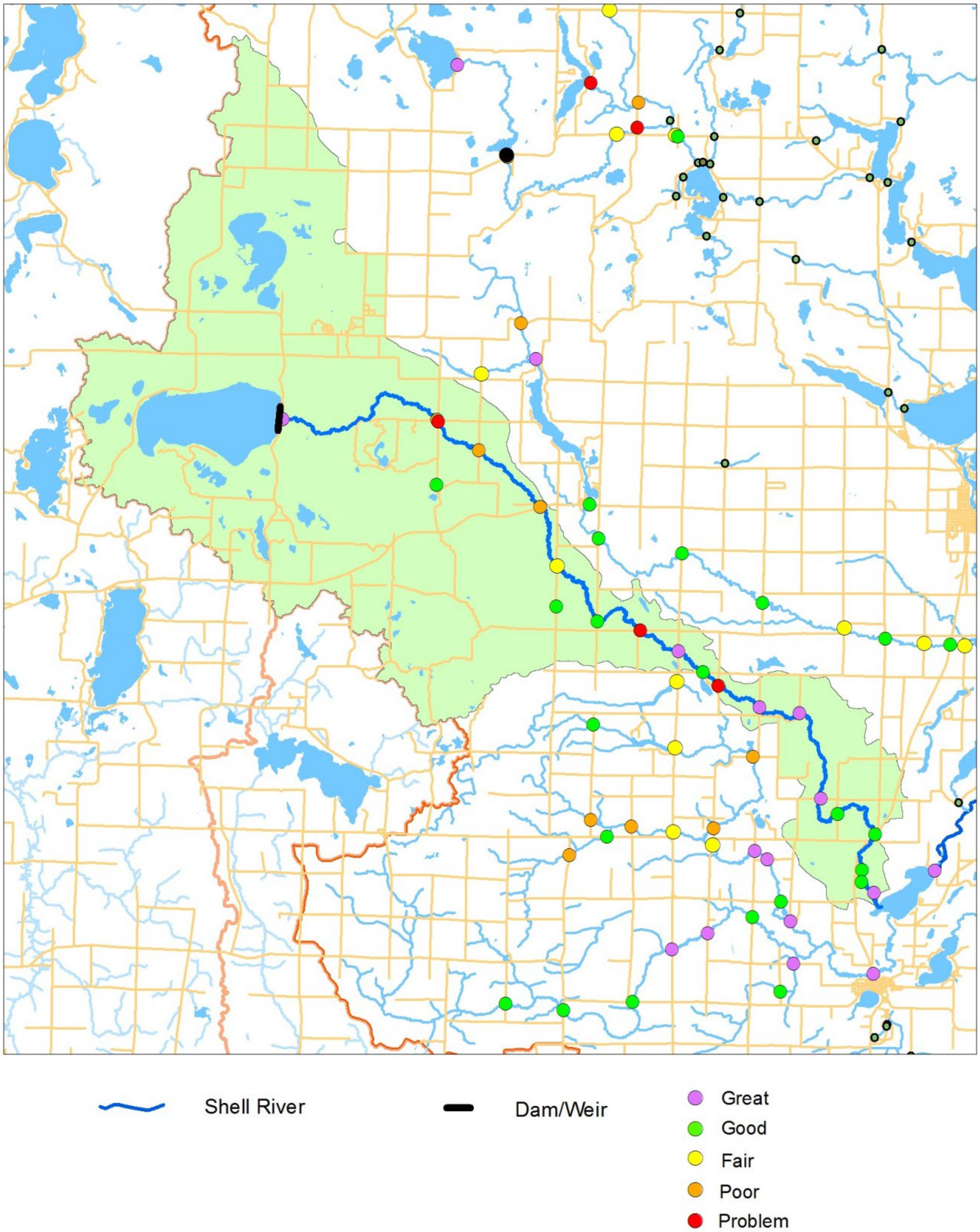

Figure 20. Upper Shell River Connectivity Assessment. MDNR performed as assessment of the road crossing structures, denoting their effect on the channel and fish passage. ***Survey and map by Mike Kelly, MDNR.***

Photo 16. The small dam at outlet of Shell Lake (beginning point of AUID - 537) in fall 2012 - blocks fish movement between the lake and river, possibly restricting access to winter refuge habitat

Photo 17. Dam at outlet of Shell Lake a week after lake opened, May 2013

Photo 18. Culvert at Guyles Road, a) intake of culvert, b) outfall of culvert

Photo 19. Old bridge structure at 580th Ave., May 2013. High velocity occurs through the constriction between the concrete bridge abutments and a large scour pool results. A couple large suckers (~14”) were seen on upstream side of bridge. Small species would have much difficulty passing through this level of water velocity.

Photo 20. Culvert at 520th Ave. Strong velocity was observed coming from the culvert, which is undersized, and this large scour pool is the result of these more-erosive flows.

Dissolved oxygen – continuous data

At site 10UM053, (uppermost site), Sonde data from a week-long deployment in 2011 showed low DO during each day's pre-dawn period (~ 3.0 mg/L). There is geomorphologic alteration here from improper culvert elevation at two closely-occurring culverts leading to channel widening and sedimentation above each culvert, and scouring below. A comparison of archived aerial photographs from the 1930s to 1960s shows the channel in a narrow condition, equivalent to the adjacent stream reach widths, whereas the 1970s to current photos show the channel has significantly widened (Photos 21 and 22). It was noted at the invert visit that the substrate above the culvert was deep detritus, which seems to be depositing due to the culvert base being at too high an elevation, and thus having a bit of a damming effect. A later trip confirmed this (Photo 23). The areas just upstream of each of these culverts show telltale signs of excess deposition of sediment, that being mid-channel bars, and the resulting over-widening of the channel (Photos 24 and 25). The slowed flow coupled with deposited decaying organic particles, increased macrophyte growth, could be responsible for the daily sag in DO below the standard. More Sondes were deployed in 2012 (Figure 21). At 10UM053, the daily minimum DO level is often below the standard, while at County State Aid Highway (CSAH) 47, which is a short distance DS of 10EM133, the daily drops are just barely below the standard on some days, while at CR 111, several miles further downstream, the DO minimums did not drop below the standard. So, from upstream to downstream, the DO improves in this AUID.

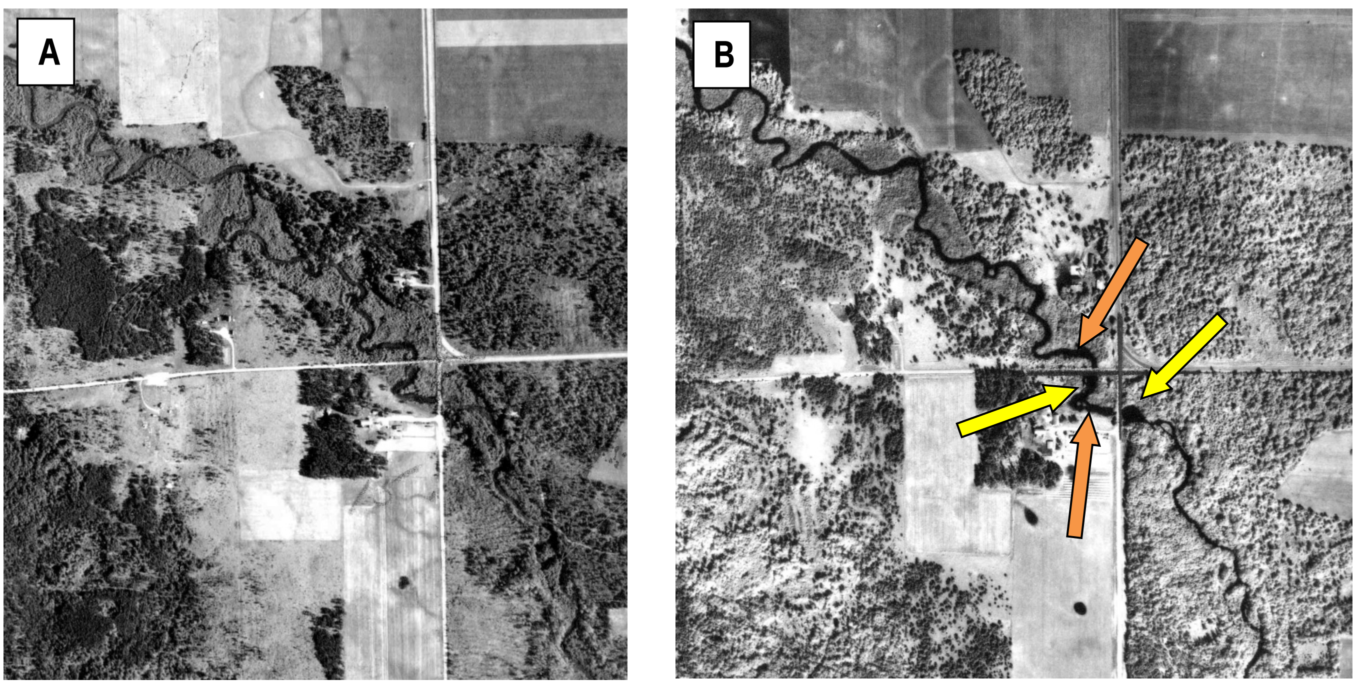

Photo 21. Historic aerial photos of site 10UM053. A. 1953 aerial photo, B. 1973 aerial photo. Yellow arrows point to new scour pools and orange arrows to widened channel.

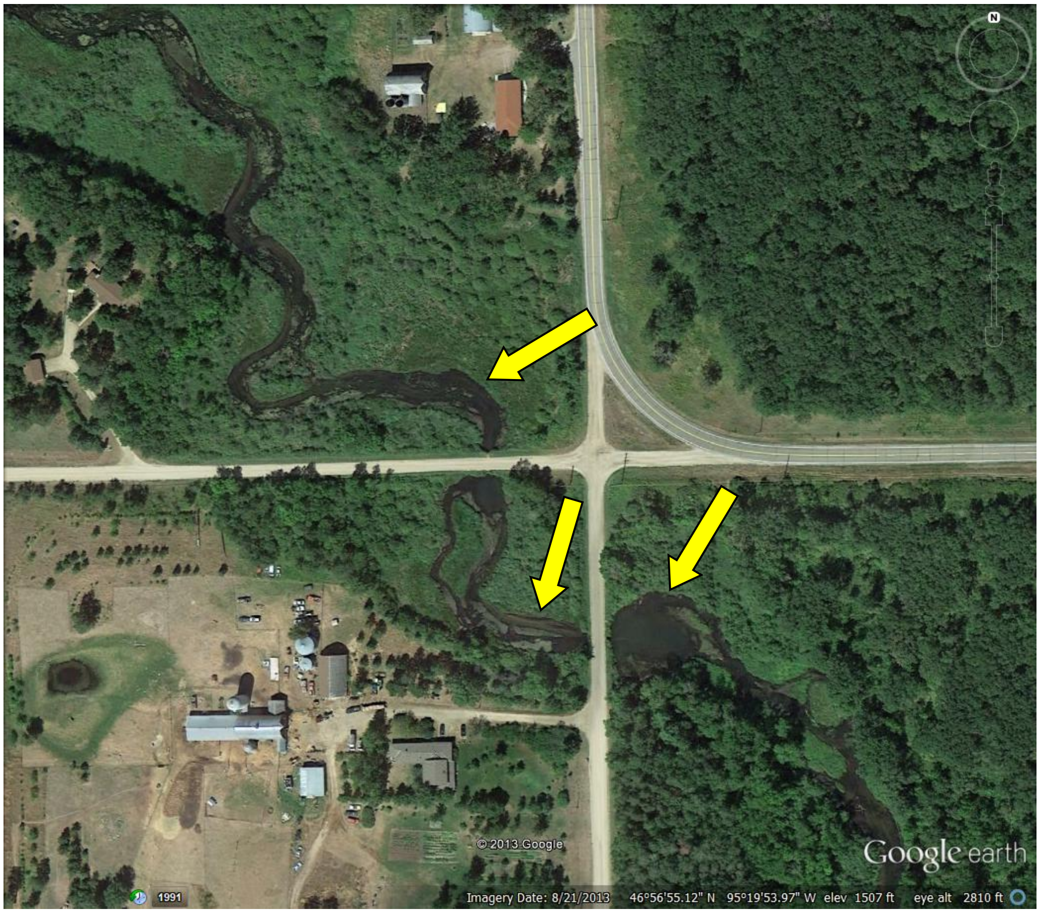

Photo 22. 2013 Aerial photo of site 10UM053. This is a low-flow period. Arrows point to detritus deposition areas.

Photo 23. Muck at site 10UM053. Culvert downstream is set too high, decreasing gradient, and likely causing deposition of this organic material here. This organic sediment likely adds to the DO sag that occurs here.

