Knife River Stressor Identification, Kanabec County, Minnesota

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Abstract

The Environmental Protection Agency (EPA) developed the Stressor Identification (SI) process to identify stressors causing biological impairment. The SI process precedes a TMDL (Total Maximum Daily Load) and offers a means by which developers of a TMDL can more confidently identify stressor(s) causing impairment. The EPA's Causal Analysis/Diagnosis Decision Information System (CADDIS) framework was utilized to develop a SI for the Knife River Basin, Kanabec County, Minnesota. Data collected by the Minnesota Pollution Control Agency (PCA) during biomonitoring and the EPA's STORET database were analyzed using nonmetric multidimentional scaling (NMDS) ordination to evaluate the relationships between fish species and abundance, and environmental and chemical stressors. A least-squared regression between fish index of biotic integrity (IBI) scores and environmental variables was also calculated. The NMDS analysis suggests there is similarity between the two headwater sites, which are correlated with low gradient and a high percent fines, agriculture, urban, and rangeland. High gradient, percent forest and percent riffles were correlated with the mid-stream reaches of the Knife River. Only pH was significantly correlated with fish IBI scores (p=0.034). The Knife River SI identified three potential stressors; low dissolved oxygen (DO), high pH, and excess bedded sediment.

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List of Abbreviations

CWA - Clean Water Act

TMDL – Total Maximum Daily Load

DO – Dissolved Oxygen

WQS - Water Quality Standards

EPA – Environmental Protection Agency

CADDIS – Causal Analysis/Diagnosis Decision Information System

IBI – Index of Biotic Integrity

WSU – Western Superior Uplands

DELT – Deformities, Eroded fins, Lesions, and Tumors

POET – Plecoptera, Odonata, Ephemeroptera, and Tricoptera

TSS – Total Suspended Solids

MPCA – Minnesota Pollution Control Agency

MSHA – Minnesota Stream Habitat Assessment

STORET – STOrage and RETrieval, U.S. EPA’s water quality database

NTU – Nephlometric Turbidity Units

D_{50} – Median particle diameter in the streambed

$7Q_{10}$ - The lowest 7-day average flow that occurs once every 10 years

WAT – Watershed Assessment Tool

DNR – Department of Natural Resources

1. Introduction

1.1 Clean Water Act

The Clean Water Act (CWA) is the federal legislation to protect waters from pollution and ensure that surface waters meet standards for swimming, fishing and drinking. The CWA was passed in 1972 with the objective of "restoring and maintaining the chemical, physical and biological integrity of the Nation's waters" (section 1251). Waterbodies that do not meet applicable water quality standards are required to go through the total maximum daily load (TMDL) process. The TMDL is a multi-step process to restore and maintain the chemical, physical, and biological integrity of a waterbody.

1.2 TMDLs

Assessing Water Quality

The first step in the TMDL process is to assess water quality. Water quality assessment can be done through chemical testing, examining the physical integrity of a stream channel, or through biological measures (e.g. fish and macroinvertebrates). Chemical water assessments are a snapshot of the water's state and may include: dissolved oxygen (DO), nitrogen, phosphorus, and pH. Physical assessment may include: habitat, bank structure, or water flow. Biological assessment, sometimes called biological monitoring or biomonitoring, is also used to determine the health of a waterbody.

The current Minnesota TMDL process is unlikely to reach its goal without assessment using biological criteria (Karr and Yoder 2004) since biological criteria link the impacts of stressors with designated uses. Biological monitoring uses species assemblage composition and structure to evaluate the cumulative effects of a stressor. Both fish and macroinvertebrate communities respond in predictable ways to changes in water quality or environmental stress (Niemela and Feist 2000, Chirhart 2003) and are the most common indicator taxa used to assess streams.

Listing Impairments

Waterbodies found to be impaired through the assessment process are listed under the CWA section 303(d) in the second step of the TMDL process. Impaired waters are defined by the Minnesota Rule Chapter 7050.0150 as “a water body that does not meet the applicable water quality standards or fully support applicable beneficial uses, due in whole or in part to water pollution from point or nonpoint sources or any combination thereof.” Waterbodies are assigned "beneficial uses" such as drinking water or aquatic-life, and different water quality standards (WQS) support each beneficial use. When a waterbody is found not to support the water quality standards for a beneficial use it is said to be in "non-support" and is therefore listed as impaired.

Identifying Cause

The cause of impairment must be determined before a TMDL can be implemented. An impairment, such as a low DO concentration may be easy to diagnose with field measurements, however, determining the cause of biological impairments is often more difficult. The EPA has developed a process called stressor identification (SI) to identify stressors causing biological impairment. The SI process precedes a TMDL and offers a means by which TMDL developers can more confidently identify stressor(s) causing impairment. Information gathered in the initial phase of biomonitoring and new data are used to determine the underlying stressor(s).

De-listing

The final step in the TMDL process is allocating pollutant loads to bring the listed water into compliance. A TMDL is a calculation of the maximum pollutant load that a waterbody can receive while meeting water quality standards (WQS). In the case of biological impairment, the stressor identification process identifies stressor(s) for which a pollutant load reduction can be allocated. Once the pollutant load is determined, a plan is established to reduce pollutant loading to bring the impaired water into compliance with WQS for beneficial uses. Once water quality meets compliance, the waterbody is removed from the 303(d) list.

1.3 Stressor Identification

The Environmental Protection Agency (EPA) has developed the stressor identification process (SI) to identify the stressors causing biological impairment. The goals of the SI process are to identify stressors causing biological impairment, and provide a structure for organizing the scientific evidence supporting the conclusions. The SI process incorporates components of biological, chemical, physical, and hydrological assessments into a procedure for identifying the stressor(s) underlying the biological impairment.

1.4 Causal Analysis/Diagnosis Decision Information System

The EPA has developed an online guide for the SI process called the Causal Analysis/Diagnosis Decision Information System (CADDIS) (http://cfpub.epa.gov/caddis/). The CADDIS is a multistep method for evaluating, identifying, and ranking the causes of biologically impaired water bodies (Figure 1). The first step in the CADDIS process is to identify and define the impairment. The second step in the CADDIS process is to list the candidate causes for impairment. The third and forth steps in the CADDIS process evaluate case-specific data and data from other sources to determine which stressors are most likely causing impairment in a waterbody. The final step identifies the probable cause of water quality impairment.

The CADDIS process is used in this thesis to identify stressors for the Knife River in the Snake River Basin in Minnesota by critically reviewing available data, generating possible stressor scenarios to explain the impairment, analyzing those scenarios, and then determining which stressor(s) are most likely causing the impairment. Accurate and defensible causal analysis is important to help land and water managers find solutions to improve biological integrity in the Knife River and surrounding Snake River Basin.

The goal of this study was to conduct a SI to determine the stressor(s) causing biological impairment for the Knife River Basin in Kanabec County, Minnesota utilizing the EPA's CADDIS framework. This SI has two objectives: (1) evaluate fish and macroinvertebrate scores in the Knife River Basin using the first four steps of CADDIS for each stressor in the basin, and state which stressor(s) may be worthy of further TMDL development, and (2) determine data gaps in the Knife River Basin. Multiple stressors are expected to impact biota that may include hydrologic alteration, nutrient enrichment, or erosion in the

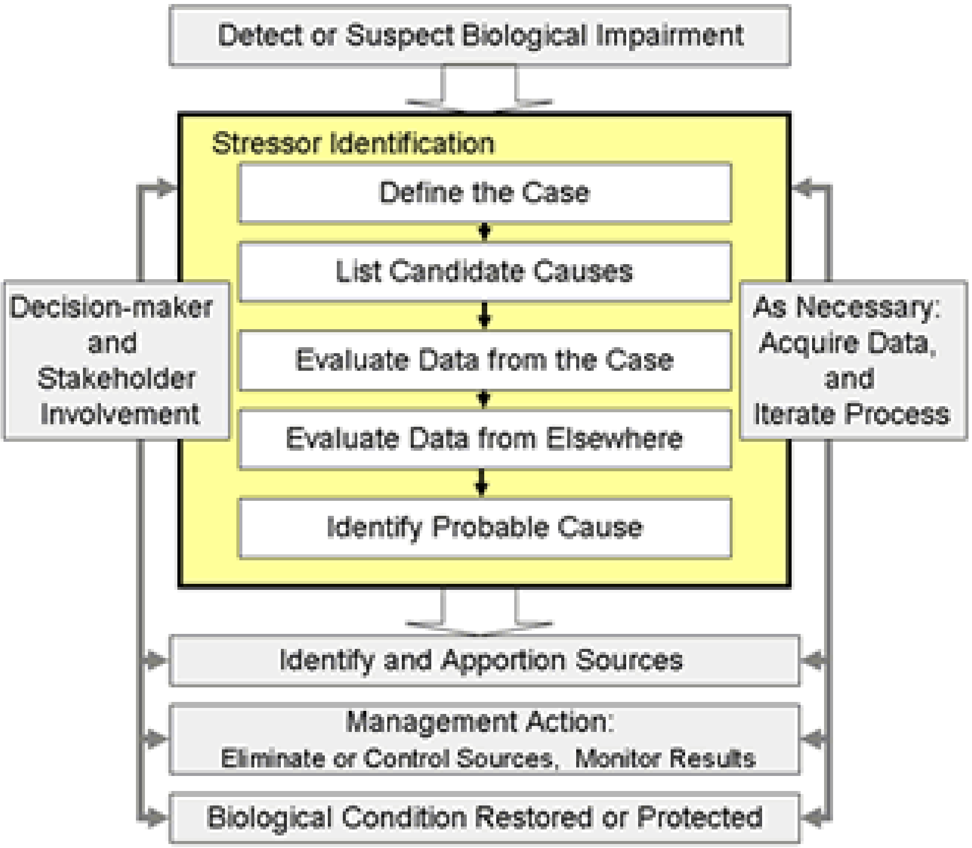

Figure 1: Steps in the CADDIS process from EPA's CADDIS website: http://cfpub.epa.gov/caddis/index.cfm

basin. Possible data gaps include: not enough samples taken in areas of impairment, or lack of watershed-wide information.

2. Knife River Impairment Listing

The CWA requires states to designate beneficial uses to waters and then develop standards to protect those uses. In Minnesota, most surface waters are protected for aquatic life and recreation. There are two classes of waters protected for aquatic life including coldwater streams (2A) and warmwater or coolwater streams (2B). The Knife River is classed as a coolwater "class 2B" stream. The upper Knife River has failed to meet the biological standards for both fish and macroinvertebrate assemblages for class 2B waters and has been listed as "impaired" in the 303(d) list.

The Knife River was first listed as impaired on the 303(d) list in 2002 by the Minnesota Pollution Control Agency (MPCA) for a low fish index of biological integrity (IBI) (Table 1). Six biological assessment sites were sampled and each has been given a number from Knife River headwaters to confluence with the Snake River. For the remainder of this thesis biological assessment sites will be referred to as biosites. The fish IBI threshold for impairment established for waters of the St. Croix River Basin at biosite 4 (Table 2) was not met in 1996. Since listing the Knife River as impaired for aquatic life, biological monitoring data have been collected in 2005 and 2006 and include three new assessment sites (biosite1, biosite 3, and biosite 5). In 2006, three of the four biological assessment sites within the impaired segment of the river were below the fish IBI thresholds.

Table 1: Knife River 303(d) listing.

Reach description	*Year placed in impairment inventory*	*Affected designated use*	*Pollutant or stressor*	*TMDL target start*	*TMDL target completion*
Headwaters to Knife Lake	2002	Aquatic life	Fish bioassessments	2010	2015
Headwaters to Knife Lake	2004	Aquatic life	Aquatic macroinvertebrate bioassessments	2010	2015

Only biosite 3, in the Upper Knife River, was above the threshold with an excellent fish IBI score of 82 in 2006. Fish IBI scores within the Knife River were variable between sites generally decreasing with proximity to the headwaters (Table 2). The site below Knife Lake (biosite 6) is in support of the aquatic life standard and has not been classed as impaired in 1996, 2005 or 2006 (Tables 2 and 3).