Photo 24. Sediment deposition at 10UM053 just above the Smokey Hills Road culvert

Photo 25. Sediment deposition just above the Guyles Road culvert

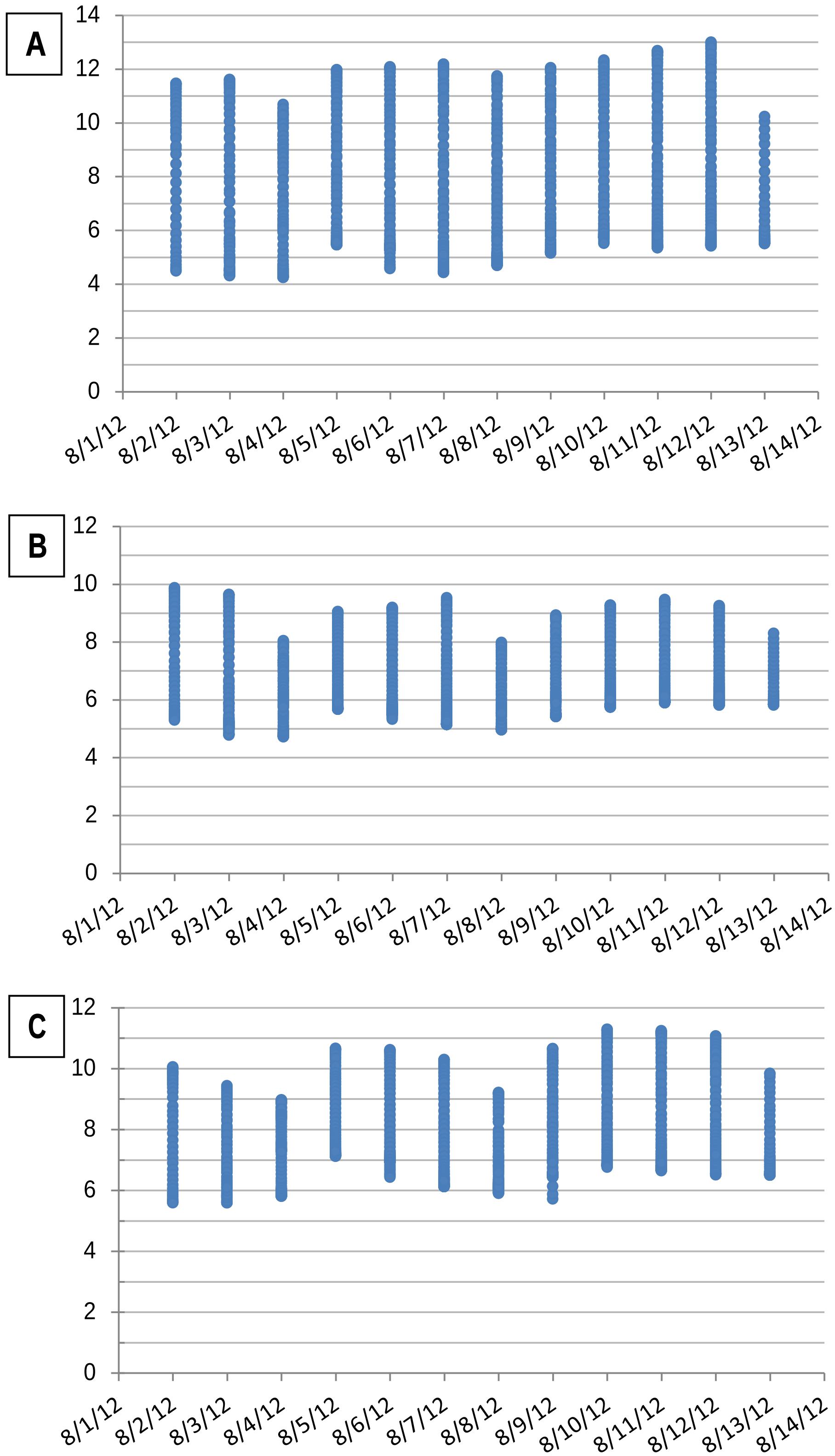

Figure 21. Sonde DO data from the upper Shell River AUID. A. Smokey Hills Road (10UM053), B. CSAH 47, C. CR 111

Dissolved oxygen – synoptic data

On October 5, 2011, a synoptic DO sampling of the upper Shell River AUID was conducted (Figure 22). DO is elevated in fall relative to mid-summer, so the absolute levels measured in this particular effort are not very informative of stress, but it provided some information as to how specific sites compare to one another. These differences would likely be more pronounced during mid-summer. However, daily temperatures for the week or more previous to this sampling were in the upper-70s to mid-80s with bright sun each day, and October 4, 2011, was in the 80s, so it was unusually warm for the period. Even so, the stream temperatures were much lower than they were a month earlier, on September 6, 2011. One small tributary (site 2) was not flowing, and access was difficult below the first big wetland (site 4), so no samples were collected at those two sites.

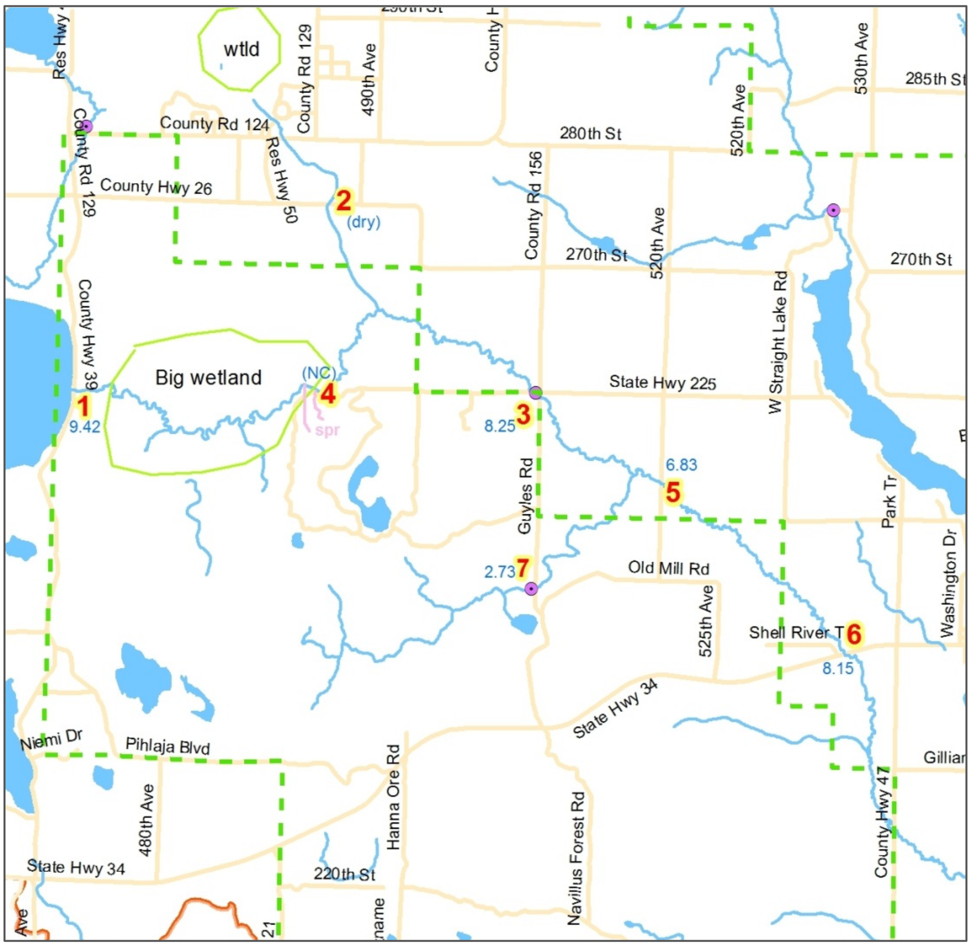

Figure 22. Map of Shell River early morning longitudinal, synoptic DO sites. Blue numbers are the DO measurements.

Dissolved oxygen levels dropped between the Shell Lake outlet and 10UM053 (site 3), though the 8:55 AM reading at 10UM053 was now much higher that it was in August, and well above the level of concern. However, there does appear to be a negative influence on DO by the large wetland /beaver-impounded area above 10UM053. Dissolved oxygen had dropped further at the next site DS (site 3), though still higher than 5 mg/L. There are no wetlands between these two sites, but there is a wetland-influenced tributary that enters just upstream, which had very low DO (site 7, 10UM054, 2.73 mg/L). The flow volume from this tributary did not appear to have been enough to drop the DO in the Shell by two mg. Perhaps there is some low-DO groundwater entering below site 7 too. By Highway 34 (site 6), the DO had recovered into the low 8 mg/L level. Temperature readings from previous 2011 measurements are lower downstream than at 10UM053, possibly due to groundwater inputs. The

Smokey Hills State Forest (in the green dashed area) is much higher elevation than the river channel, and thus would likely be transmitting surficial aquifer groundwater to the river channel. Indeed, numerous springs were observed near map site 4, coming down from the hills.

Nutrients

Because the original nutrient data did not show concentrations that are problematic for creating eutrophication, no additional chemistry samples were collected. However, observations of stream conditions were made by the author during numerous visits to the Shell River, and at many locations, and observable evidence of eutrophication was also lacking. Most sites have very low abundance of macrophytes (e.g. Photos 10 and 11), and no notable filamentous or suspended algae was observed. Some duckweed was observed during the fall of 2012, but summer 2012 was very atypically dry. A local resident said they had never seen the river as low as it was in late summer 2012.

Habitat

Three natural environmental factors combine to reduce the availability of primary habitat for many important macroinvertebrates and some fish species in the Shell River. The two most important aquatic habitats for sensitive macroinvertebrates (those most useful for assessing stream health, the Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa) are rock (large gravel, cobble, and boulders), and wood (e.g., trees that have toppled into the stream and become lodged). The third factor that influences the utility/quality of these first two is water velocity. Most sensitive inverebrates are found on/in hard substrates in areas with significant water velocity. There were six and 13 EPT taxa at the upstream and mid-stream sites respectively. Nearly all taxa were habitat generalists (e.g. Leptophlebiidae, Caenis, Iswaeon), rather than those reliant on hard substrates and swift flows. Taxa utilizing the later habitat were few; only one immature Perlidae, three immature Hydropsychidae, and six Baetis individuals were sampled in the mid-stream site. None of the upstream EPT taxa were hard substrate/swift flow dwellers. No hard substrate was found to sample in either location. This habitat association for sensitive EPT taxa is very well known in the field of stream ecology, and an example to validate this comes from studies done by Allan et al. (2012) in Michigan, who found that, "Statistical analysis indicated that stream condition was positively associated with the extent of undisturbed land (forest + wetland), with coarse glacial geology [gravel/cobble], and with higher stream slope [velocity]." They further state: "The probability of finding excellent habitat is roughly twice as high when the riparian buffer is undisturbed; the sub-catchment consists of coarse geology, and the stream slope is high." (Allan et al., 2012) The Shell River is naturally lacking these important habitat factors because: 1) a geological condition exists where the surficial geological material over much of the watershed is composed of pure sand to a depth of tens of feet, 2) though the riparian buffer is generally undisturbed, it is generally not forested but rather is palustrine wetland, and thus many of the positive habitat factors a forested buffer provides (wood input, shade, and creating increased geomorphic variability) are not present here, and 3) the flatness of the terrain in much of the watershed, which influences water velocity, resulting in the commonly-found low velocities in many CWRW streams.

The lack of large woody debris (LWD) may be the primary fish habitat factor missing in this AUID. It seems odd, given that the Shell River runs through a forested region, but as mentioned, the lack of woody debris in the river appears to be a natural condition. Johnston's et al. (2007) review of woody debris recruitment to streams listed four methods by which wood enters streams: bank erosion, toppling, windfall, and landslides. Only the first three apply in this area of Minnesota. They discussed that the riparian source areas for the wood for these three mechanisms was within about one tree height of the channel edge. Due to the characteristic sedge-meadow riparian landscape along the Shell River, trees cannot grow close to the channel due to saturated soils, and the tree line occurs much farther away from the channel than a typical tree height along much of the Shell. The author measured the amount of wetland in the 20m on either side of the river in this AUID and found that it covers 69.4 percent of that land area (Table 11). Cordova et al. (2007) noted in reviewing other studies that there is an apparent relationship of LWD increasing in importance for pool formation in low gradient streams lacking coarse substrate (as is the case with the Shell River). Angermeier and Karr (1984) discuss the various benefits of woody debris: pool formation, protective cover, current refuge, and production of invertebrate food. Gurnell et al. (1995) discuss the importance of LWD in streams of forested areas, stating that it influences “a wide range of physical habitat characteristics including light, temperature, flow, sediment transport and substrate conditions, thereby promoting high biological diversity within the river environment.” The lack of LWD in the Shell River means that the habitat diversity which wood produces is largely missing.

Conclusion

Unless some of the habitat parameters are in a degraded condition due to the original clearcutting of the landscape 100+ years ago, it does not appear that land use is a significant contributor to the poor habitat found in the river. Original logging did not likely alter the riparian area because the channel corridor is bordered by extensive palustrine wetland. Though no information could be found as to whether the Shell River was used for log drives, which were damaging to stream channels, it seems that the Shell would be a poor river to drive logs using the dam-breaching approach, because the wide flood plain would not contain the flush of water, and logs would be scattered and beached well away from the river.

Because there is no information on the aquifer levels in the upper Shell River subwatershed, and what exists for the adjacent Straight River watershed does not currently show a reduction in stream flow volumes, the effect of the irrigation occurring in this subwatershed is not considered a stressor at this time as no data are available to assess flow trends. The MDNR has been equipped by the 2013 Legislature to dramatically increase aquifer monitoring and management, and will be closely monitoring water levels of the Pineland Sands aquifer in the years ahead, and so much more information on this factor will be available in years to come.

The low DO found in the upper part of the subwatershed is most likely due to the extensive wetlands below Shell Lake and the addition of water from tributaries draining wetlands, input of groundwater, and the extremely low gradient of the river in the upper reaches, which is poor at naturally re-aerating the water by turbulent flow.

One anthropogenic cause of fish impairment here is likely several road crossing structures that at least at times are barriers to fish migration. In addition, the culverts at the two crossings below site 10UM053 have altered the river’s geomorphology, and in a way that may be exacerbating the low DO condition. Replacement of these two culverts, with proper sizing and elevation setting, would allow for a return to proper gradient and channel width and depth to form, which would increase the passage of the currently-depositing, decaying vegetation and decrease water temperatures, both of which would move the DO in the right direction, as well as allowing for better fish passage within this upper reach. MDNR - Park Rapids has initiated contact with the township regarding possible replacement of these culverts. The MDNR also has the Shell Lake outlet structure on its list of structures to inspect/review.

A review of the data collected during the SID effort was conducted by a MPCA committee, which determined that the Upper Shell River could be assigned to a non-pollutant category (CALM Category 4C), with the impairment stemming from anthropogenic physical barriers to fish migration. Given the habitat challenges that also naturally occur here, fixing the fish migration barriers (Shell Lake outlet and problems culverts) should improve conditions for fish in the river, but still may not result in a fish community that meets the MPCA non-impaired threshold. However, the river’s geomorphology and fish community would be able to attain their natural conditions.

Swan Creek (AUID 07010106-527)

Impairment: Swan Creek had three 2010 biological sites used for assessment. The creek was assessed as impaired for not meeting macroinvertebrate community expectations at 10UM108 and 10EM086 (76th Street southwest and near the intersection of CSAH 32 and 91st Avenue southwest). These two sites were in the headwaters and near the mouth respectively. The third site (10UM081), midway between these two impaired sites, had an excellent IBI score for macroinvertebrates. All three sites scored well for fish. Both of the impaired sites are in reaches that are pastures with unrestricted animal access to the stream. Two additional sites for macroinvertebrate sampling were added in 2012, each of them fairly near and downstream of the pastured sites. These will be discussed below.

Review of the subwatershed

Aerial photos were reviewed to understand the landscape and land use within the subwatershed. The area is completely rural, and residences are sparse. Thus urbanization stressors (e.g. impervious surface area) were eliminated as a potential cause of the impairment. The complete length of the stream was followed on aerial photos to look at riparian conditions, and overall, the riparian vegetation is very natural, and there is a wide buffer of this vegetation along the channel. The exception is the few areas where pasture extends into the riparian area. There are two registered feedlots in the subwatershed, with one being inactive, though it appears there may be a couple more that are not registered. Wetland acreage is abundant, and there are many times more wetland acres than those used for intensive agriculture, a ratio of over 18 to 1. The primary agricultural land use is hay/pasture (Table 14), and cattle are grazed on large-acreage pastures, some of which are wooded or semi-wooded pasture.

Photo 26. Iron Creek, showing the extreme iron conditions found in area tributaries, which are also found in the CWRW in the adjacent are north of Swan Creek. This iron is a sign that there is significant groundwater entering the creek.

With the abundance of wetland area, and similar geology and topography of the CWRW area to the north of Swan Creek, there is potential to find the **same naturally-caused low DO and elevated** phosphorus levels as found in those streams (as discussed above). Tributaries to Swan Creek show the same dominance of groundwater inputs (Photo 26) as those streams north of Swan Creek. Given the findings above regarding human activities in the landscape, the most likely anthropogenic stressors are those having to do with animal agriculture, which can include nutrient elevation and physical alteration of stream habitat from a change in riparian vegetation as well as trampling of the banks. It is also likely that there could be natural factors contributing to conditions that are less favorable for macroinvertebrate communities, such as substrate type. These are the stressor pathways investigated further as potentially causing the macroinvertebrate impairment.

Table 14. Land use statistics for each of five subwatersheds of Swan Creek. The subwatershed delineations are based on SID water chemistry sampling locations. Figure 18 shows these five land areas. Source: USDA 2011 GIS shapefile. Note: 0.00 = some present, but less than 0.005, NP = none present on 2011 USDA shapefile within the Swan subwatershed.

Aggregated cover types	% area of Swan Creek subwatersheds					Total % area
	Upper Swan Cr.	Lower Swan Cr.	Little Swan Cr.	Iron Cr.	Unnamed Cr.	Swan Cr. above CSAH 32
Row Crops	1.52	2.14	1.29	1.17	1.36	**1.6**
Alfalfa/Clover	1.39	0.38	0.52	0.57	0.07	**0.6**
Other Hay/Non Alfalfa	17.87	9.13	20.22	37.78	1.25	**17.9**
Developed/Open Space	2.37	3.10	2.50	3.37	1.99	**2.7**
Developed/Low Intensity	0.02	0.00	0.05	0.00	NP	**0.0**
Developed/Med Intensity	NP	NP	0.00	0.00	NP	**0.0**
Developed/High Intensity	NP	NP	NP	NP	NP	**NP**
NWI Palustrine wetlands	30.07	29.47	25.12	33.28	43.03	**30.3**
NWI Lacustrine wetlands	NP	0.29	NP	NP	NP	**0.1**
NWI Upland	69.93	70.24	74.88	66.72	56.97	**69.5**
Ratio of wetland to row crop acreage	19.7	13.8	19.5	28.5	31.6	**18.6**

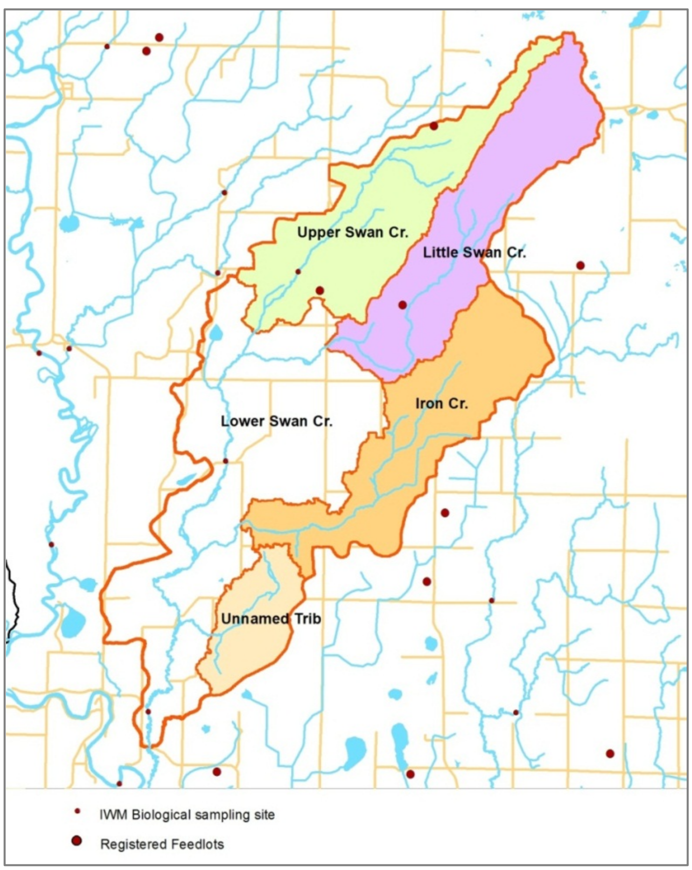

Figure 23. Swan Creek subwatershed with smaller subwatershed delineations based on SID water chemistry sampling locations. Registered feedlots are also shown on map.

Review of initial data

Chemistry

Swan Creek had a fair amount of chemistry data available from the IWM phase, with one site (CSAH 32, near the mouth) being a 10x site. These data are presented in Tables 15 and 16. Sample results show that, at least in places, this AUID has substandard DO levels and phosphorus levels that are sometimes at or slightly exceed the proposed TP standard for this area (0.100 mg/L). The TP in the lower part of the AUID nearly always meets the proposed TP standard, though in 2010, a year in which TP measurements were relatively higher than normal in this area due to abnormally wet conditions, were often quite near the threshold (Figure 24). Nitrate and ammonia levels were very low, often below the lab detection limit.

The DO in Swan Creek is low in the summer months (Figure 25, Table 15). These numbers are instantaneous measurements taken at various times, and are not daily minimums. The data do however signal that DO concentrations are problematic for the biological community during at least parts of the summer.

Table 15. Chemistry data from the three IWM biological sites collected at 2010 visits to sample fish and macroinvertebrates. Values are in mg/L.

Site	Time	Date	Cond.	Temp.	pH	DO	Time	TP	Nitrate	Ammo
10UM1	10:03	06/30/	328	19.0	7.36	3.70	9:55	0.125	< 0.05	0.116
10UM1	15:14	09/16/	339	16.0	7.65	7.87	--	--	--	--
10UM0	11:30	08/17/	292	16.2	7.38	5.23*	11:30	0.092	< 0.05	< 0.100
10UM0	14:23	09/16/	276	12.5	7.56	7.87	--	--	--	--
10EM0	9:05	07/07/	333	21.8	7.78	6.60	9:05	0.067	< 0.05	< 0.05
10EM0	--	08/10/	--	--	--	--	--	--	--	--

*Based on normal daily DO fluctuations and the time of day this sample was taken, this site was highly likely to have been below the 5.0 mg/L standard earlier on this morning.

Table 16. Data collected May - September 2010 at the 10x site, S006 -293, CR32. Values are in mg/L.

	DO	TP	Nitrate
Average	5.14*	0.073	< 0.053
Maximum	6.82	0.102	0.130
Minimum	2.43*	0.029	< 0.030

*Data not necessarily from daily minimum values.

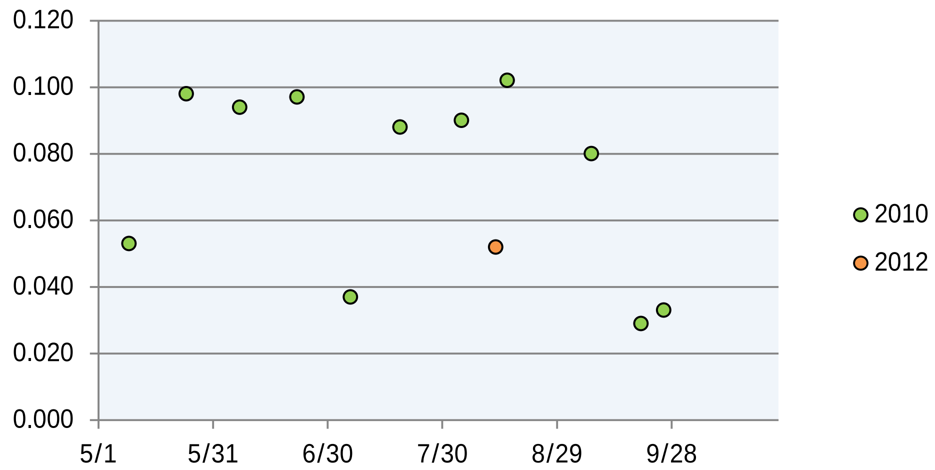

Figure 24. TP in mg/L at S006-293, at CSAH 32, which is near the confluence with the Crow Wing River

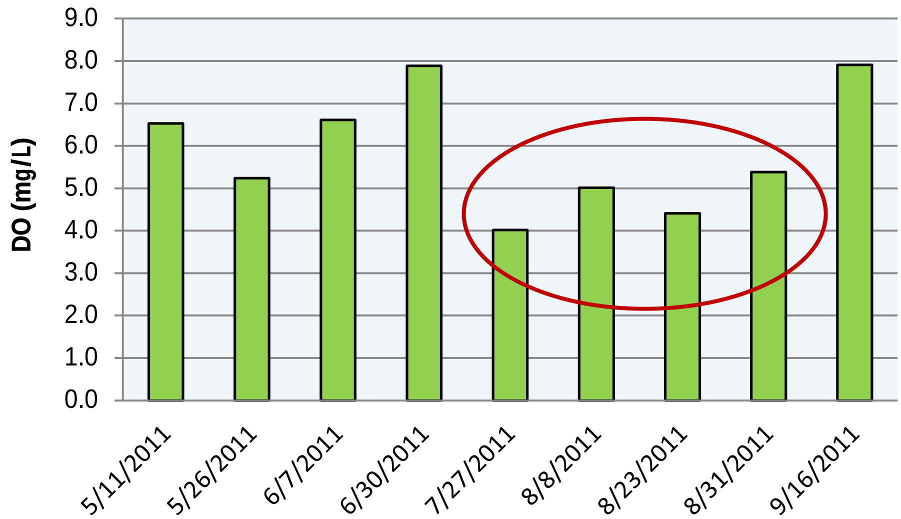

Figure 25. Dissolved oxygen measurements from the 10X data set at S006-293 (CSAH 32)

Transparency

Transparency tube readings in 2011 (10 visits) were all > 100 cm. In 2010 (9 visits), five were > 100 cm, two > 90, one = 80, and one = 76. The summer of 2010 was abnormally wet, and high flow volumes are the likely cause of the somewhat reduced water clarity, though even the lowest numbers measured are still quite good.