Table 2: Fish IBI scores for six assessment sites in 1996, 2005, and 2006 for the Knife River.

Biosite Number	*Site Number*	*Drainage* mi^2	*1996*	*2005*	*2006*	*Standard*	*Assessment*
1	06SC129	11.5			16	46	non-support
2	96SC008	12.4	60		20	46	partial-support
3	06SC128	31.7			82	68	support
4	96SC006	55.5	53			69	non-support
5	06SC125	83.5			67	69	non-support
*6	96SC097	103.9	80	76	74	69	support

*Site occurs downstream of impaired section of the Knife River

In 2004, the MPCA listed the Knife River as impaired for macroinvertebrate bioassessment based on data from 1996; biosites 2 and 4 failed to meet the macroinvertebrate IBI threshold of 50 for the St. Croix River Basin (Tables 1 and 3). The Knife River was not originally listed as impaired based on macroinvertebrate assemblages in 1996 because a macroinvertebrate IBI had not been developed. Macroinvertebrate IBI scores for biosite 6, located below Knife Lake, were above the designated aquatic life standard for macroinvertebrate bioassessment in 1996 and 2006.

Table 3: Assessment of Knife River macroinvertebrate IBI scores for compliance with standard.

Biosite Number	*Drainage* mi^2	*1996*	*2006*	*Standard*	*Assessment*
1	11.5		-	50	not assessed
2	12.4	44		50	non-support
3	31.7		-	50	not assessed
4	55.5	25		50	non-support
5	83.5		63, 35	50	partial support
*6	103.9	58	52	50	support

*Site occurs downstream of impaired section of the Knife River

Macroinvertebrate scores were variable in 2006. Two new biosites (1 and 3) were assessed, but not given a macroinvertebrate IBI score due to low flow conditions and biosite 5 was sampled twice during the 2006 assessment period (Table 3). Biosite 5 received a score of 63 one week prior to a second score of 35 for the same reach, presumably due to low-flow conditions.

The Knife River is impaired from the headwaters to Knife Lake. At this time the lower Knife River from Knife Lake to the confluence with the Snake River is not listed as impaired for either fish or macroinvertebrates. The remainder of this thesis will focus on determining stressors in the Knife River from the headwaters to Knife Lake.

3. Geomorphic Setting

3.1 The St. Croix and Snake River Basins

The Knife River is located within the St. Croix and Snake River Basins and is a tributary to the Snake River. The St. Croix River Basin encompasses 7,760 mi^2 (4,966,400 acres) of second growth mixed-hardwood forests, pasture, and cropland. Many of the headwaters within the St. Croix Basin originate in peat lands with dark tannic acid-stained water. The Snake River Basin makes up the western portion of the St. Croix Basin (Figure 2). The Snake River is one of the largest tributaries to the St. Croix River (Niemela and Feist 2000). Headwaters are generally low gradient streams that lack riffles and are sinuous. These tributary streams tend to have fine substrates and wetland vegetation in the riparian zone. As streams in the Snake River Basin converge with the Snake River, their morphology changes into a riffle/run/pool morphology with a wooded riparian zone.

3.2 The Knife River Basin Setting

The Knife River Basin covers 104.2 m^2 (66,667 acres) in Kanabec and Mill Lacs Counties (Figure 3). The Knife River basin spans two ecoregions, the North Central

Hardwoods Ecoregion and the Northern Lakes and Forests Ecoregion. The upper Knife River, from the headwaters to Knife Lake is located within the Northern Lakes and Forest Ecoregion, whereas the lower Knife River from Knife Lake to the confluence with the Snake River is in the North Central Hardwoods Ecoregion. The Northern Lakes and Forests Ecoregion is characterized by mixed forests and nutrient poor soils, whereas the North Central Hardwoods Ecoregion is more agricultural and forested areas are limited mostly to the northern region. Ecoregions influence a waterbody's sensitivity to disturbance. For example, ecoregions in northern Minnesota are often rocky with thin soil and a minimal buffering capacity, whereas ecoregions in the south have deeper soils, a better ability to buffer acidic inputs and more potential to have sediment or turbidity problems.

The headwaters of the Knife River begin in wetlands which are scattered throughout the basin. The Knife River runs through Knife Lake, where a dam controls the water level and moderates flow to the lower section of the Knife River. The dam likely influences sediment regime and temperature in the lower Knife River, where there is no impairment. The Knife River terminates at the confluence with the Snake River.

3.3 Geology of the Knife River Basin

The Knife River Basin is a part of the Western Superior Uplands Section (WSU), a region of non-calcareous till deposited by glacial ice from the Superior Lobe sediments (Department of Natural Resources 2012). The parent material in the Grantsburg (Des

Moines Lobe) portion is more calcareous and finer textured than Superior Lobe sediments (lower Knife River). The till is deposited in ground moraines and drumlins throughout the area. Peatlands and wetlands are incorporated within the depressions of the moraines. The coarser textured till in the south most likely includes the Knife River Basin, and till becomes more clayey to the northern section of the WSU where sediments from Glacial Lake Duluth are incorporated.

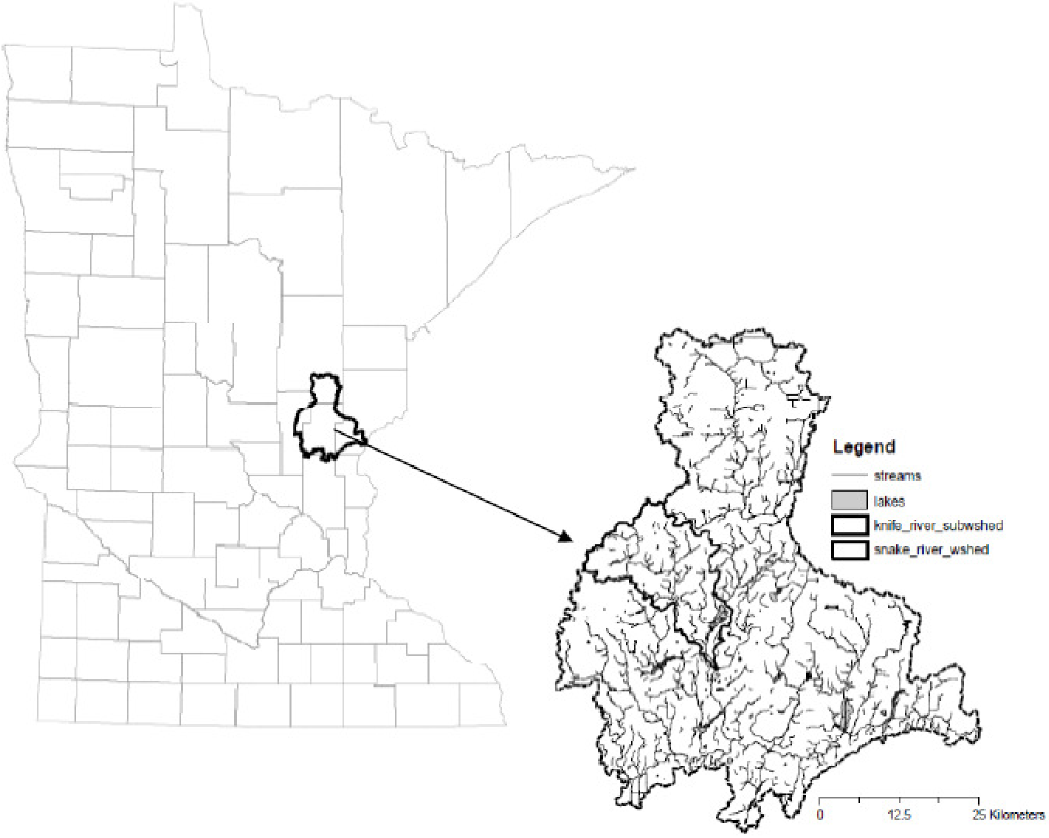

Figure 2: Snake River and Knife River basin boundaries

3.4 Precipitation Trends

Data collected during 1996 were used to determine the impairment listing. In 1996, January precipitation averaged 1.85 inches across Kanabec County, Minnesota, July precipitation averaged 3.28 inches, and September rainfall averaged 2.28 inches. More recent data from July of 2006 and 2007 was collected during dry periods. During July 2006 and 2007 precipitation averaged 0.82 inch and 1.53 inches, respectively across Kanabec County. Precipitation was average in the Knife River Basin during July and September of 1996, when Knife River data were collected according to the Minnesota Climatology Working Group (2010). Data from dry periods may not accurately reflect the health of the Knife River because distribution and life cycles of biota may be different during dry conditions than during average rainfall conditions due to water temperature fluctuations (Merritt et al. 2008).

Both 2006 and 2007 were dry years and macroinvertebrate data collected during this timeframe has been deemed unusable by the MPCA due to the presumption that drought conditions may have a negative effect on macroinvertebrate IBI scores (Joel Chirhart, personal communication, April 7, 2010). This thesis will include data collected from these years for macroinvertebrate analysis since these data are limited, however, the majority of analysis will focus on fish IBI data for this reason.

3.5 Landuse in the Knife River Basin

The Knife River basin contains areas that are agricultural, pasture, urban, forested, and wetlands. The dominant landuses are deciduous forest, and pastureland (Figure 3). Percentages of agriculture decrease and pasturelands increase in the riparian area from Knife River headwaters to Knife Lake (Table 4). There is also a similar trend of high to low percentage urban and wetlands in the riparian area along the Knife River. An inverse trend of lower to higher percentage of forested land in the riparian area occurs from the Knife River headwaters to Knife Lake. There is no mining activity recorded in the riparian area. Disturbed land use includes agriculture, pasture, and urban areas. A much higher percentage of disturbed land occurs in the riparian area of the first two biosites along the Knife River.

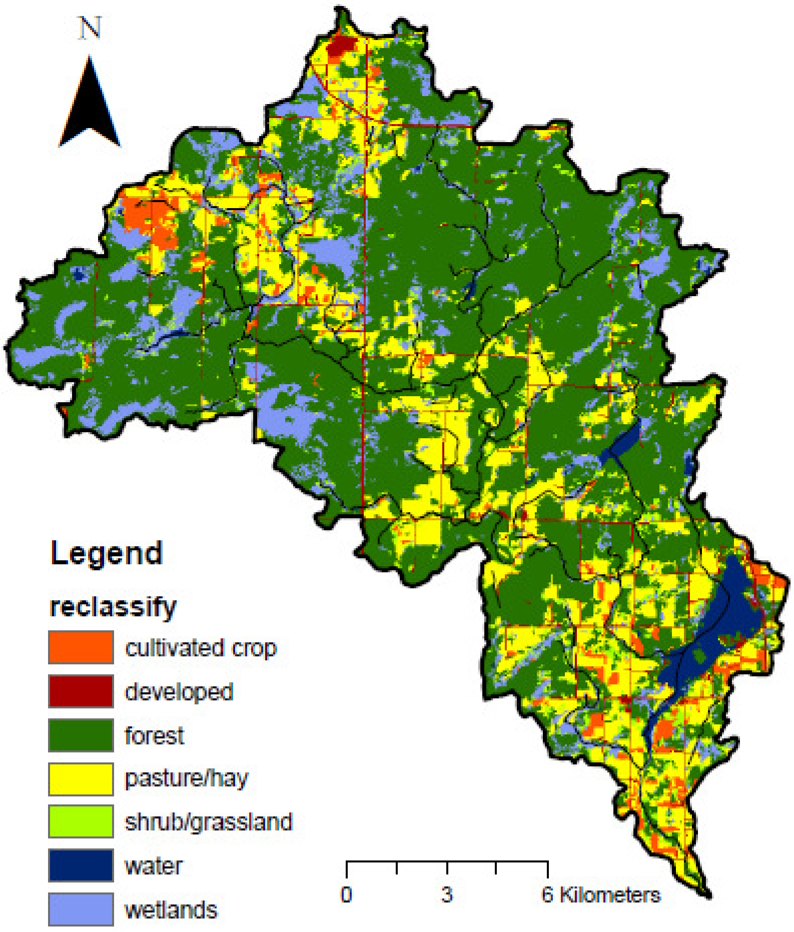

Figure 3: Landuse in the Knife River Basin, NLCD data.