Biology

At the headwaters site, 10UM108, the only targeted macroinvertebrate habitat found and sampled was undercut banks, so habitat is limited. This is reflected in the Taxa Richness metric, which scored very poorly, meaning the macroinvertebrate community had low diversity. Other metrics, related to the sensitive EPT groups, also scored badly (e.g. EPT Taxa Richness = 2, Clinger Taxa = 5, Intolerant Taxa = 0), thus the community is mostly composed of tolerant, generalist taxa. It appears that there should be some rock or gravel substrate (i.e. EPT habitat) here, because this site is in a higher elevation area fairly near the St. Croix moraine, which is formed of glacial till. There are exposed boulders in the pastures that surround this location. Thus, it may be that the animal usage of this reach may have contributed fine sediment that has smothered the rock substrate, which is a common result of animal access to streams (Tufekcioglu *et al*., 2013).

At the downstream impaired site 10EM086, of the 10 metrics that compose the Class 4 Macroinvertebrate IBI, seven scored quite poorly, and three were in the neutral range, neither good nor bad. The Taxa Richness metric, the number of types collected (at genus level), scored quite low. Other metrics that scored poorly were those related to Clingers and Filterers. Habitat needs for clingers and most filterers include some type of hard, stable substrate (rock or wood), and at least a moderate water flow velocity. A general ecological positive relationship exists between habitat diversity and taxa diversity, and with the low biological diversity here, it suggests that habitat diversity may be low as well. Further, it appears that one of the important habitats missing here is the hard substrate. This is further validated by the fact that the staff who sampled macroinvertebrates only found one of the four habitats that are targeted in the MPCA protocol for macroinvertebrate sampling, that being aquatic macrophytes. Water velocity was recorded at the sampling visit as moderate, so it seems that the flow habitat component is not limiting. The general composition of the macroinvertebrate community reflects more of a wetland community, rather than a stream community. There were several snail taxa (Hydrobiidae, *Gyraulus*, and *Physa*, fingernail clams, high numbers of amphipods, abundant immature coenagrionid damselflies, the hemipterans *Neoplea* and *Belostoma*, and the Trichopteran *Oxyethira*. These organisms are oriented to wetlands, or slow-moving, well-vegetated streams. The MSHA scores also substantiate habitat as a likely factor for the poor macroinvertebrate community, and are discussed next.

Habitat

A local landowner with a long history in the Swan Valley shared that cattle farming had historically been relatively heavy in the Swan Valley. There still are significant amounts of cattle present here, which are typically grazed on large acreages. Often, pasturing has created alterations in the riparian vegetation, sometimes via direct human intervention by removal of woody plants, or by cattle feeding and traversing. The two sites where the macroinvertebrates are impaired are reaches that currently have or historically had pastured riparian corridors. The third site is between these two sites, and has a natural riparian condition. It showed a very healthy fish and macroinvertebrate community.

The habitat assessments at these three sites match well with the health of the biological communities (Table 17). Site 10UM086 had the second highest MSHA score of 83 sites in the CWRW, while the two impaired locations had the third and sixth worst scores in the CWRW. This significant difference in scores, being on the same stream, may be explained by localized human influences, and the common factor occurring at both sites is cattle pasturing with animals having unrestricted access to the stream channel. The stream habitat degradation that occurs with animal trampling of stream banks has been well-documented (Kauffman and Krueger, 1984). Among the most common effects are bank erosion, channel widening and reduced depth, and conversion of substrates to fine particles (due to bank sediment deposition and the lowered stream power of the wider channel).

Table 17. MSHA scores for three Swan Creek biological sites.

Field number	Macro-invertebrate assessment	Land use total	Riparian total	Substrate total	Cover total	Channel morph. Morphology total	Total score
10UM108	Impaired	1.5	4.0	9.0	14	13	**41.5**
10UM081	Healthy	5.0	13.5	18.9	16	29	**82.4**
10EM086	Impaired	2.5	9.5	9.0	8	11	**40.0**

Some of these effects can be seen at site 10EM086. Photo 27 shows the 1939 aerial photo of the channel and surrounding landscape. The inset on the right shows a closer view of the channel. The naturally wet soils along the stream here, as is so common in the CWRW, originally grew woody brush (alder and willow shrubs). This vegetation is seen in the photo both above and below this pastured area. On the lower part of the insert, it can be seen that all of the woody vegetation has been removed and only grasses remain. At this date, the channel still appears to be narrow, and of the same approximate width as upstream and downstream, where cattle were fenced out.

Photo 27. 1939 Swan Creek channel and land use around site 10EM086

Over time, the stream in the pastured reach has widened significantly, as can be seen in the 2010 aerial image (Photo 28). The widening here is probably a combination of the removal of woody riparian plants and animal trampling. Stream banks are greatly stabilized and protected by the roots of woody vegetation and can erode more easily when the root systems of woody vegetation are no longer present, resulting in a wider channel. Animal trampling exposes soil which exacerbates the erosion of the banks. In lower gradient channels, such as here, this fine-particle bank material is deposited on the stream bed, where it smothers important habitat features. This process likely explains the low scores of the MSHA's riparian sub-score, as well as the poor-scoring substrate and channel morphology sub-scores.

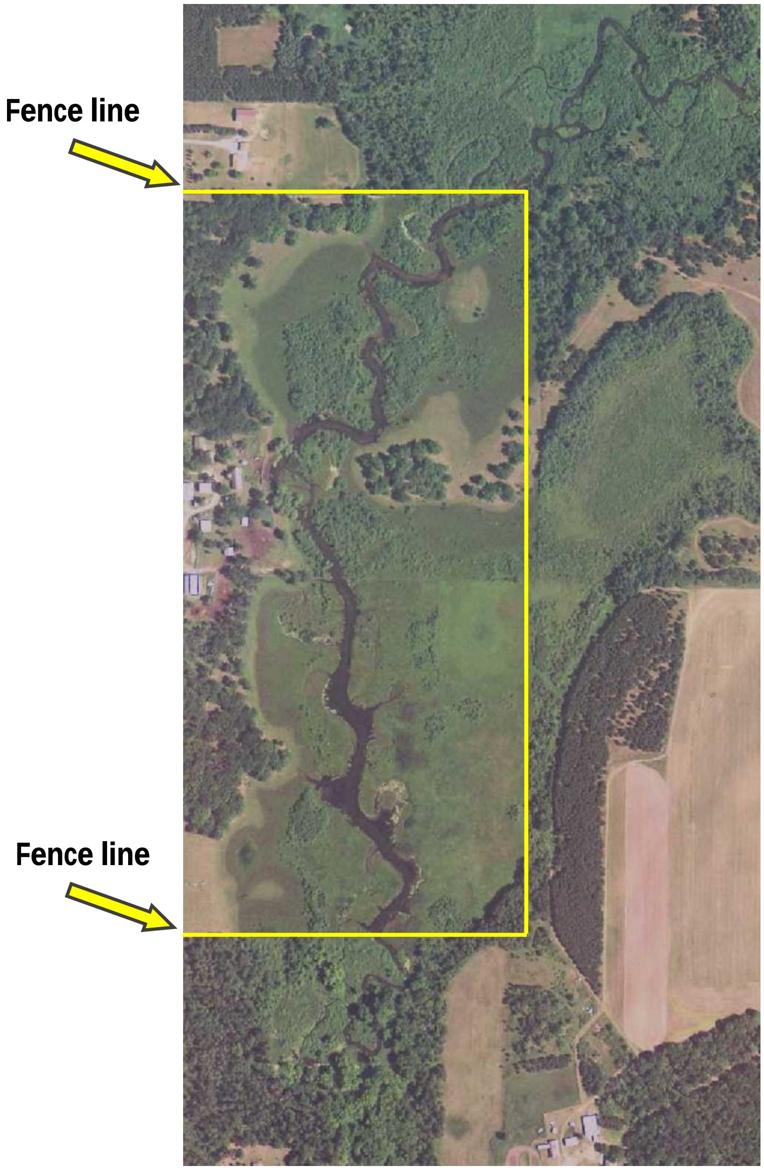

Photo 28. Recent aerial photo of the 10EM086 reach. Note how much wider the stream is in the pastured area versus the natural areas up and downstream.

Targeted investigation and results

Biology

Two additional biological stations were added to Swan Creek to see if there seemed to be effects from the pastures on locations a short distance downstream, where the riparian conditions were natural and forested. These were sites 4 and 10 on Figure 28, 12UM143 and 12UM144 respectively. Site 4 did not pass the Macroinvertebrate Class 3 IBI, even though the habitat here appeared healthy. There were several small, cobble-lined runs within this reach, and no macrophytes. All 20 sample parts were from rock and wood. The percent Clingers metric scored very well, which would be expected in a sample of only rock and wood, but two important Clinger groups, the insect orders Plecoptera and Trichoptera scored very poorly. Plecoptera were actually absent. These groups need good levels of oxygen, and yet the DO from the early-morning longitudinal sampling day was quite good here. One parameter that may be limiting the macroinvertebrates here is iron. The level on the date of the biological sample was 1480 µg/L, a fair bit above the EPA-recommended aquatic life standard of 1000 µg/L. This was the highest iron level found in the mainstem of Swan Creek, and is a natural phenomenon also occurring in neighboring streams.

Site 10 did pass the Macroinvertebrate Class 4 IBI, despite the fact that oxygen levels do drop below the standard during early morning. However, the IBI score was only a couple points above the threshold. This new site had a taxa richness of 44, versus 24 at 10UM086, and twice the number of POET taxa (Plecoptera, Odonata, Ephemeroptera, and Trichoptera). More target habitats were found here as well (3 of the 4). Since the below-pasture site scored considerably better than the in-pasture site, it does not appear that the upstream pasture is having strong influence downstream, though the DO regime downstream likely has lower daily minimums, due to the abundant plant life and greater solar radiation at site 10EM086 resulting from the open exposure and widening of the stream from pasturing there.

Dissolved oxygen

As one of the factors that showed up in the initial data as a problem for aquatic life was low DO, Sondes were deployed at two locations in August 2012 in order to capture the daily minimum oxygen levels and the daily oxygen flux. Sonde sites were at 80th St. SW and CSAH 32. At the US site, the daily flux was between about 0.8 and 2.4 mg/L, and typically about 1.0 mg/L (Figure 26). This is a very low flux, and represents a stream with little aquatic plant material (and thus not undergoing eutrophication here). The daily minimums were usually above the 5 mg/L standard, though on two days did dip to about 4.7 mg/L.