Table 4: Percent landuse within the 30m riparian area of the Knife River.

Biosite number	*Agriculture*	*Pasture*	*Urban*	*Forest*	*Wetland*	*Water*	*Disturbed*
1	9.5	33.1	5	34.3	18	0.1	47.6
2	9.3	33.8	4.9	33.4	18.6	0.1	48
3	4.8	18.9	3.1	54.7	18.1	0.4	26.8
4	3	15.6	2.5	64.6	13.9	0.4	21.1
5	2.4	17.8	2.5	64	12.7	0.6	22.7

4. IBIs and Biological Impairment

Although the CWA was designed to protect biological integrity, the CWA does not describe the ecological components or attributes that compose biological integrity or how the condition of aquatic biota should be measured. Many systems of classifying biological integrity have been developed. Most notably, Karr (1981) identified fish as biological indicators of water quality in wadeable streams of the Midwest. Individual fish metrics were developed and combined to form a composite score called an Index of Biological Integrity (IBI) (Karr1981).

Since 1981, the IBI has been adapted to a variety of stream types, and additional aquatic biota, such as macroinvertebrates and plants, and for many additional regions throughout the country. This thesis uses fish and macroinvertebrate IBIs since data for these two taxa are available state-wide for Minnesota for use in the SI process.

There are three categories of IBI metrics used for fish IBIs in the St. Croix River Basin: species richness and composition, trophic composition and reproductive function, and fish abundance and condition (Karr 1981, Niemela and Feist 2000). Species richness metrics include: the total number of species, number of darter species, number of minnow species, number of headwater species, number intolerant species, percent individuals that are tolerant, and percent of the dominant two species. Trophic composition and reproductive function metrics include: the number of invertivore species, number of omnivore species, percent individuals that are piscivores, and percent of individuals that are simple lithophilic spawners. Finally, fish abundance and condition metrics include: the number of fish per meter of stream sampled, and percent individuals with deformities, eroded fins, lesions or tumors (DELT). Similarly, four categories of metrics make up macroinvertebrate IBIs in the St. Croix River Basin, these include: richness, composition, tolerance, and trophic structure (Chirhart 2003). Macroinvertebrate richness metrics include: the number of Ephemeroptera, Plecoptera, Tricoptera, Chironomidae, Tanytarsini and a combined count of Plecoptera, Odonata, Ephemeroptera, and Tricoptera (POET) taxa. Examples of composition metrics include: percent dominant two taxa, and percent Amphipoda. Tolerance metrics include measures of intolerant and tolerant taxa. Lastly, trophic structure metrics include clinger, gatherer, and filterer taxa. Metrics change in a predictable way with increasing levels of human influence and can be used to quantify a change in a biological assemblage.

For an IBI to accurately assess changes in biological condition that result from anthropogenic activity, the IBI must incorporate natural variability. Climate, topography, and geology all impact species distribution and assemblage structure. Variables, such as stream size, gradient, and water temperature, influence an aquatic assemblage. Therefore, an appropriate basin-level approach has been designed for the St. Croix River Basin, which accounts for reach and regional differences using different metrics based on stream classification (Niemela and Feist 2000).

Originally Karr (1981) developed 12 metrics, but between 8-12 metrics are used in an IBI depending on stream size and classification. Four fish IBIs have been developed with a different set of metrics for four different stream sizes based on drainage area in the St. Croix River Basin: very small streams (<20 mi^2), small streams (20-54 mi^2), moderate streams (55-270 mi^2) and rivers (> 270 mi^2) (Niemela and Feist 2000). Knife River IBIs utilize the very small, small, and moderate stream classes. Metrics receive a score from 0 to 10 with 0 indicating impairment and 10 indicating conditions similar to reference sites. Ten fish metrics are used in the moderate and river-size classes, whereas 9 fish metrics are used for the two smallest stream classes, for which a correction factor of 1.11 is applied, such that the highest possible score is 100.

A description of the fish communities ranging from excellent to poor is used to interpret the IBI score. A ten-point difference in stream fish IBI represents a significant change in biological integrity. In cool water streams in the St. Croix River basin, the minimum IBI scores for very small, small, and moderate sized streams are 46, 68, and 69 respectively (MPCA 2009). These values denote a threshold level, where scores below this threshold indicate impairment requiring a 303(d) listing.

Often separate macroinvertebrate IBIs are developed for glide/pool, small riffle/run (<50 mi^2 drainage), and large riffle/run streams (>50 mi^2 and <500 mi^2 drainage area) (Chirhart 2003). Streams classified as glide/pool have smooth laminar flow and a variety of substrates. Riffle/run streams have slow-fast non-laminar flow and gravel or cobble substrates. The macroinvertebrate threshold for the St. Croix Basin is 50 and is not dependent upon stream size-class (Neimela et al. 2005). Macroinvertebrates scores ≤50 are considered impaired and may result in 303(d) listing.

The MPCA made a new macroinvertebrate IBI public in 2011, with revised macroinvertebrate IBI scores for all Knife River locations. Two separate macroinvertebrate IBIs were developed for high gradient streams <500 mi^2 and low gradient streams <500 mi^2. Biotic indices are continuously being updated as new information arises, and though it is wise to utilize the most recent data available, this thesis utilizes the older macroinvertebrate IBI because that was what was available during the writing of this thesis.

4.1 Biological Assessment Sites

There are six biological assessment sites within the Knife River. Biosites 1-5 are located on the Upper Knife River above Knife Lake (Table 5, Figure 4). One biological assessment site (biosite 6) is below Knife Lake. Each site was monitored for macroinvertebrates and fish, as well as for quantitative habitat data and water chemistry. Not all sites were monitored each year.

Table 5: MPCA biological assessment sites along the Knife River. Biosites are numbered from headwaters of the Knife River to confluence with the Snake River.

Biosite Number	*Location*	*Years Sampled for Fish*	*Years Sampled for Macroinvertebrates*
1	Lat: 46.0819280409988° Lon: -93.4629667366329°	2006	2006
2	Lat: 46.0702764136767° Lon: -93.4642791798174°	1996, 2006	1996
3	Lat: 46.04766° Long: -93.43636°	2006	2006, 2007
4	Lat: 46.0352796304499° Lon: -93.380000366641°	1996	1996
5	Lat: 45.9800511629271° Lon: -93.3377685600898°	2006	2006
*6	Lat: 45.9203808977269° Lon: -93.3081972015327°	1996, 2005, 2006	1996, 2006

*Site occurs downstream of impaired section of the Knife River

4.2 Sampling Methods

Assessment of a site is done in three stages within a year. First, a site reconnaissance is conducted in the spring. Fish, water chemistry, and habitat data are collected in the summer during a second visit. Macroinvertebrate data are collected during a third visit in the fall.

The Minnesota Pollution Control Agency's (MPCA) fish IBI sampling procedures for wadeable streams are similar to Wisconsin's warmwater stream guidance (Lyons 1992). Sampling is conducted during daylight hours from mid-June through September. Measurements are taken during baseflow conditions and high or low-flow periods are avoided. Electrofishing gear is used to sample fish communities according to procedures outlined in Niemela and Feist (2000). Four types of electrofishing gear are used depending upon stream size and type. A backpack electrofisher is used in small wadeable streams <8m wide. A stream electrofisher is used in larger wadeable streams and rivers (>8m wide). A mini-boom electrofisher is used in small or hard to access non-wadeable streams or rivers. A boom electrofisher is often used in large accessible rivers. For all electrofishing methods, all fish stunned are netted and all available habitat types are sampled in the proportion in which they occur within a site.

Fish are sorted into separate containers by species and a minimum and maximum length and total weight is recorded for each species. Juvenile fish <25mm are not recorded. All fish with DELT are noted. Two specimens from each species are retained for verification and the remaining fish are released into the stream. An IBI score is not calculated if there are <25 individuals at a site (Niemela and Feist 2000). Instead these sites are rated very poor because of low catch rate, as an indication of impairment.

Macroinvertebrate assessment is conducted in late August through October under stable baseflow conditions (Chirhart 2003). Five major habitat types including riffles, undercut banks, submergent or emergent aquatic macrophytes, snags and woody debris, and leaf packs, are assessed in proportion to their presence within a reach. Sample reaches are determined by prior fish collection.

A D-frame dip net with 500 micron mesh is used to sample macroinvertebrates. The net is held downstream of the assessment area and the substrate directly upstream across the width of the net is disturbed. At low-flow conditions, the net may be swept several times in an upstream direction to ensure an adequate sample (Chirthart 2003). Twenty samples are collected moving upstream, combined and preserved in 100% denatured ethanol. Organisms are then placed on a 24 inch by 24 inch tray with 1inch square delineation, and squares are selected at random until a minimum of 300 organisms have been sorted from the sample. These specimens are then identified to genus. Five percent of the samples are checked by another biologist and a sample collection is maintained for comparisons.

Upstream land use in the watershed is characterized using GIS according to Chirhart (2003). Percentages for each land use are determined by summing land use across the entire drainage area and then dividing by the total area. The percent watershed disturbance is calculated by adding the percentages of agricultural and urban land uses, grassland associated with pasture, and mines and open pits (Chirhart 2003).

Grab samples of stream water are collected for chemical analysis immediately prior to fish assessment. Water chemistry variables include DO, turbidity, conductivity, temperature, pH, total suspended solids (TSS), nitrite/nitrate, total phosphorus, and total ammonia (NH_4). More information on water chemistry collection can be found at http://www.pca.state.mn.us/publications/wq-bsm3-01.pdf.

Habitat data are collected immediately after fish sampling at biosites. The MPCA's Stream Habitat Assessment (MSHA) incorporates sixteen metrics, including watershed land use, riparian quality, bank erosion, substrate type and quality, instream cover and channel morphology characteristics. Depth to fines and dominate substrate type are determined. Fines refers to any particles ≤ 2.0 mm in diameter. Particle size classes include: bedrock (>4,000mm), boulders (250-4,000mm), cobble (64-250mm), gravel (2-64mm), sand (0.06-2.0mm), silt (feels greasy between fingers and particles are difficult to see), clay (particles too small to see but that hold their shape when lumped together), and detritus. Information on the MSHA monitoring protocol and physical habitat assessment can be found at http://www.pca.state.mn.us/publications/wq-bsm3-02.pdf.

4.3 STORET Water Chemistry Sites

STORET (STORage and RETrieval), is the U.S. EPA's repository for water quality information for the nation's waters. STORET contains data from 1999 to the present and is an active repository where data are continually added (http://www.pca.state.mn.us/index.php/water/water-monitoring-and-reporting/storet/storet-program.html). Some static archived Legacy Data Center (LDC) data are also contained in STORET.

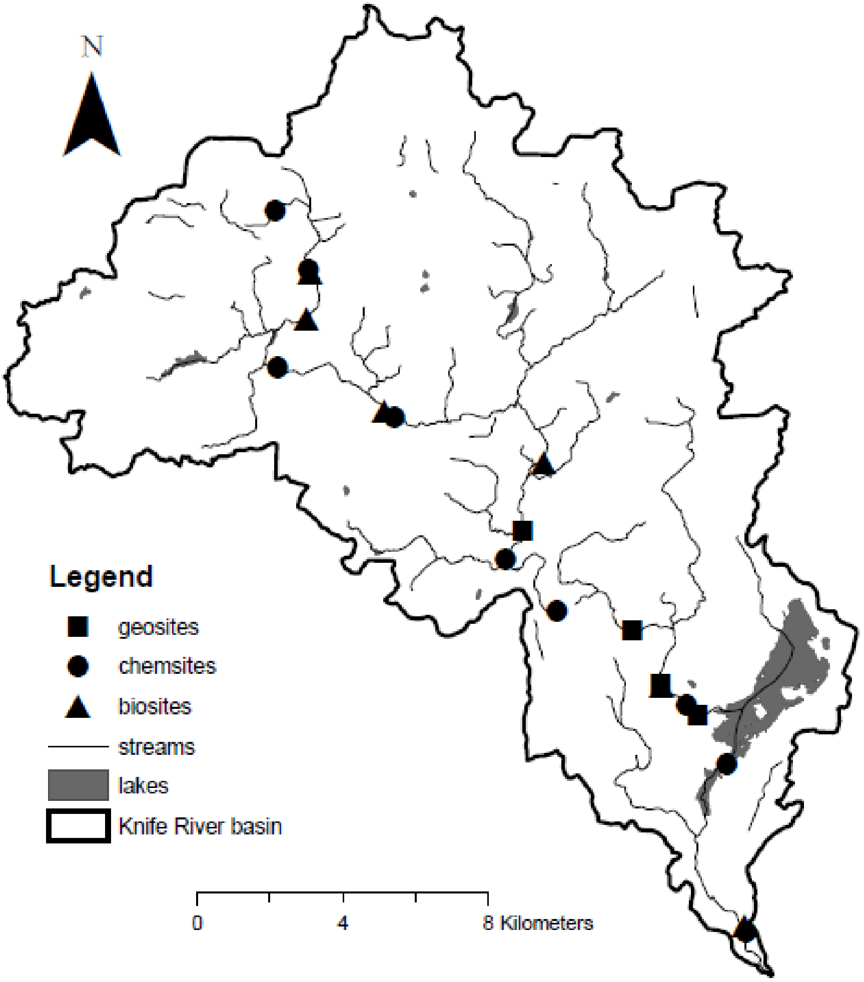

Figure 4: Minnesota Pollution Control Agency biological assessment sites, geomorphology sites, and STORET water chemistry sites in the Knife River Basin.

In addition to data collected during biological assessment, water chemistry data were retrieved from STORET for seven locations along the upper section of the Knife River from the headwaters to Knife Lake and for two locations below Knife Lake (Figure 4).

These sites are hereafter referred to as chemsites and numbered according to their location on the Knife River (Table 6).

Table 6: Chemsite identification number, location, and year(s) sampled for water chemistry from the STORET data base for the Knife River. Chemsite numbers are assigned from Knife River headwaters to confluence with the Snake River.

Chemsite Number	*Site ID Number*	*Location*	*Years Sampled*
1	S005-849	Lat: 46.096886° Lon: -93.475689°	2009
2	S005-833	Lat: 46.0825° Lon: -93.463611°	2009
3	S003-896	Lat: 46.057923° Lon: -93.474385°	2006, 2007, 2008, 2009
4	S002-676	Lat: 46.0460662° Lon: -93.4330132°	1989, 2006, 2009
5	S004-352	Lat: 46.01072° Lon: -93.3932°	2006, 2007, 2008, 2009
6	S002-592	Lat: 45.998° Lon: -93.375°	1989, 2009
7	S002-675	Lat: 45.9748° Lon: -93.329°	1989, 2004, 2005, 2006, 2007, 2008, 2009
8	*S002-677	Lat: 45.9602368° Lon: -93.3146647°	1989, 2009
9	*S003-528	Lat: 45.918988° Lon: -93.307734°	1999, 2001, 2002, 2003, 2004, 2005, 2006, 2008

*Site occurs downstream of impaired section of the Knife River

4.4 Fluvial Geomorphology Sites

Four geomorphology sites were assessed in 2009 (Figure 4) including the Wilkens property, Schlegel property, 06SC125 (biosite 5), and Cada property. These sites will be referred to as geosites and numbered according to their location on the Knife River (Table 7). Data collected at geosites included stream channel dimensions, channel materials, and channel classification and were collected based on methods in Rosgen (1996). Stream channel dimensions include: bankfull channel width, bankfull channel depth, and cross-section width measured along longitudinal transects. Channel sinuosity is estimated based on aerial photography and is the ratio of stream channel length to down-valley distance (Rosgen 1996). Channel materials refer to the surface particles that make up the bed and banks within a bankfull channel. Channel materials are sampled across two meander wavelengths and various bed features (riffles, pools) are sampled in proportion to their frequency. Particles are sampled along a transect and selected via the "first blind touch" to avoid bias using the Wolman pebble count method (Rosgen 1996).

Table 7: Geomorphology sites along the Knife River. Geosites are numbered from headwaters of the Knife to confluence with the Snake River.

Geosite Number	*Site Name*	*Location*	*Date Sampled*
1	Wilkens Property	Lat: 46.018083° Long: -93.387079°	14-Jul-09
2	Schlegel Property	Lat: 45.993659° Long: -93.348334°	21-Sept-09
3	06SC125	Lat: 45.980358° Long: -93.338152°	21-Aug-09
4	Cada Property	Lat: 45.972763° Long: -93.324821°	16-Jul-09

The software package RIVERMorph, LLC 2001-2006 was used to calculate channel dimensions, channel material characteristics, sinuosity, slope, and channel classification at all four geosites. RIVERMorph was designed to "streamline time consuming tasks performed by river restoration professionals…. including assessment, monitoring and natural channel design". Important channel dimensions include the width-to-depth ratio, and entrenchment ratio (flood-prone width/width). Data for channel materials (cobble, gravel, sand, silt) is used to calculate the median particle diameter or D_{50}. Channel classification is based on Rosgen (1996) river classifications and is computed using the entrenchment ratio, width/depth ratio, sinuosity, slope, and channel materials.

4.5 Data Limitations

Limited data are available to evaluate the stressors causing fish and macroinvertebrate impairment from only a few years and six sample sites. Some data limitations include lack of pesticide data, herbicide data, and biochemical oxygen demand data. Most recent fish and macroinvertebrate data are five years old and available at only five sites along the impaired stretch of the Knife River. Most recent biological data are from 2006, a drought year, which may have a negative effect on IBI scores. STORET contains a vast amount of information on some parameters, whereas others have only a few measurements. Data found in STORET may be collected using differing techniques and is citizen reported. Geomorphology data is limited to four geosites in the middle section of the Knife River.

4.6 Statistical Analysis

Nonmetric multidimensional scaling (NMDS) ordination using statistical software R (R version 2.12.2 2011) was performed to determine similarity between fish species at sites along the Knife River. The labdsv (Roberts 2010), vegan (Dixon 2003) and ecodist (Goslee and Urban 2007) packages were used. The NMDS evaluates multiple variables simultaneously, whereas the SI approach evaluates each variable separately. Following the ordination, environmental and chemical stressors were correlated with the ordination using a Pearson correlation and Kendall's rank correlation ($P = 0.05$) to evaluate the relationships between fish species and abundance, and environmental and chemical stressors. Distance matrices were calculated using Sorensen (Bray-Curtis) distance measures. A random starting point was used and 100 runs were performed with real data. Three dimensions were considered and the number was reduced through iteration to optimize the stress of the final configuration. A final stress <10 indicates little risk in making inferences, whereas interpretation of an ordination with a final stress >10 may be misleading as values near 20 (Clarke 1993). Fish abundance data were log transformed. Following the ordination analysis, a least-squared regression between fish IBI scores and environmental variables were calculated.

5. Defining Potential Indicators of Impairment Using Biological Data

Fish and invertebrate assemblages respond in predictable ways to anthropogenic stress (Niemela and Feist 2000, Chirhart 2003). Therefore, by examining the values for metrics of abundance, species richness and composition, trophic composition and reproductive function within the IBI, potential sources for biological impairment may be determined. This section addresses the metrics used in obtaining each IBI score to assess potential indicators of biological impairment.

The goal of the following approach is to examine potential indicators of impairment and determine whether a stressor(s) may be present that would reduce a metric score. Both systemic and localized impairments are possible. Systemic impairments are those that are present at more than one site and may indicate non-point stressors or larger-scale stressors across the watershed, such as excess nutrients. A localized impairment may be restricted to a single site and is often linked with a point source stressor, such as discharge from an industrial source, unique habitat or a geologic feature. IBI metrics with a mean score of ≤4 are considered potential indicators of impairment for the remainder of this thesis. Most metrics receive a higher score as they increase, such as number of sensitive species; however, others such as DELT are scored inversely. All metrics were scored. In figures with no histogram the metric received a score of 0.

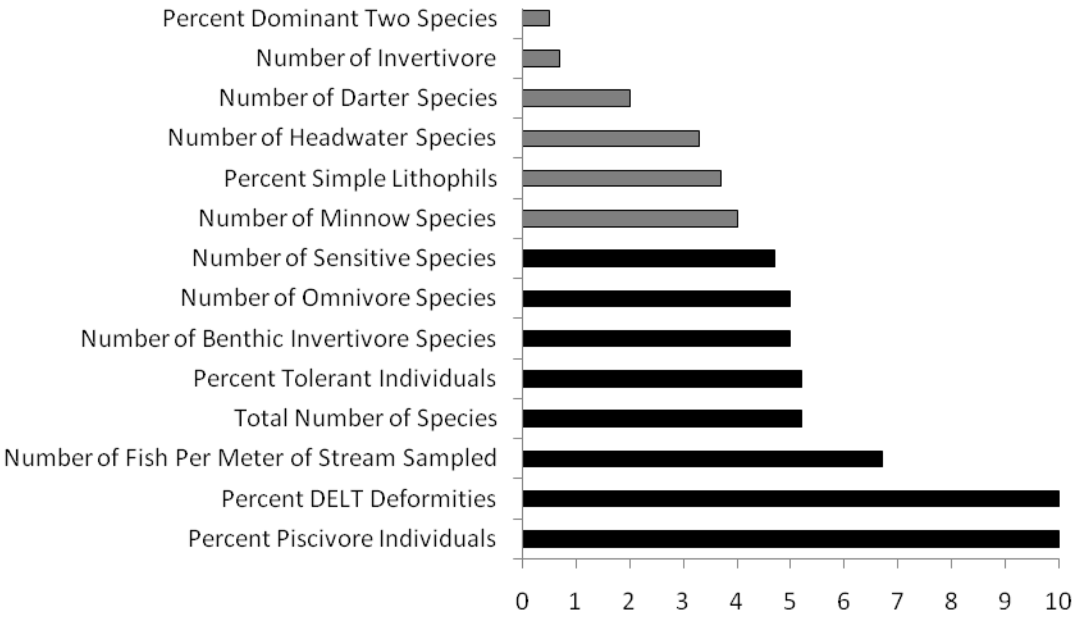

Figure 5: Mean fish metric scores across biosites from the headwaters to Knife Lake, on the Knife River. Grey bars indicate potential systemic impairments.

5.1 Systemic Indicators of Impairment

Fish

Systemic indicators of impairment are those that exist throughout the watershed and appear to be present at most assessment sites. Six of fourteen fish IBI metrics may indicate systemic impairment in the Knife River across all biological monitoring sites and years (Figure 5). The six metrics with a mean score ≤ 4 include percent dominant two species, number of invertivore species, number of darter species, number of headwater species, and number of minnow species. The number of invertivore species metric is a trophic composition metric, whereas the other metrics are species richness and composition metrics. The majority of potential systemic indicators of impairment are located in the upper reaches of the Knife River (Figures 6-8).