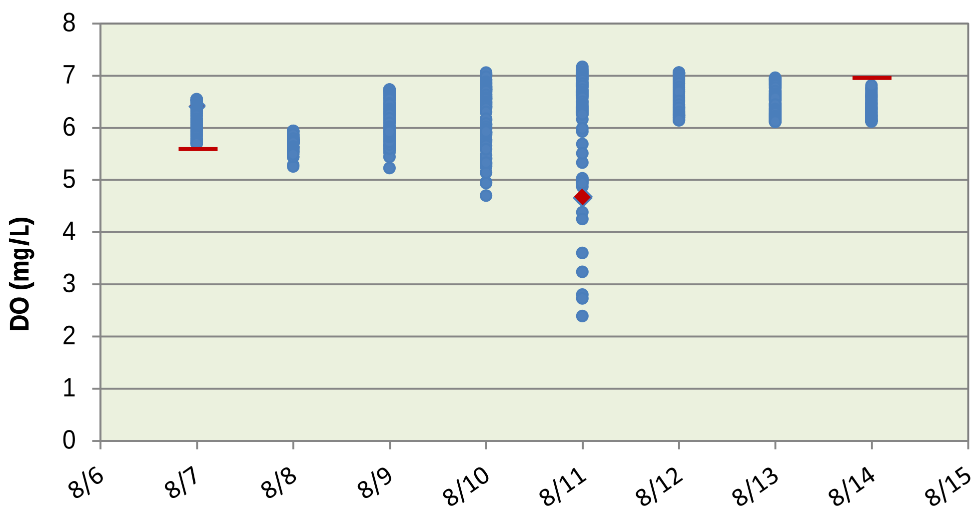

Figure 26. Sonde readings during August 2012 at 80th St. SW. On August 11, 2012, there was a temporary issue with the Sonde where a drifting leaf or other material caught on the Sonde. The red diamond represents the approximate low value for the day derived from a linear plot of the data.

The lower site showed problematic DO levels (below the standard) occurring daily (Figure 27). Note that the flux is significantly larger here as well, probably owing to some areas where the stream was wide and wetland-like, and where significant aquatic macrophyte growth was observed (e.g. at 92nd Avenue southwest). These daily maximums are also quite low for a stream that would be undergoing eutrophication.

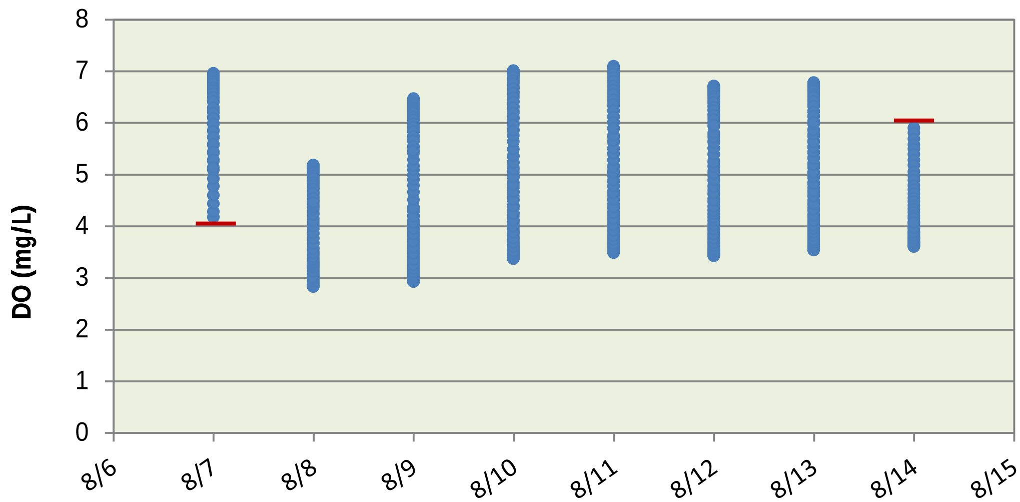

Figure 27. Sonde readings during August 2012 at CR32

A synoptic sampling effort was conducted during the period the Sondes were deployed. On August 12, 2012, seven additional sites were sampled in early morning, which included some sites on Swan Creek tributaries Figure 28. Results are shown in Table 18. Many of these locations showed DO that was substantially below the state standard, particularly the tributaries to Swan Creek. These tributaries were all turbid orange from high iron content (Photo 26), suggesting the water in these tributaries is resurfacing groundwater. Groundwater is often low in DO, and here the peat soil along the stream channels are further depleting the oxygen in the groundwater before it surfaces near or in the streams, due to microbial decay of the organic material.

Table 18. Synoptic DO readings (mg/L), August 12, 2012

Map site #	Stream name	Time	Temp.	DO	Color
1	Swan	--	--	--	--
2	Swan	7:38	15.60	5.62	Slight orange
3	Little Swan	7:46	17.55	1.53	Orange
4	Swan	8:00	16.17	6.45	Clear
5	Swan	8:10	16.36	4.34	Clear
6	Swan	8:27	16.01	6.35	Clear
7	Iron	8:45	17.08	1.45	Orange
8	Swan	9:00	18.16	1.14	Clear
9	Unnamed	9:15	15.03	2.31	Orange
10	Swan	8:00	18.40	3.64	Clear

Nutrients

In order to further examine whether excess nutrients are responsible for lowering the DO (via eutrophication), additional chemistry sampling was conducted. Nutrient samples (TP and nitrate) were collected at a subset of the synoptic DO sites, also on August 12, 2012 (Table 19). A few additional samples were collected on August 30, 2012 (Table 20). As was seen in the IWM samples above, phosphorus was elevated at several of the sites (two tributaries), while other sites (the mainstem Swan Creek sites) had phosphorus below the proposed standard of 0.100 mg/L. Also as previously, nitrate was extremely low at all of the sites, both tributaries and mainstem. Finally, a short reach just upstream of and including site 5 was chosen as a study site to look at phosphorus additions coming from riparian peat soils. Sampling of OP was added to the suite of parameters here. Many nutrient samples have been collected at site 5 in this ongoing study (Table 21). A seasonal trend can be seen here where TP is lower in the early season (mid-June), peaks during July/August, and then begins to decline again in the fall. It is also noteworthy that the fraction of phosphorus that is OP is always above 45%, which may mean that less of it is being sequestered by iron than what occurs at neighboring Tower Creek. This makes sense because iron levels, though still fairly high, are lower than at Tower Creek.

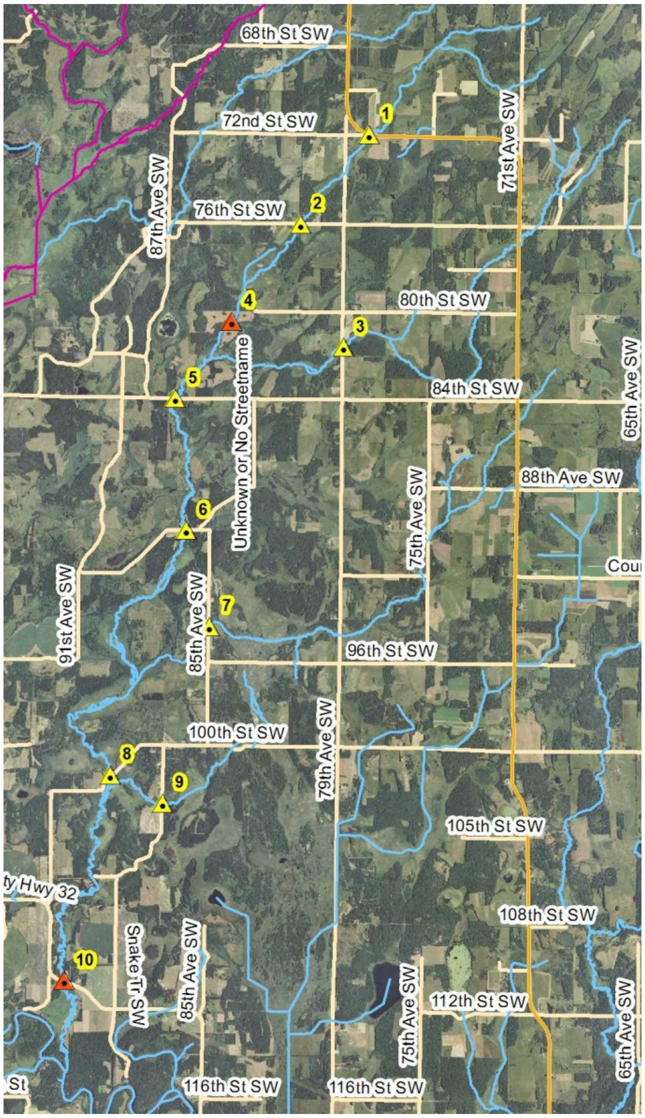

Figure 28. Synoptic sample sites for DO, temperature, TP, and nitrate. Orange markers are Sonde locations.

Table 19. TP and nitrate samples (mg/L) from August 12, 2012

Map site #	Stream name	Time	TP	Nitrate
2	Swan	10:35	0.082	< 0.05
6	Swan	10:12	0.065	< 0.05
7	Iron	9:57	0.100	< 0.05
9	Unnamed	9:47	0.285	< 0.05
10	Swan	9:31	0.052	< 0.05

Table 20. TP and nitrate samples (mg/L) from August 30, 2012

Map site #	Stream name	Time	TP	Nitrate
7	Iron	15:10	0.158	< 0.05
6	Swan	14:55	0.068	< 0.05

Table 21. TP, OP, nitrate, and ammonia samples (mg/L) from site 5 (Swan Creek, S007-235) "nc" = not collected.

Date	TP	OP	% OP	Nitrate	Ammonia
8/30/2012	0.074	nc	--	< 0.05	nc
11/1/2012	0.057	nc	--	nc	nc
6/13/2013	0.031	0.016	51.6	nc	nc
7/19/2013	0.074	0.034	45.9	nc	nc
8/15/2013	0.077	0.038	49.4	nc	nc
10/3/2013	0.051	0.023	45.1	nc	nc
10/23/2013	0.022	0.016	72.7	< 0.05	< 0.05
11/7/2013	0.027	0.014	51.9	< 0.05	< 0.05
Averages	**0.052**	**0.024**	**52.8**	**< 0.05**	**< 0.05**

Other chemistry

Because the streams in this area have shown high iron content, iron samples were collected at Swan Creek tributaries and the two new biological sites. Concentrations in Swan Creek were higher in the upstream portions, and were above the EPA aquatic life threshold. The concentration was extremely high in the most downstream tributary, Iron Creek, though Swan Creek below this input was below the EPA aquatic life threshold. Much of the iron from Iron Creek may precipitate before the water reaches Swan Creek, or is diluted from the flow volume in Swan Cr.

Table 22. Iron concentrations in Swan Creek and its tributaries. Map sites pertain to figure 27.

Map site #	Stream name	Date	Iron (µg/L)
4	Swan Cr., 12UM143	8/29/12	1480
5	Swan Cr.	8/30/12	1380
5	Groundwater seep	8/30/12	6080
6	Swan Cr.	8/30/12	1080
7	Iron Cr.	8/30/12	33500
10	Swan Cr., 12UM144	8/29/12	943

Conclusion

An overall analysis of the data strongly suggests that the biological impairments in Swan Creek are partly the result of localized human (animal husbandry related) physical alterations to the stream channel, and probably also partly due to natural factors influencing DO and iron concentrations. The majority of the Creek has a very good, natural riparian condition, and a site in about the middle of the Creek's longitudinal course has the second highest habitat rating of all of the stream sites sampled in the CWRW, and excellent fish and macroinvertebrate communities.

The localized human activity contributing to the biological impairments involves animal husbandry practices, occurring in areas with animal (primarily cattle) access to the stream. The negative effects on streams and their biological communities of long-term, unrestricted pasturing of animals along stream corridors are well documented (Kauffman and Krueger, 1984, Tufekcioglu *et al*., 2013). The effect of domestic/agricultural animals has also been shown via restoration projects where specific animal husbandry practices were changed, and the physical and/or chemical character of the streams and their biological communities were significantly improved (USEPA 2012a., 2012b., Agourdis *et al*., 2013).

Cattle influence on stream channel geomorphology is evident at both of the impaired sites. Overwidening of stream channels is a common result of cattle having access to stream riparian areas and channels, and this has clearly occurred at the downstream site. As is also typical for unfenced stream channels, the upper pasture has bank erosion from animal trampling, and thus excess sediment in stream. The MSHA metrics also substantiate the degraded habitat in these pastured reaches. The pasturing practices are likely contributing to some degree in the depressed DO levels in Swan Creek via altered riparian vegetation leading to reduced shading and warming of the water. The substrate metric score was very different between the healthy biological site and the two pastured sites - 18.9, 9.0, 9.0 respectively. Siltation is a very common result of cattle routinely treading on the bank (banks become raw and collapse and wash fine sediment into the stream, where there may not be enough gradient to wash it downstream). Fine substrate presence and/or abundance will depress the MSHA substrate metric score.

Human alterations of the landscape often lead to a reduction in water clarity. The very good to exceptional readings of water transparency in Swan Creek provide some evidence that the overall AUID is not being systematically impacted by human activities.