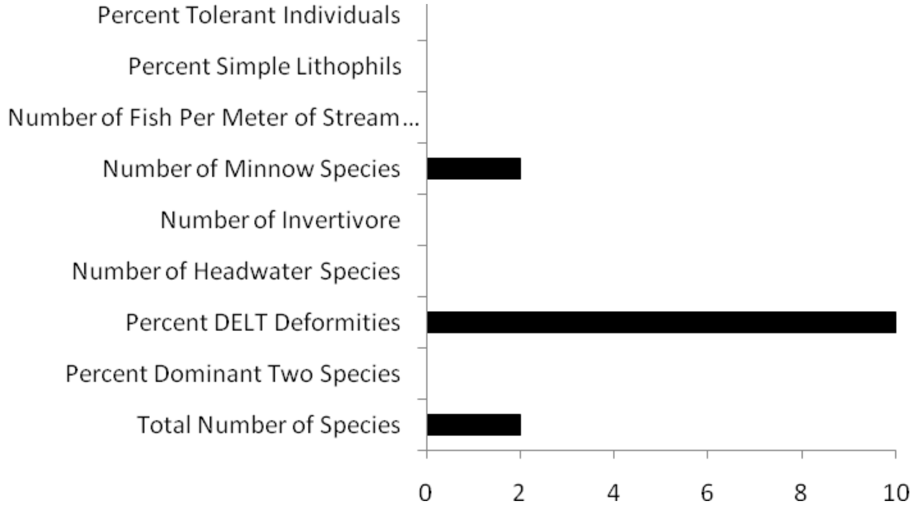

Figure 6: Fish IBI metric scores for biosite 1 on 7 July 2006. The total IBI score was 16 indicating biological impairment.

Percent Dominant Two Species:

One or two species may dominate a community in lower water quality systems with increasing levels of human disturbance as other species decline and tolerant species generally increase following a change in their environment (Niemela and Feist 2000, Chirhart 2003). Healthy systems generally have diverse and evenly distributed taxonomic groups.

Central mudminnow (*Umbra limi*) was the dominant fish species sampled in three of the four impaired samples (Figures 6-8). Central mudminnow are native tolerant wetland invertivores (Niemela and Feist 2000). The common shiner (*Luxilus cornutus*) was also a dominant fish species at two of the four impaired sites (Figures 8 and 9). Common shiners are native tolerant minnow species and are simple lithophilic spawners (Niemela and Feist 2000).

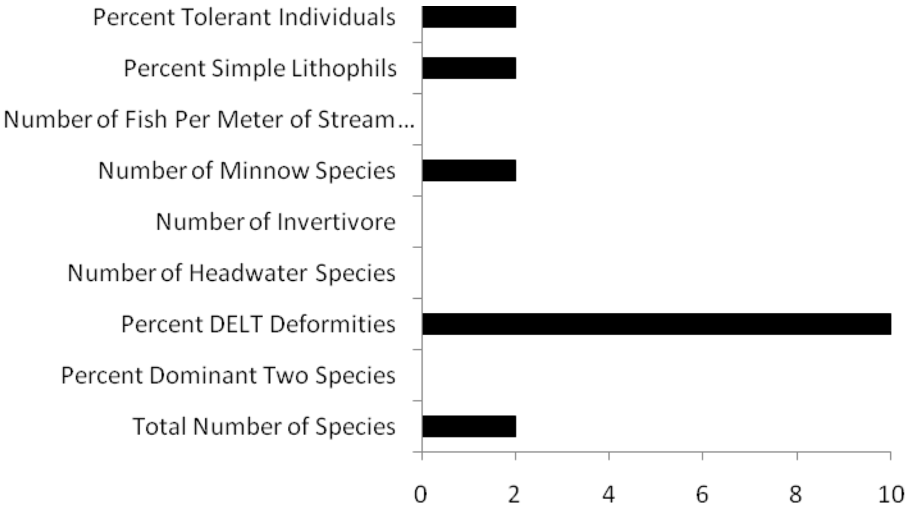

Figure 7: Fish IBI metric scores for biosite 2 on 6 July 2006. The total IBI score was 20 indicating biological impairment.

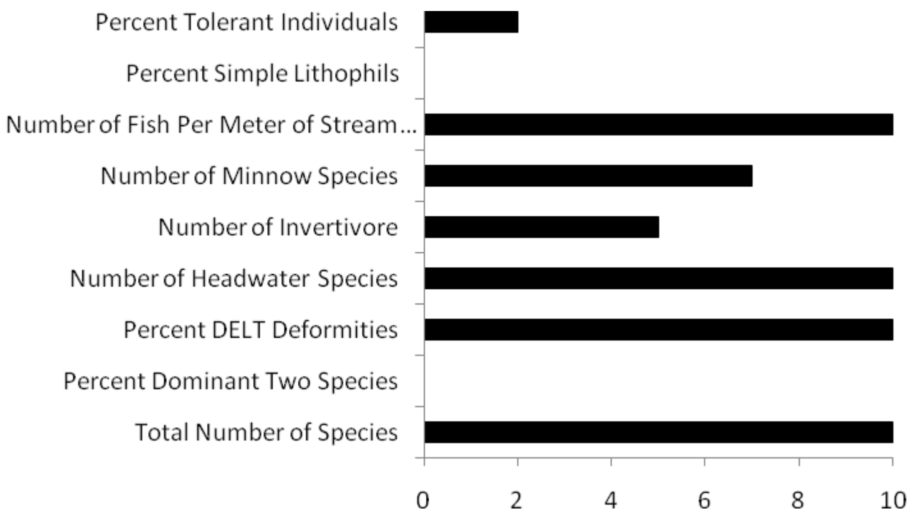

Figure 8: Fish IBI metric scores for biosite 2 on 2 July 1996. The total IBI score was 60 indicating the site was not impaired.

Number of Invertivore Species:

Invertivores depend on a stable invertebrate population as prey (Niemela and Feist 2000). Fluctuations in or reduction of the invertebrate population may be related to a decline in invertivore species. Fish invertivore species received a score of 0 in 2006 at biosites 1 and 2.

Number of Darter Species:

Darters are sensitive to water quality because they require clean, coarse substrate found in riffle habitats. Darters are both benthic invertivores and lithophilic spawners that rely on undisturbed benthic habitats to feed and reproduce. Darters tend to disappear in streams that have lost channel complexity, or where coarse substrates have become embedded due to siltation (Niemela and Feist 2000). Low numbers of darter species were found at biosites 4 and 5.

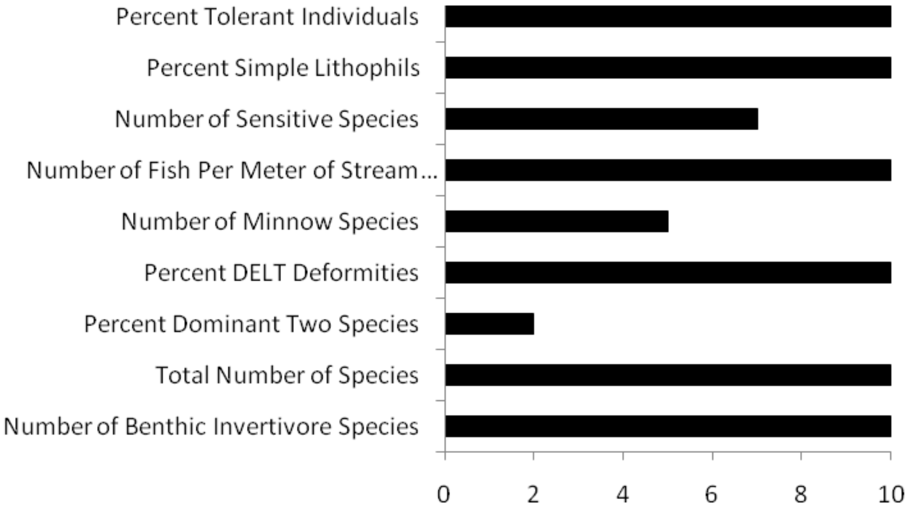

Figure 9: Fish IBI metric scores for biosite 3 on 18 July 2006. The total IBI score was 82 indicating the site was not impaired.

Number of Headwater Species:

Many headwater streams connected to wetlands in the Knife River retain some permanence of fish habitat, although, flow and other chemical parameters can change quickly in headwaters streams. Watershed urbanization and channelization amplify fluctuations and reduce available habitat (Niemela and Feist 2000). Species, such as redbelly dace (*Phoxinus eos*) and finescale dace (*Phoxinus neogaeus*), are adapted to live in headwaters; however, large-scale human disturbances, such as urbanization or agriculture, in the watershed often result in elevated nutrients and sediments, eliminating these species. Both headwater biosites 1 and 2 have a score of 0 for number of headwater species in 2006; a decline from 10 at biosite 2 from 1996.

Percent Simple Lithophils:

Lithophilic spawners broadcast their eggs over clean gravel substrates and do not provide parental care. Eggs develop in the interstitial spaces between the gravel and cobble. Low numbers of lithophilic spawners indicate deposition of fine sediment in the stream channel (Berkman and Rabeni 1987; Neima and Feist 2000). The uppermost reaches of the Knife River have low scores for percent simple lithophils.

Number of Minnow Species:

Many minnow species are sensitive to water quality changes (Niemela and Feist 2000). Minnows often thrive in slack water habitats where accumulating silts and toxins may negatively affect their ability to feed, reproduce and osmoregulate. The two biosites in the headwaters have low minnow species scores.

Percent Omnivores:

Omnivores are more flexible in the type of food that they eat, and therefore, often fare-better when the food supply is disrupted. Their dominance within a fish community indicates an unstable food base and can be indicative of increased nutrient loading (McCormick et al. 2001; Thoma and Simon 2003). Biosites 4 and 5 received metric scores of 5 for percent omnivores, whereas biosite 6 received a score of 10 in 1996, and a score of 7 in both 2005 and 2006.

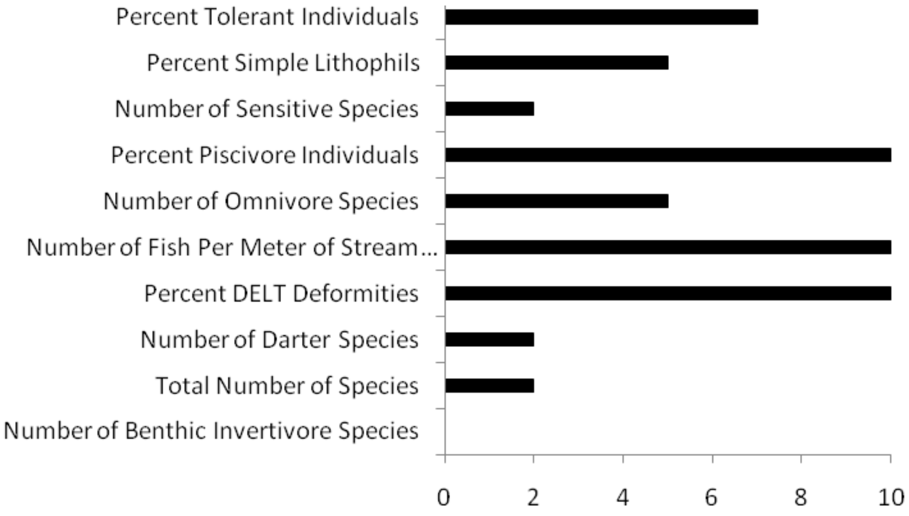

Figure 10: Fish IBI metric scores for biosite 4 on 25 June 1996. The total IBI score was 53 indicating biological impairment.