The levels of DO drop below the state standard of 5.0 mg/L at several locations, particularly in July and August, which is a typical time of year for DO to be at its lowest annual levels. There are natural explanations that can likely account for some of this phenomenon. Tributaries to the Swan have significant groundwater inputs, as evidenced by their cold temperatures, orange color from iron oxide precipitation, and visual observance of many spring seeps along bank channels and within riparian meadows. Groundwater commonly has low DO due to numerous causes, the most obvious of which is a lack of connection to the atmosphere. Chemical reactions with geological material and bacterial usage of oxygen in decomposition within certain soils also reduce oxygen levels in groundwater. All three of the Swan tributaries have very low DO. In addition to having low-DO water input from tributaries, the streams in this area have very low gradients (slow flow), and lack the rocky substrate (naturally) that form riffles in streams. The result is that the streams of this area are poor at re-aeration of their waters. So, this combination of landscape attributes join together to cause naturally-depleted oxygen levels in stream waters. Addition of nutrients from animal waste can also lead to a reduction of DO, though nutrient water chemistry results do not suggest this is happening to a significant degree here.

From the substantial chemistry data collected at multiple locations on Swan Creek, evidence for a generalized, problematic nutrient contamination in Swan Creek is lacking. Nitrate and ammonia levels are very low, while phosphorus levels are typically within the range considered normal for this area. The observed nutrient concentrations make the low DO somewhat perplexing, since that situation is often caused by eutrophic conditions. Other factors that can influence DO concentration are groundwater inputs (discussed in the previous paragraph) and water temperature. Alteration of riparian vegetation, particularly when taller vegetation is removed, will result in water temperature increases due to increased exposure of the channel to sunlight. Some riparian alterations have occurred along Swan Creek in the pastured reaches, and they will have had some influence on water temperature. The widened, silted channel at 10EM086 is also allowing more sunlight to reach and warm the water there. Under natural vegetative conditions, Swan Creek would be running colder, and thus hold more oxygen.

Iron may be limiting the macroinvertebrate community in the headwater reaches of Swan Creek, as iron concentrations were above the EPA aquatic life threshold. Interestingly however, the biological site with a stellar macroinvertebrate community (10UM081) also exceeded the EPA threshold, but by a relatively small amount. Other than applying the EPA guidance, information on the influences of iron at specific concentrations on macroinvertebrates is lacking, and thus the strength of this stressor here is difficult to judge. See the Tower Creek section for more information on the effects of iron on aquatic biological organisms.

Because evidence suggests that the anthropogenic impairment factors are quite local in both source and effect, and due more to physical, rather than chemical issues, a TMDL is not the most efficient way to tackle the issues for improving the biological community. As animal agriculture, with its associated habitat and DO influences, is the only evident anthropogenic stressor, and the fact that there is also an *E. coli* (bacterial) impairment on this AUID, the implementation of practices to correct that impairment will likely also improve the physical condition of the stream channel and improve habitat for the macroinvertebrate community, since BMPs will likely involve keeping the animals at least somewhat more separated from the Creek than occurs currently. Multiple BMPs are available to reduce the impact animals have on streams (MDA, NRCS).

Farnham Creek (AUID 07010106-522)

Impairment: This is a very short AUID (0.56 miles long) at the mouth of Farnham Creek and is completely channelized. The creek was sampled here (99UM022) for biology in 1999 and then again in 2010. Macroinvertebrates were impaired both years, while the fish were impaired in 1999, but had a passing IBI in 2010. As of 2008, channelized reaches are being deferred for assessment pending the development of appropriate biological criteria and the implementation of Tiered Aquatic Life Uses (TALU). Because AUID 522 was placed on the 303(d) list prior to 2008, when the policy decision was made to defer channelized streams from assessment, it is being addressed in this report.

Review of the subwatershed

The Farnham Creek watershed is adjacent to the Tower Creek subwatershed discussed above, and has the same types of landscape features. Tower and Martin Creeks are tributaries to Farnham. There are extensive sedge meadow peatlands in the subwatershed, and a great deal of channelization has occurred throughout the subwatershed as prior generations tried to dry out these areas to some degree for agricultural purposes (Figure 29). A large percentage of the subwatershed is forest, with much of it in various stages of active management (recent clearcuts, young regrowth, and older plantations). Row crop acreage is very minor, and most open land used for agriculture is cut for hay or used as pasture. There are no registered feedlots within the subwatershed; however, there are farms raising cattle within this area. There is no readily-apparent anthropogenic activity stressing the ecology of the stream. The aerial photography shows many locations where the channel contains extreme levels of iron floc in large sedge meadow areas.

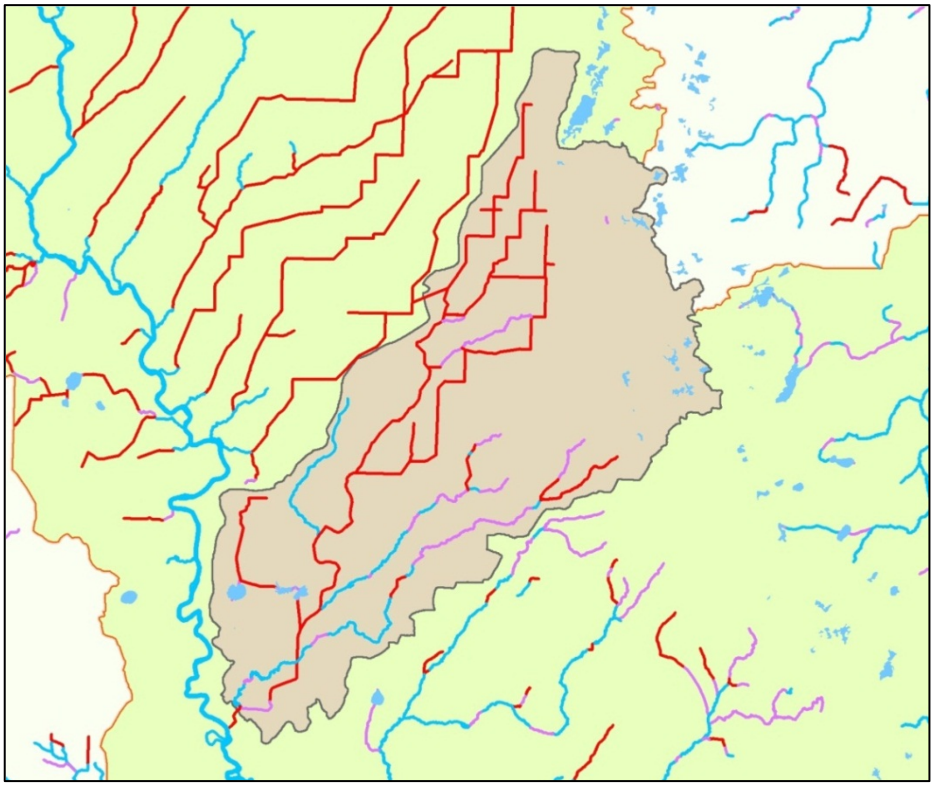

Figure 29. The Farnham Creek subwatershed (tan area) from the point of the lower biological site, and within the Crow Wing watershed (lime area). Blue indicates a natural channel, red is channelized, and lavender is ponded or peat wetland with indistinguishable channel in aerial photos. Arrows point to abandoned channel reaches. Designations are from MPCA/MnGeo Altered

Review of initial data

Chemistry

The biological site on CSAH 30 was a 10x chemistry site (S004-065), so significant data is available here. The common chemistry patterns of extremely low nitrate, low summer DO, and seasonally-high TP found in surrounding streams are evident here as well (Table 23 and Figure 30, Figure 14E respectively). As mentioned above, there is almost certainly high iron content in the water due to the extreme floc evident in aerial photos, another similarity with adjacent streams.

Table 23. Nitrate and ammonia (mg/L) at Farnham Creek, CSAH (S004-065).

	Nitrate	Ammonia
Average	< 0.027	< 0.070
Minimum	< 0.02	< 0.04
Maximum	< 0.03	0.137

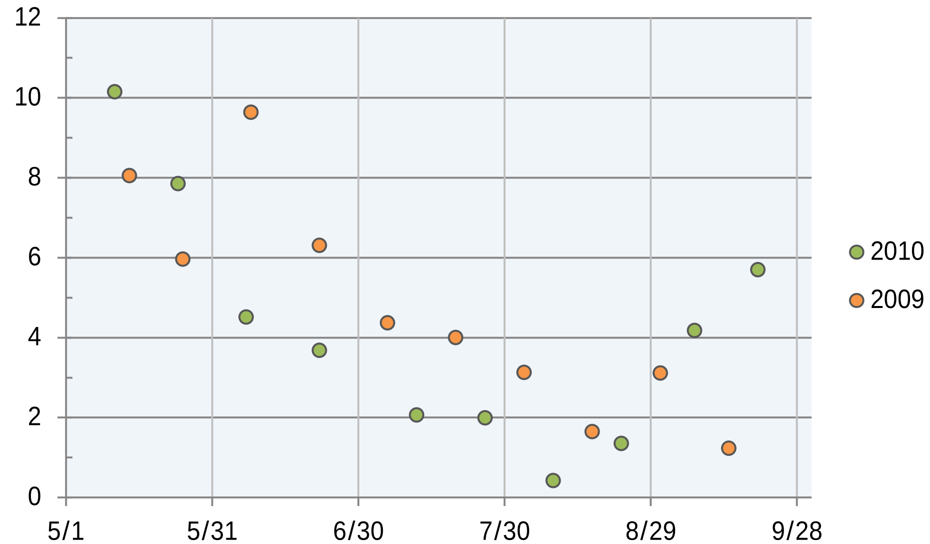

Figure 30. DO (mg/L) at Farnham Creek, CSAH 30 (S004-065)

Habitat

The overall habitat rating here, using the very similar MSHA scores from 1999 and 2010 of 55.7 and 56.5, fall right in the middle of the "Fair" category, in the Good-Fair-Poor classification system created by the MPCA Biological Monitoring Unit.

Biology

The fish IBI scored quite well here given the channelized status of the stream. The score was exactly at the threshold of passing for natural stream channels. The macroinvertebrates, however, scored poorly. The stream is greatly lacking sensitive macroinvertebrates, and the EPT taxa are almost completely lacking, as one mayfly individual was collected. Often such low gradient streams would at least have numerous *Caenis* and/or *Trichorythodes* mayflies, neither of which was collected here. EPT taxa require good levels of oxygen, and as seen in the DO data, there are times when DO gets extremely low and those measurements were not daily minimums. There were also numerous taxa that are not oxygen-limited, including several snail species. Notably, the sample was highly dominated by the midge genus *Chironomus*. This genus is well known for its ability to live under low DO conditions, as per Rasmussen (1999): "The dipteran family Chironomidae is widespread and abundant in extremely low oxygen environments where other insects would quickly die or enter anoxybiosis. Although many chironomids are tolerant of low oxygen conditions, the species *Chironomus plumosus* perhaps best typifies least oxygen dependence. This well-studied species is a common and abundant inhabitant of oxygen depleted lake sediments."

Targeted investigation and results

No additional data were collected for this AUID after the IWM effort.

Conclusion

For two reasons, TMDL work here will not be pursued at this point in time. The first reason is that this stream has chemical parameters that are behaving very similarly to all the adjacent streams, and much evidence points to these seemingly problematic chemical concentrations being caused by natural factors (see Tower Creek section). Several of these streams are being studied further in attempts to determine the degree to which natural factors are responsible for the measured concentrations – it appears to be high. Results from that effort will contribute to an understanding of the chemical dynamics occurring in Farnham Creek. Second, this is a channelized system, and the expectations for the biological communities are less than for those in natural channels. Within a few years, MPCA may have TALU in place and appropriate biological standards determined for channelized streams. It is uncommon for channelized streams or ditches to meet the current aquatic life use thresholds, simply due to the significantly altered habitat.

Indian Creek (AUID 07010106-569)

Impairment: The creek originally was judged as impaired for not meeting fish community expectations at 10UM065 (CR 127). A later review of that conclusion determined that the habitat of the sampled location was anomalous for Indian Creek, and thus the fish data were not used to determine the health of the creek. Therefore, the invertebrate data alone were used, and that community did meet the established criteria for non-impairment. However, interesting and pertinent findings about the creek and biological habitat from the intervening period are considered important to note for future sampling and understanding of the creek's biological communities.

Review of the subwatershed

Indian Creek lies in a quite undisturbed subwatershed (Figure 31). The whole stream length flows within the Two Inlet State Forest. Notable from the National Wetland Inventory GIS layer is the dominant landscape feature of extensive palustrine wetland bordering almost the whole length of Indian Creek (Figure 32). GIS calculations of palustrine wetland within a 50 meter distance of the stream (on each side, so a 100m wide belt), starting at the outlet of Basswood Lake, show that 79.7% of this land area is palustrine wetland (peat soils that are generally saturated near the surface). Aerial photos show significant beaver activity in the creek (numerous dams are evident). There is a beaver dam with ponding approximately 0.4 river miles DS of site. There are also numerous beaver dams upstream of site. These could be impeding fish movement in the creek.