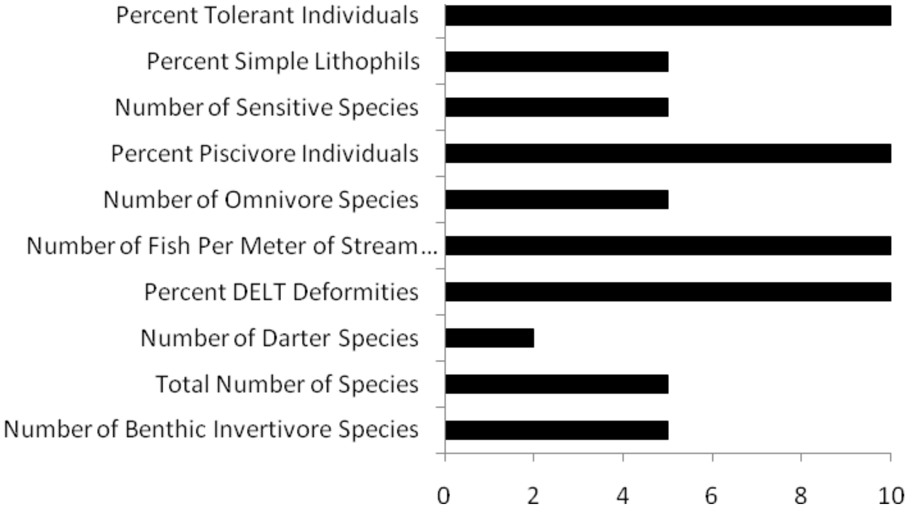

Figure 11: Fish IBI metric scores for biosite 5 on 19 July 2006. The total IBI score was 67 indicating biological impairment.

Percent Deformities, eroded fines, lesions, and tumors (DELT) Deformities:

The percent DELT is usually an indicator of industrial pollutants. Since all scores in the Knife River Basin were a 10 for DELT (no occurrences recorded), there is little support for heavy metals and chemicals as stressors.

Macroinvertebrates

Taxa Richness

Taxa richness is the most common measure used to describe macroinvertebrate communities (Rosenberg, Resh and King 2008). The number of taxa decreases as water quality declines.

EPT Richness

Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness is a common variation on taxa richness. The taxa in these three orders are pollution sensitive and decrease as water quality declines (Rosenberg et al. 2008). Orders of EPT inhabit a wide variety of habitats and their diversity is a good indicator of habitat quality (Jasperson 2011). Odonota are sometimes added to this metric, which is then referred to as POET, to make it more useful in slow moving water where stoneflies are not as abundant.

Number Intolerant Taxa:

The number of intolerant taxa is a measure of organisms that receive a score of 2 or less in the Hilsenhoff Biotic Index (HBI) (Hilsenhoff 1987). Organisms with high scores have been identified as tolerant to organic pollution. The presence of moderate numbers of intolerant taxa is an indicator of good aquatic health (Jasperson 2011).

Percent Tolerant Taxa:

Abundance of tolerant taxa included those that received an 8 or greater in the HBI. Tolerant invertebrates thrive in areas of low DO, high turbidity, or heavy siltation, and occur at all sites, but dominance increases as condition is degraded (Fore et al. 1996).

Enumeration:

Total number of individuals or ratio of EPT to Chironomidae abundance and percent dominant taxa describe the increase or decrease in total individuals associated with some stressors (Rosenberg et al. 2008).

Number of Filterer Taxa:

Filtering taxa collect their food by filtering the water column. A high number of filtering taxa indicate an abundance of particulate matter in suspension (Jasperson 2011), which could be caused by erosion or increased organic debris.

Number of Clinger Taxa:

Clinger taxa are adapted to fast moving water. A diverse group of clinger taxa indicate that substrate has not become embedded or covered by fine material. Lack of clingers indicates siltation or embeddedness, often the result of erosion (Jasperson 2011).

5.2 Localized Indicators of Impairment

Local indicators of impairment are those that occur only at a few sites along a river. There are several potential local indicators of impairment at sites within the Knife River. The potential local indicators of impairment can be separated into two regions, the headwaters and middle reaches.

The headwaters region of the Knife River contains two biosites that indicate local impairment. In 2006, low metric scores for every metric in the IBI, with the exception of the DELT score, were found at biosites (1 and 2) in the headwaters region. Changing chemical water properties may result in low headwater IBI scores since the headwaters region begins in a wetland. A high percentage of tolerant species and dominant two species were found at biosite 2 in 1996, which indicate reduced water quality.

The midstream region of the Knife River contains 3 biosites. A low score for percent dominant two was recorded at biosite 3 in 2006, which may indicate human disturbance (Niemela and Feist 2000). Further downstream, biosite 4 (Figure10) and 5 (Figure 11) had low numbers of darters and benthic invertivores which may indicate excess sediment deposition in the midstream region of the Knife River.

6. Results of the Nonmetric Multidimensional Scaling Analysis

In the Knife River, biosites 1 and 2 are the most similar, whereas other sites are spread across ordination space, with more dissimilarity between them. The headwaters region of the Knife River is correlated with low gradient and higher percent fines (Figure 12). Higher percentages of agricultural, urban and rangeland are also correlated with the headwaters region of the Knife River (biosites 1 and 2). Higher gradient, percent forest and percent riffles are correlated with the mid-stream reaches of the Knife River (Figure 12).

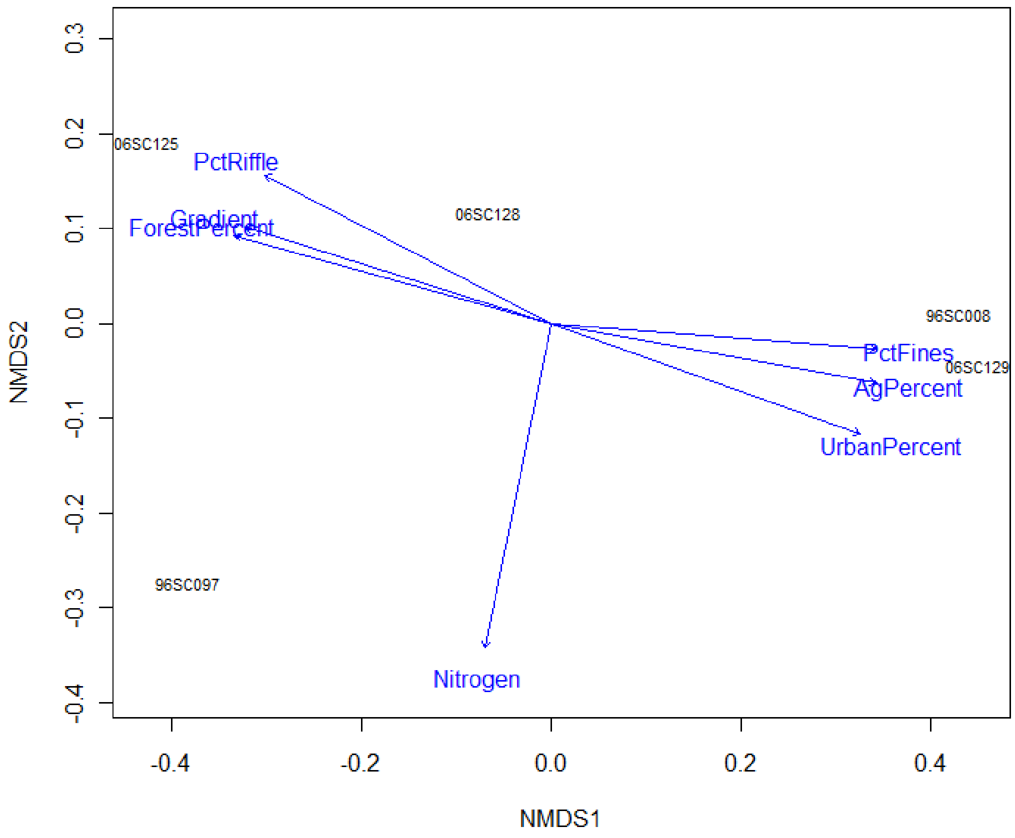

Figure 12: Non-metric multidimensional scaling of fish species abundance data and environmental variables from 2006 at five biosites along the Knife River.

Table 8: NMDS analysis output from R, including significance values for all environmental and water chemistry data based on the ordination of fish presence and abundance. Significant values: '***' = 0.001, '**' = 0.01, '*' = 0.05, and '.' = 0.1. P-values based on 999 permutations.

	P-value	r2	NMDS1	NMDS2
Gradient	0.040 *	0.9431	-0.9538807	0.3001861
PctRiffle	0.046 *	0.9559	-0.8875535	0.4607047
PctPool	0.83	0.1884	-0.0381169	-0.9992733
PctRun	0.207	0.8018	0.9984529	-0.0556045
PctFines	0.001 ***	0.9672	0.9971396	-0.0755822
PctEmbed	0.6	0.3828	-0.6883581	0.725371
PctCover	0.258	0.755	0.9662055	0.257773
PctBoulder	0.188	0.82	-0.9983558	-0.0573215
PctUnderCut	0.899	0.1544	-0.0031143	0.9999952
PctOverVeg	0.563	0.3624	0.9996533	0.0263319
PctEmerMac	0.058 .	0.9648	0.9999311	-0.0117377
PctSubMac	0.493	0.4163	0.9423107	0.3347396
MThalDepth	0.803	0.1637	-0.3372161	0.9414273
MDepth	0.511	0.4721	0.6124206	0.7905321
MWidth	0.2	0.8257	-0.7143862	0.6997516
AgPercent	0.001 ***	0.9944	0.9835198	-0.1808002
RangePercent	0.116	0.8909	0.8391212	-0.5439444
UrbanPercent	0.001 ***	0.9791	0.9412305	-0.3377649
ForestPercent	0.001 ***	0.9946	-0.9636841	0.2670449
WetlandPercent	0.158	0.8607	0.7849384	0.6195738
TempH2O	0.667	0.3534	-0.9448744	-0.327433
Conduct	0.911	0.0624	-0.3329351	0.9429497
Turbid	0.598	0.4161	0.168512	0.9856996
DO	0.412	0.5477	-0.0405474	-0.9991776
pH	0.492	0.5813	-0.6912603	-0.7226058
FishIBI	0.223	0.7775	-0.9816564	0.1906584
Nitrogen	0.001 ***	0.9998	-0.2020737	-0.9793703
Phos	0.544	0.4912	0.1200644	0.9927661
TSS	0.438	0.5719	-0.1743676	0.9846806

7. Candidate Stressors

The first step in the CADDIS process is to list all potential causes of impairment (stressors) within the Knife River. Twenty-two stressors were considered in this SI process (Table 9).

Table 9: Potential causes of impairment from EPA's CADDIS website at: http://cfpub.epa.gov/caddis/index.cfm

Low dissolved oxygen
Hydrologic regime alteration
Nutrients
Organic-matter
pH
Salinity
Bed sediment, siltation
Suspended solids, turbidity
Water temperature
Habitat destruction
Habitat fragmentation
Toxic substances: such as herbicides, chloride, metals, and organic substances
Interspecies competition
Complications due to small populations
Genetic alteration (e.g., hybridization)
Overharvesting or legal, intentional collecting or killing
Parasitism
Predation
Poaching, vandalism, harassment, or indiscriminate killing
Unintentional capture or killing (e.g., artillery explosions, roadway casualties)
Vertebrate animal damage control (includes trapping, shooting, poisoning)
Radiation exposure increase (e.g., increased UV radiation)

7.1 Eliminated Stressors

Several stressors were eliminated in the stressor identification process. Stressors were eliminated based on data within normal ranges or lack of probable cause. Many stressors were eliminated simply because their effects are not known to occur in the Knife River Basin, such as poaching, unintentional capture, overharvesting, or animal control. Other stressors that were eliminated include: toxic substances such as chloride, phosphorus, nitrogen, habitat fragmentation and temperature. The following provides a brief description of some of the eliminated stressors and their justifications for elimination.

Toxic Substances and Harmful Chemicals at High Concentrations

Heavy metals and other toxic chemicals cause an increase in DELT to occur at dilute concentrations, and can be lethal to biota at high concentrations. Toxic substances were not specifically assessed in the Knife River watershed; however, there are no known uses of toxic substances such, as halogen, fish killing agents, lampricides, molluscucides, hydrocarbons, metals or endocrine disrupting chemicals. There is a wastewater treatment plant in the watershed, but all DELT scores were considered excellent in the Knife River. Toxic substances are not candidate stressors due to lack of data on application, and no known occurrences of DELT.

Chloride and Salinity

High levels of chloride can interfere with osmoregulation in aquatic organisms. The class 2 standard for chloride is 230 mg/L. Sources of excess chloride may be from wastewater treatment effluent, discharge waters from industries, and road salt. Levels of chloride in the Knife River are well below the 230 mg/L standard and are unlikely to be a threat to aquatic life. Salinity levels are between 2.5 and 6.2 mg/L which are in typical range for freshwater ecosystems.

Ammonia

Elevated concentrations of unionized ammonia are toxic to aquatic life, because ammonia readily diffuses across gill membranes. Elevated concentrations of ammonia affect respiration, organ function and nervous system function in fish and macroinvertebrates (IPCS 1986). Sensitive species and fish fry may not be found at concentrations above 0.04 mg/L the Minnesota standard for unionized ammonia in class 2B waters (MPCA 2010). The percent of unionized ammonia was calculated using temperature and pH from the equation (Emerson et al. 1975):

$f=1/(10^{(pka-pH)}+1)x100$

f = the percent of total unionized ammonia

pka = 0.09+(2730/T)

T= temperature in degrees Kelvin (273.16°K = 0°C)

The concentration of unionized ammonia increases with increasing pH and decreasing DO due to reduction of nitrate to ammonia. One potential source of ammonia is fertilizer application, as anhydrous ammonia on row crops. Another potential source of ammonia is manure application on cropland or where cattle have direct access to the river. Runoff from feedlots, point source industrial discharge, municipal waste treatment plants and landfills are other sources of ammonia loading. There is one waste treatment plant in the Knife River Basin, however calculated levels of un-ionized ammonia were well below 0.04mg/L (Table 10).

Table 10: Calculated fraction of unionized ammonia at five biosites in the Knife River.

Biosite number	*Date of Collection*	*Temperature °C*	*pH*	*Total Ammonia µg/L*	*Fraction of unionized ammonia µg/L*
1	7-Jul-06	18.2	6.5	60	0.065
2	2-Jul-96	22	7.26	30	0.245
2	6-Jul-06	21.8	7.4	50	0.554
3	18-Jul-06	26.76	7.57	50	1.152
3	19-Jun-07	22	7.6	50	0.885
5	19-Jul-06	21.92	7.4	50	0.559
6	18-Sep-96	11	8.3	20	0.761
6	11-Jul-06	24.5	7.47	50	0.786

Nitrogen and Phosphorus

Nitrogen and phosphorus enrichment lead to an increase in primary production (Mason 2002). In most freshwaters, phosphorus tends to be the nutrient limiting productivity because natural concentrations tend to be low in proportion to nitrogen. Nutrients can be derived from sewage, industrial wastes, run-off from animal manure, soil erosion, and leaching from fertilizers. Most assessed values of phosphorus are below the 0.3 mg/L threshold at biosites (Figure 13). However, chemsite 7 had an elevated phosphorus concentration of 0.34 mg/L in May 2008 (Figure 14). A single value exceeding the threshold for phosphorus is not sufficient for phosphorus to be considered a stressor. All assessed nitrogen values were below the 10 mg/L standard (EPA 2010) (Figure 15).

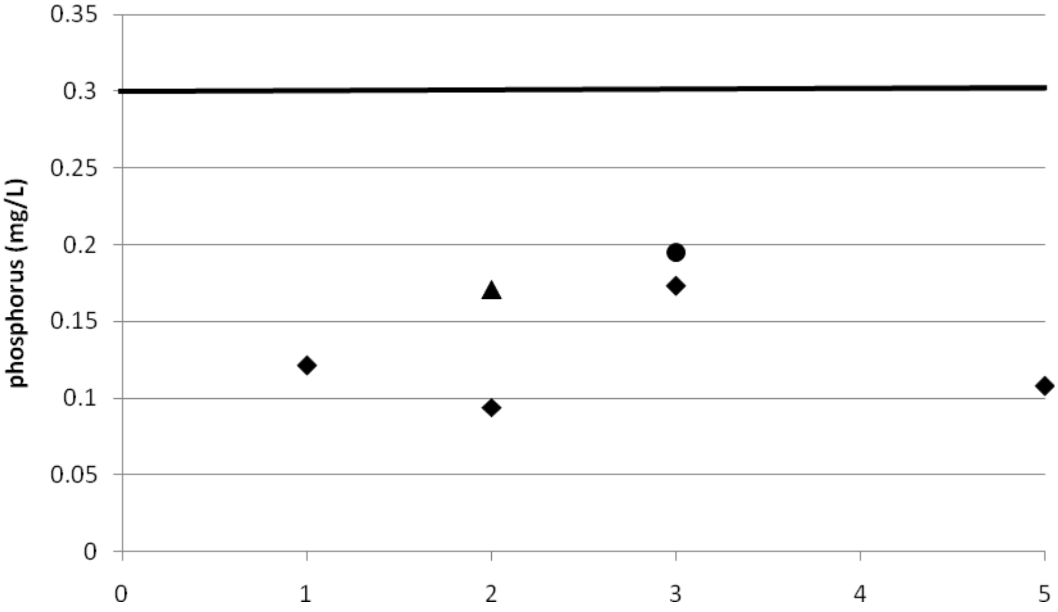

Figure 13: Phosphorus measurements at four biosites along the Knife River. Triangles represent data collected in 1996, diamonds represent data collected in 2006 and the circle represents data collected in 2007. The bold line at 0.3 mg/L indicates the threshold level.

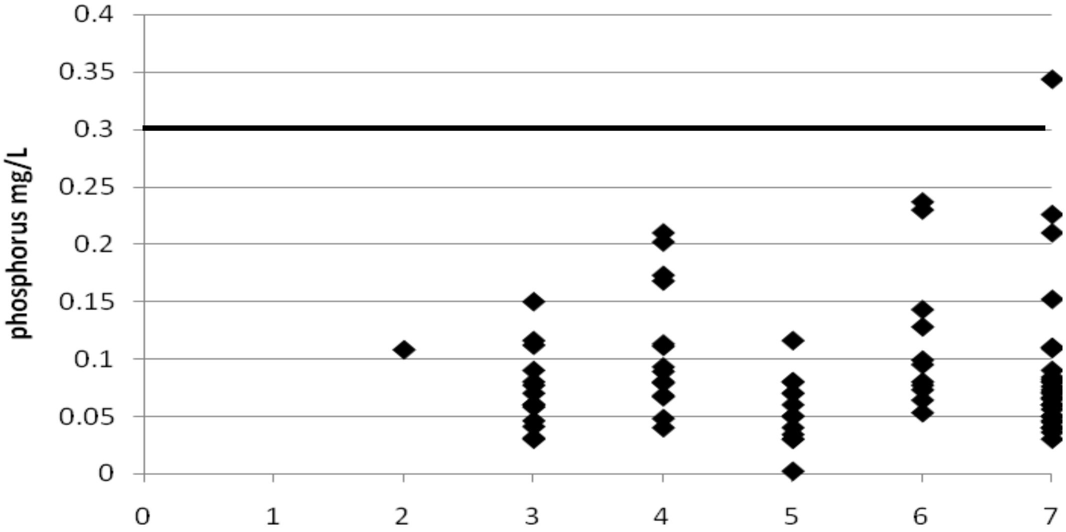

Figure 14: STORET phosphorus concentrations for seven chemsites along the Knife River from 1989, 1999, and 2001-2009. The bold line at 0.3 mg/L indicates the threshold level.

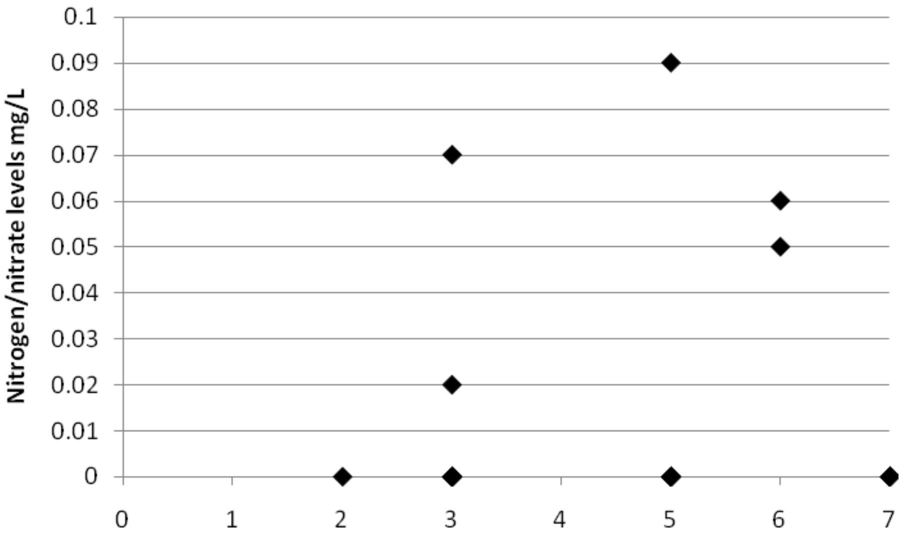

Figure 15: STORET nitrogen concentrations at seven chemsites along the Knife River from 1999-2009.

Habitat fragmentation and destruction

Habitat fragmentation results in barriers to movement, limiting the available space for biota, as well as food sources, and reproduction potential. Habitat fragmentation can result from culverts, dams, and weirs on a river, or loss of riparian habitat. There are no dams or weirs on the upper Knife River, however Knife Lake is an impoundment. The dam likely moderates environmental variables such as sediment, DO, and temperature, in the lower stretch of the Knife River, but the effects on the upper Knife River are likely limited. There are also no major stretches of riparian habitat loss along the Knife River, and the largest riparian landuse is deciduous forest. Thus, habitat fragmentation and loss are not considered stressors.

Temperature

High temperatures or rapid changes in temperature results in reduced DO availability for respiration and can lead to mortality of aquatic life. Currently, only cold water assemblages are evaluated for temperature-related impairments due to their extreme sensitivity to changes in temperature. The Knife River is a coolwater river, thus no temperature standard exists for stream biota.

The blacknose dace (*Rhinichthys atratulus*) is the most temperature sensitive fish found in the Knife River according to tolerance indicator values published by Meador and Carlisle (2007). The upper lethal temperature for blacknose dace is 29.3°C, and poor growth occurs in temperatures less than 13°C or above 27°C (Trial et al. 1983). There were 13 of 246 occurrences where temperature exceeded 27°C in the Knife River: 29.4 C was recorded twice at chemsite 7 in July 2007, only 0.1°C above the lethal temperature of the blacknose dace.

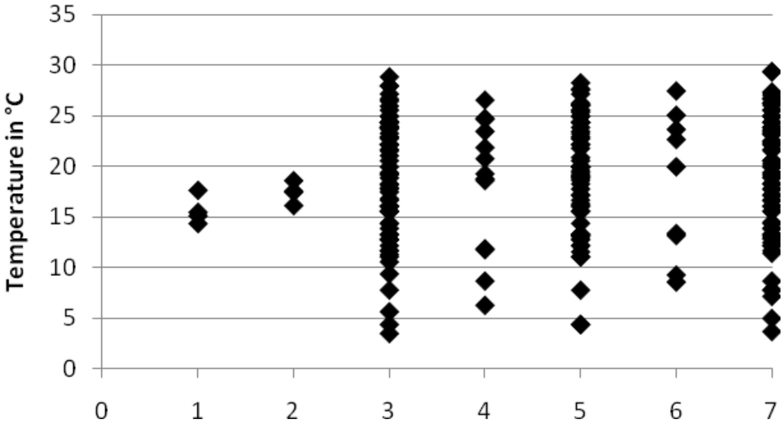

Figure 16: Temperature measurements (n=246) from STORET from April to October 1989, and 2004-2009 at seven chemsites along the Knife River.