An impoundment for wild rice/waterfowl habitat at County Highway 44 was created by MDNR many decades ago and still functions, with recent installation of a replacement dam/outfall structure. Based on the original Public Land Survey Map (1861) this impounded acreage was originally a large sedge meadow with a defined stream channel running through it. Indian Creek entering section 12 of T 141 R 37 is recorded as 30 links (~ 20 feet) wide. That location is now part of the impoundment and was approximately 350 feet wide in 2010. So, the impoundment dam is a barrier to the biological site from the headwaters area, but if that were the only barrier, there is lots of stream and lake habitat downstream of the biological site that would be a source area for immigration to the study reach.

From the CWRW Professional Judgment Group (PJG) meeting: "This stream may have been stocked with trout in the past." If so, it may have been determined to lack the necessary low water temperatures for sustaining trout. It is not classified as a designated trout stream.

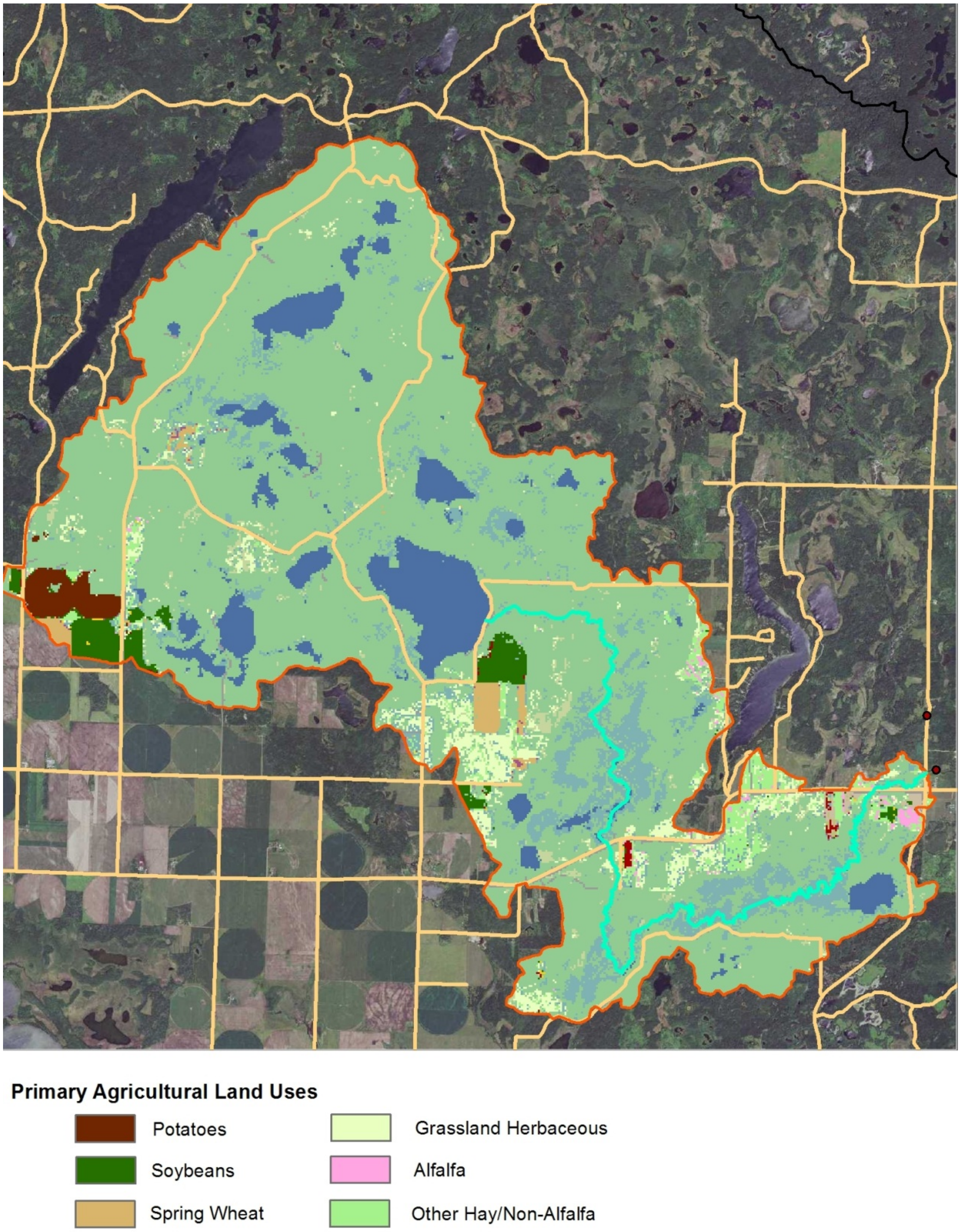

Figure 31. Land use in the Indian Creek subwatershed

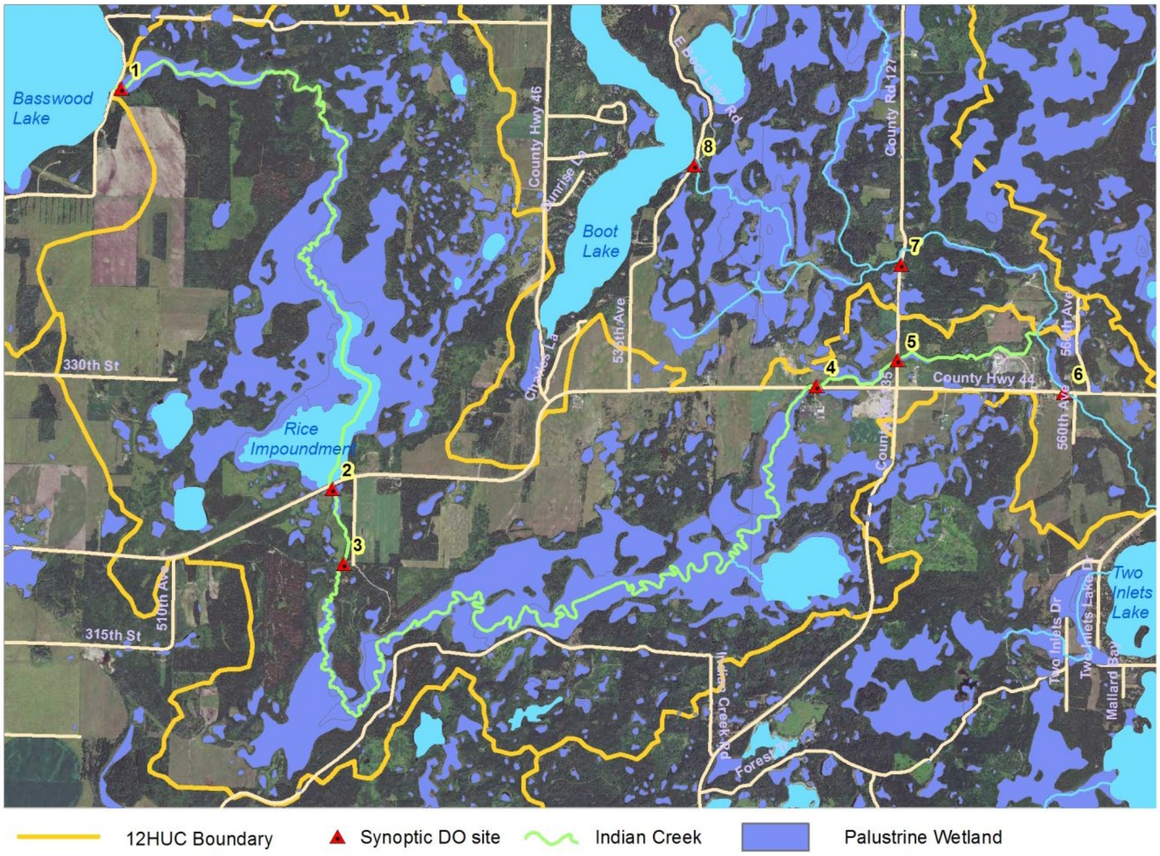

Figure 32. Lower Indian Creek subwatershed (starting from Basswood Lake outlet) showing water and wetland features and DO measurement locations

Review of initial data

The habitat is good, particularly the in stream habitat. There is a good variety of microhabitats here due to the nice variability of the substrate types and flow velocities, and presence of multiple habitat features (riffles, runs and pools). The physical channel did not show signs of instability or degradation. The invertebrate community is quite healthy, with a number of sensitive types present, though missing were stoneflies, which based on the habitat characteristics, should have been present. The 1x chemistry was very good regarding nutrients, with very low concentrations of both N and P (0.029 mg/L and 0.065 mg/L). Filamentous algae, however, was abundant here which is somewhat curious given the low nutrient concentrations. The stream here is fairly wide, gets lots of sun, and has much hard substrate to attach to, and so there are some natural factors that benefit algal growth. The only chemistry issue that appeared was DO, having concentrations below 5.0 mg/L at both the fish and invertebrate visits.

A comment from the PJG meeting hypothesized that the impoundment might be a contributor to reduced DO downstream and also possibly a source of nutrients. This outlet structure is a complete barrier to fish migration, but also contains a drop structure that aerates the water leaving the impoundment.

Based on the review of initial information and data, it was determined that the DO was a candidate stressor, and that the DO regime should be examined in more detail. Any time the invertebrate community is healthy, and the fish community is not, a possible explanation is a fish migration barrier somewhere on the stream. As that was the case here, a survey of road crossings was performed.

Targeted investigation and results

A synoptic longitudinal sampling of DO was conducted in the early morning of July 12, 2012, between 8:10 AM and 9:30 AM (Table 24). Locations are shown in Figure 31. The DO levels show a relationship to surrounding landscape type. Where the stream flows through sedge meadow habitat (between site 1 and 2a, and from 3 to 4) DO levels drop significantly. Where there is a forested riparian border (and thus non-wetland soils), DO levels improve (above sites 3 and 5). The reach ending at site 5 had no riparian wetland characteristics with its narrow, steep-sided and forested corridor and swifter stream flow. Such a setting is good for aeration of stream water and this site did indeed have the best oxygen levels. The stream then flows through a very large sedge wetland, with many beaver dams. A sample from downstream of this wetland, at the second Highway 44 crossing, showed that DO levels are depleted in the wetland. Some re-aeration occurs by the time the water reaches the biological site at CR #127, as wetland characteristics are more moderate. Thus, the low DO levels in much of the AUID are natural, due to several factors occurring in the wet-meadow locations; low stream gradient/velocity, beaver dams, bacterial decomposition of deposited organic matter, and input of shallow groundwater. Evidence for the latter phenomenon can be seen in the conductivity increase between site 3 and 4, as well as the temperature drop in the same reach, despite the channel being very shallow and sun-exposed. Groundwater moving through the streamside peat soils (an anoxic environment) on its way to the stream will thus contribute additional water having low DO. Beaver dams create wide, unshaded pools, slow flow, and induce fine sediment deposition, all of which allow solar radiation to warm the water, and bacteria utilize oxygen to break down the accumulated organic material common in slow, wetland reaches.

Table 24. DO values (mg/L) from the synoptic longitudinal survey.

Site number	Location	Time	Temp	Cond	DO
1	Basswood Lake outlet	9:30	25.95	.206	8.14
2a	CH44 in impoundment	8:38	23.90	.291	1.18
2b	CH44 US crossing*	8:34	23.70	.293	4.55
3	520th	8:51	23.90	.291	5.15
4	CH 44 DS crossing	8:21	21.97	.351	1.90
5	127 (10UM065)	8:10	22.01	.351	2.91

*South side of CH44

In addition to examining the pattern of DO along the length of the stream, it is also important to understand the degree of daily fluctuation of DO as well as the minimum concentrations, which occur in early morning. In August 2012, two continuous-recording Sondes were simultaneously deployed in two locations in the creek, at Highway 44 and CR 127, for approximately 10 days. Readings from both showed DO minimums well below the state standard, with the Highway 44 location being extremely low in DO (Table 25). This area of state was experiencing drought conditions in 2012, so these data represent essentially the worst-case scenario. Though the DO flux is nearing the level where it can become problematic to fish, the maximum DO level (8.56) is not indicative of a stream experiencing eutrophication, particularly one that gets this much sun exposure.

Table 25. Dissolved oxygen (mg/L) summary from Sondes

Site	Dates of measure	Avg. daily min.	Lowest daily min.	Highest daily min.	Avg. daily flux
Hwy 44	8/2 - 8/13/12	0.03	0.02	0.04	na - not stream
CR #127	8/2 - 8/13/12	4.46	3.52	5.09	4.30

The DO leaving the culvert below the drop structure of the impoundment is apparently related to the water levels in the wetland, because a one-time measurement on July 12, 2012, at the culvert outlet, when the surface waters in the area were higher, showed much higher DO (4.55), though still below the standard. It is not known what the DO level would be in this impounded reach if it were flowing naturally. Given its wetland borders, it likely had low DO in pre-settlement times. At some water stages, the impoundment is probably improving the DO concentration relative to natural conditions, due to the drop structure turbulence. At the July 12, 2012, sampling, the DO of the impoundment water entering the outlet structure was 1.18 mg/L, so the drop structure added 3.37 mg/L of oxygen. At lower stages, the impoundment may be reducing oxygen levels as water is more stagnant and the drop structure is not helping aerate the exiting water very much, due to much lower turbulence. The impoundment seems not to cause a temperature problem, as the temperatures measured here were much lower than at CR #127, a sign that there may be significant groundwater input within the impoundment. This also was the case later in the summer (August 3, 2012) when the Sondes were deployed. On August 3 at 5:00 PM, the Sonde at Highway 44 just below the impoundment was 22.5^{o}C, whereas downstream at CR 127 the water temperature was 27.1^{o}C at the same time.

In regard to fish barriers, inspection of those crossings below the Indian Creek study site down to Two Inlets Lake revealed none that were considered problematic to fish passage. The culvert at the upstream end of the study site (on CR 127) is a likely barrier to fish movement due to the increased flow velocity produced through it. A somewhat larger culvert, and one placed at a correct elevation and slope, would correct this issue and allow fish to migrate through to upstream areas.

Conclusion

A different sample location on this AUID should be chosen when the CWRW is sampled in the next cycle (2020). A location upstream of 10UM065 should be sampled. The AUID channel upstream of Highway 44 is fairly homogeneous regarding in-channel habitat (sand dominated substrate and wetland bordered), which would provide a more representative judgment of the health of the overall AUID. It would also be good to investigate the likely barrier culverts on CR 127 by collecting another sample at 10UM065, or an area downstream more similar in channel habitat to the above-Highway 44 reaches.

Observed stressors at other locations

During IWM sampling and SID work, some stressors were observed at streams that currently are passing the IBIs, are deferred from assessment currently (channelized streams), or are at sites that were not sampled during IWM.

Partridge River

The author was one of the crew that sampled macroinvertebrates at biological site 10UM050, near the confluence with the Crow Wing River. There were several signs of some channel instability here. Often such instability is brought on by an alteration of the hydrological flow regime (i.e., an increase in flow volumes). It is common for human alterations of the landscape to cause precipitation to arrive at the stream faster than under the proceeding natural conditions. This causes steams to become “flashy”, meaning there is a fast, high volume pulse of water sent through the channel following significant rain events. Impermeable surfaces are a primary contributor to increased surface runoff, and this reach receives the runoff from Highway 210. Highway ditches also efficiently deliver runoff to stream channels.

Channel instability typically reveals itself via raw, eroding banks, excess fine sediment accumulations, and trees toppling into the stream. These symptoms were all seen in reach 10UM050 (Photo 29).

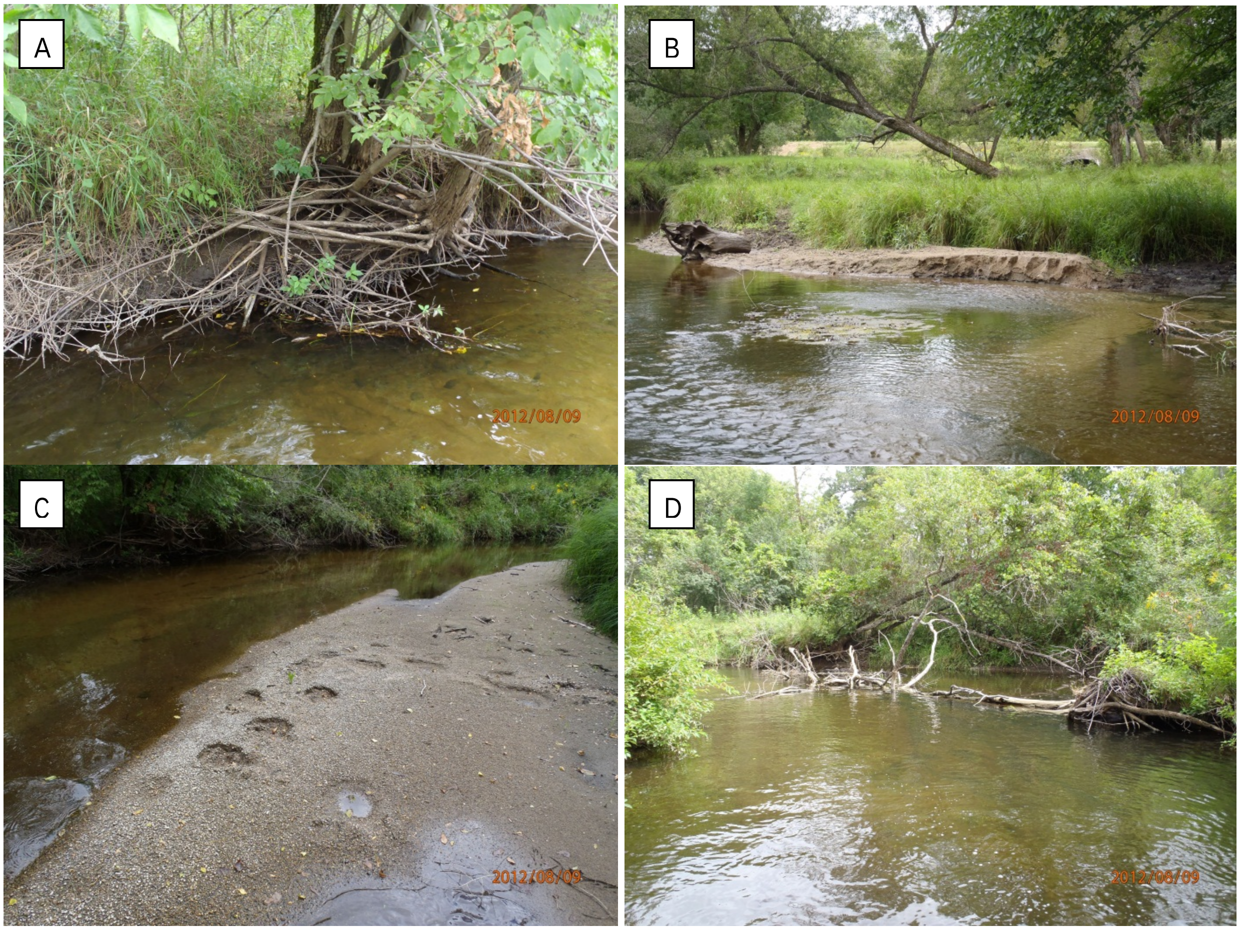

Photo 29. Goemorphology of Partridge River. A. Bank erosion exposing roots, B. Thick, recent sand deposition, C. Excess sediment filling channel, D. Toppling of bank trees

Dam on Partridge River

An old cement crossing structure exists on the Partridge River just downstream of Highway 210. This structure has no culvert, but rather is a cement wall where water flows over the top. There is a constructed rip-rap riffle immediately downstream of the structure, which has significant gradient and which creates strong, turbulent flow. This structure is a complete barrier to upstream fish migration. Due to the IWM sample site criteria, there were no biological sites upstream from the structure for a long distance, so there is no data to show, but again, no fish can pass this structure, and the stream is definitely of a size where there would be some upstream migration through this area.

Channel damage by cattle/horses

Cattle and horses are raised at many sites within the CWRW. At numerous locations, significant damage was seen occurring to the channel, leading to bank erosion, sedimentation, and thus general aquatic habitat degradation (Photo 30). This is not unique to the CWRW, as this can be observed routinely in all areas of the state where agricultural animals are pastured with access to streams (e.g., see section 2.3.2 of the Ann River Stressor Identification Report - MPCA, 2011). However, CWRW streams would benefit from exclusion of agricultural animals and the providing of off-channel watering, or restricting access to small areas of the channel. Various practices have been developed to minimize stream channel damage from grazing animals. County SWCD offices, Minnesota Extension, and NRCS staff are able to help with the design of best management grazing practices.

Photo 30. Riparian grazing damage to CWRW streams

Road crossings

Road crossings have potential to be fish migration barriers and thus remove potentially important habitat from access to fish. The example of the Upper Shell River was presented above. Other examples of problematic crossings are likely within the CWRW (as they are in all Minnesota watersheds). Another location of a fish barrier crossing was on the Blueberry River (Photo 31). Prior to replacing a crossing structure, which can be expensive, a review of the value of upstream habitat should be considered to determine the benefit of removing the barrier to the local fish community.

Photo 31. Perched culverts on the Blueberry River on Little Long Lake Road

Conclusion

The IWM monitoring and assessment, and SID phases of the WRAPS have allowed for a much better understanding of the condition of the aquatic biological communities and the fairly unique hydrologic characteristics of the CWRW. The primary anthropogenic stressors found in the study were animal grazing in the riparian corridor and stream channel, and fish passage barriers due to incorrect culvert placement and/or sizing (Table 26). There are some natural landscape factors that are strongly influencing the DO and phosphorus levels in headwater streams, particularly the extensive sedge peatlands and groundwater interactions with streams. Some of these characteristics are not fully understood at this point. It is hoped that in the intervening period between now and the next CWRW IWM effort (in 2020), some additional time can be spent to continue to improve understanding of the interactions of several interesting landscape factors and the water resources of the CWRW. One example is that there will likely be a better understanding of the groundwater dynamics of the area, and the groundwater/surface water interactions within the CWRW, due to the MDNR pilot project in the Straight River Aquifer Management Zone.

Table 26. Summary of impaired stream stressors

Stream	AUID last 3 digits	Reach description	Biological impairment	Impairment category	Primary stressor					
					Dissolved Oxygen	Phosphorus	Channel Damage	Connectivity	Altered Hydrology	Habitat
Bender Cr.	691	Tripp Lk. to First Crow Wing Lk.	Fish and MI	4D	●			●		●
Farnham Cr.	522	Unnamed Cr. to Crow Wing R.	Fish and MI	5	●	●		●		
Indian Creek	569	Big Basswood Lk. to Basswood Cr.	Not Impaired	Not Impaired	●					
Swan Cr.	527	T135 R32W S2, north line to Crow Wing R	MI	5	●		●			
Tower Cr.	528	T135 R32W S4, north line to Farnham Cr	MI	5	●	●				●
Unnamed Trib. to Crow Wing R.	687	Unnamed ditch to Crow Wing R.	Fish	4E				●		●
Unnamed Trib. to Shell R.	553	Headwaters to Shell R.	MI	4D	●					
Upper Shell R.	537	Shell Lk. to Blueberry Lk.	Fish	4C	●		●	●		●

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Appendix 1. Excerpts from write-up of Minnesota Department of Natural Resources geomorphology study at 10UM053

Author and field lead was Dave Friedl, MDNR – Detroit Lakes Office

1) Re: Kevin's observation that organic detritus is depositing above the elevated upstream culvert due to a decrease in gradient.

Dave: "Width-to-depth ratios at the Shell River study site were at the extreme high end of the range, with a range of 38.02 to 45.35, which is approaching braided Rosgen type D channels. This is indicative of poor sediment transport and a high sediment supply, which in this case is from fine organic material and sand from the bog near Shell Lake, the transition to a sand valley, and the impounding effect of the culverts."

2) Re: Kevin's observations that culvert size and positioning are incorrect, leading to elevated velocity in culvert and scour downstream.

Dave: "The two T694 culverts are severely undersized with their 6-ft widths and 28.3 ft^2 areas. The consequences of undersized culverts are pressurized flows when full of water and higher velocities during free flow conditions, which in turn produce excess scour and bank erosion on the downstream side of the culverts and sediment deposition upstream.

The upper road crossing's culvert drops 0.81 ft over its 43.1-ft length for a slope of 1.9%, which is much too steep. The downstream culvert's upstream invert was set 0.68 ft below the upstream culvert's upstream invert for an upstream invert-to-upstream invert slope of 0.2%, which was much higher than the water surface or riffle-to-riffle slope through the reach."

Dave's conclusions about the two culverts near 10UM053: "Improvements to channel dimensions, stream stability, water quality, and stream habitat would likely occur by replacing the existing culverts. Expected improvements would include a lower width-to-depth ratio above the road crossings, improved substrate composition, less embedded substrates, more efficient sediment transport, pool scour and increased pool depth, more pronounced riffles, and higher DO concentrations."

A full assessment with detailed survey information and drawings of recommended design for replacing the culverts at these sites is available from the Detroit Lakes MDNR Office, Dave Friedl, Clean Water Legacy Specialist.