STORET temperature data were collected from April-October (Figure 16). Only two measurements were above the upper lethal limit for blacknose dace, therefore temperature is not considered a stressor in the Knife River.

Turbidity/ Suspended Sediment

Turbidity is a measure of the amount of suspended solids (organic matter, industrial wastes, and sewage) and algal particles in the water that reduce the transmission of light. High levels of turbidity make it difficult for aquatic organisms to find food, and fine sediment that settles to the streambed may cover spawning beds and inhibit gill function. High turbidity can be caused by excess sand, silt and clay due to soil erosion from agricultural practices or construction, and streambed and streambank erosion during high streamflow events. Water in wetlands can be stained a dark color from dissolved organic matter.

The Class 2B water standard is 25 Nephelometric Turbidity Units (NTU). Transparency and total suspended solids (TSS) may act as a surrogate for turbidity. A measure in a transparency tube of less than 20cm indicates a violation of the 25 NTU standard. There is no Minnesota state standard for TSS. All turbidity measurements and transparency tube measurements for biosites were under threshold levels of 25 NTU and 20 cm respectively (Figures 17 -19), thus suspended sediment will not be discussed as a stressor in the Knife River. However, bedded sediment is discussed in the next section as a potential stressor, and therefore, suspended sediment may be a potential stressor.

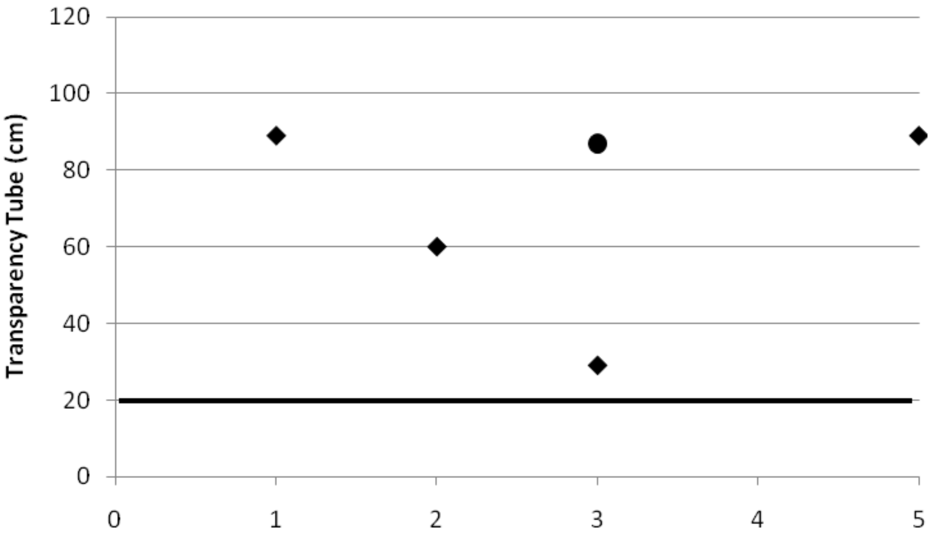

Figure 17: Transparency tube measurments for four biosites along the Knife River in 2006 and 2007. Diamonds represend data collected in 2006 and the circle represents data collected in 2007. The bold line at 20cm indicates the threshold level.

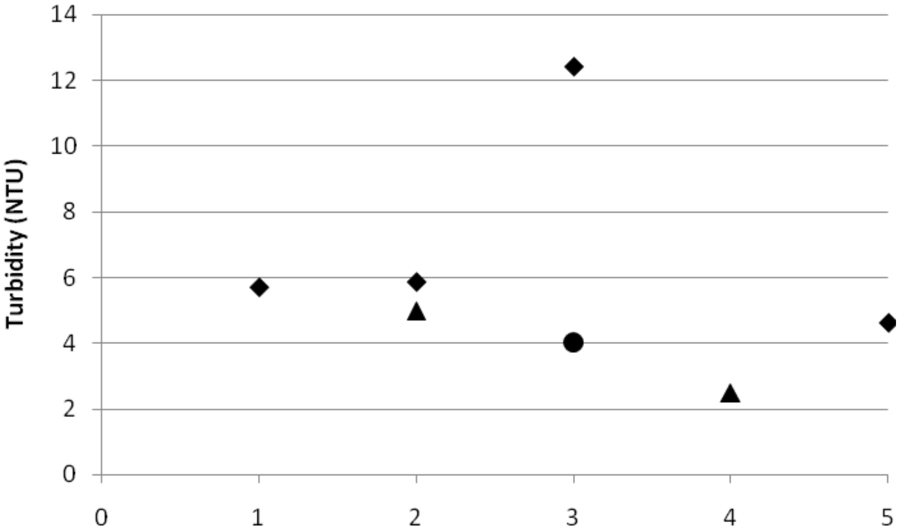

Figure 18: Turbidity measurements (NTU) at five biosites along the Knife River. Triangles represent data collected in 1996, diamonds represent data collected in 2006 and the circle represents data collected in 2007.

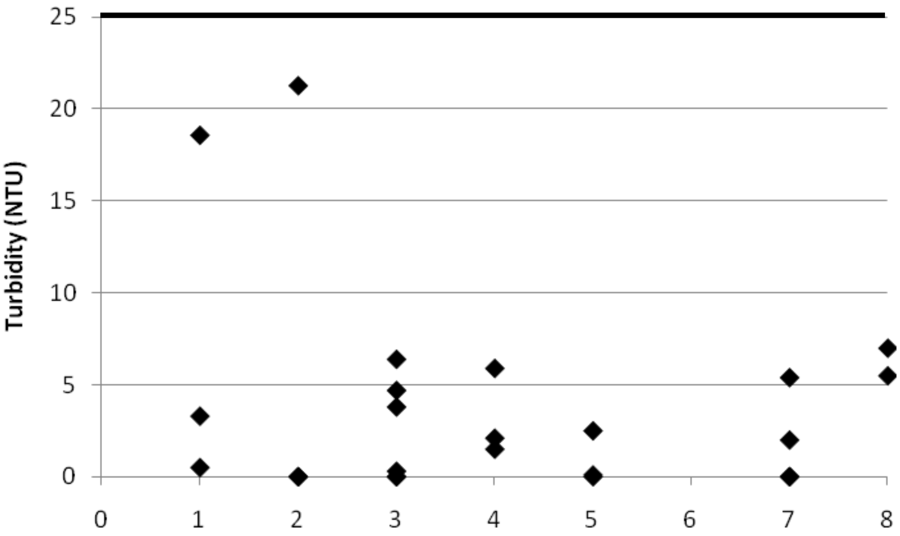

Figure 19: Turbidity measurements (NTU) at eight chemsites along the Knife River, in 2009. The bold line at 25 NTU indicated the threshold level.

Ten other potential stressors were eliminated due to lack of probable cause or lack of information. These include: interspecies competition, complications due to small populations, genetic alteration, intentional or unintentional capture or killing, vandalism or harassment, vertebrate animal control, parasitism, predation, and increased radiation exposure. If probable cause arises, or new data becomes available concerning these stressors, they should be evaluated.

8. Remaining Candidate Stressors

Three candidate stressors were identified in the Knife River, including low DO, high pH, and bedded sediment. Each candidate stressor will be evaluated for sufficiency of evidence from EPA's CADDIS in the Knife River Basin (Tables 11 and 12). Each stressor will be discussed separately before discussing their combined effects and rating them based on the evidence.

Table 11: Key to sufficiency of evidence rankings from EPA's CADDIS website

Rank	Meaning	Caveat
+++	*Convincingly supports*	*but other possible factors*
++	*Strongly supports*	*but potential confounding factors*
+	*Some support*	*but association is not necessarily causal*
0	*Neither supports nor weakens*	*(ambiguous evidence)*
-	*Somewhat weakens support*	*but association does not necessarily reject as a cause*
--	*Strongly weakens*	*but exposure or mechanism possible missed*
---	*Convincingly weakens*	*but other possible factors*
R	*Refutes*	*findings refute the case unequivocally*
NE	*No evidence available*	
D	*Evidence is diagnostic of cause*	

Table 12: Types of evidence and possible rankings for candidate stressors from EPA's CADDIS website.

Types of Evidence	Possible values, high to low
Evidence using data from case	
Spatial / temporal co-occurrence	+, 0, ---, R
Evidence of exposure, biological mechanism	++, +, 0, --, R
Causal pathway	++, +, 0, -, ---
Field evidence of stressor-response	++, +, 0, -, --
Field experiments / manipulation of exposure	+++, 0, ---, R
Laboratory analysis of site media	++, +, 0, -
Temporal sequence	+, 0, ---, R
Verified or tested predictions	+++, +, 0, -, ---, R
Symptoms	D, +, 0, ---, R
Evidence using data from other systems	
Mechanistically plausible cause	+, 0, --
Stressor-response relationships in other field studies	++, +, 0, -, --

Stressor-response relationships in other lab studies	++, +, 0, -, --
Stressor-response relationships in ecological models	+, 0, -
Manipulation of exposure experiments at other sites	+++, +, 0, --
Analogous stressors	++, +, -, --
Multiple lines of evidence	
Consistency of evidence	+++, +, 0, -, --
Explanatory power of evidence	++, 0, -

8.1 Dissolved Oxygen

Dissolved oxygen standard

The Class 2B standard for DO is a daily minimum of 5mg/L (Minnesota Rule 7050.0222). Compliance with this standard is required on 50 percent of the days for which the flow of the receiving water is equal to the lowest 7-day average flow that occurs once every 10 years ($7Q_{10}$). A stream is considered impaired if the DO standard is not met at least 90% of the time between May and September for at least 20 observations. Dissolved oxygen must be measured no more than two hours after sunrise for compliance with the standard.

Effects of low DO in streams

Dissolved oxygen is essential for all aquatic organisms. Oxygen is dissolved into water from the atmosphere via turbulence and released by aquatic plants during respiration. In general, higher concentrations of DO should support a diverse biotic community, and lower levels of DO may not support some organisms, especially if the low level persists.

Low DO can adversely impact fish growth rates (Doudoroff and Warren 1965, Jobling 1994).

Factors impacting DO concentrations

Dissolved oxygen concentrations generally cycle diurnally with the highest values present in the afternoon and minimum levels present just after sunrise. Dissolved oxygen also demonstrates a seasonal pattern with lowest levels typically in the summer when water temperature is warmest and discharge is lowest. The solubility of DO is determined by water temperature where the solubility of oxygen in water decreases with increasing temperature (Kalff 2002:226). Reduced water volume may contribute to a low concentration of DO as organisms become more concentrated in pools of water.

Several factors may reduce DO below the standard. Nutrient runoff from agricultural fields and feedlots, and lawns can deplete DO as plant activity increases and higher levels of DO are required for respiration at night. Dissolved oxygen may be depleted during decomposition of organic material (Mason 2002). Removal of riparian vegetation can also contribute to low DO related to an increase in stream temperature (reduced shading of the surface) and increased organic matter entering the stream. Organic effluents contain large quantities of suspended solids and alter the characteristics of the river bed upon settling out, creating unsuitable habitat for many macroinvertebrates due to anoxic conditions (Mason 2002).

Low DO evaluation for the Knife River

Dissolved oxygen was below the class 2B threshold of 5mg/L at multiple sites along the Knife River. Dissolved oxygen was below the threshold at biosite 2 during the initial bioassessment in 1996, and in 2006 at biosites 1 and 5 (Figure 20).

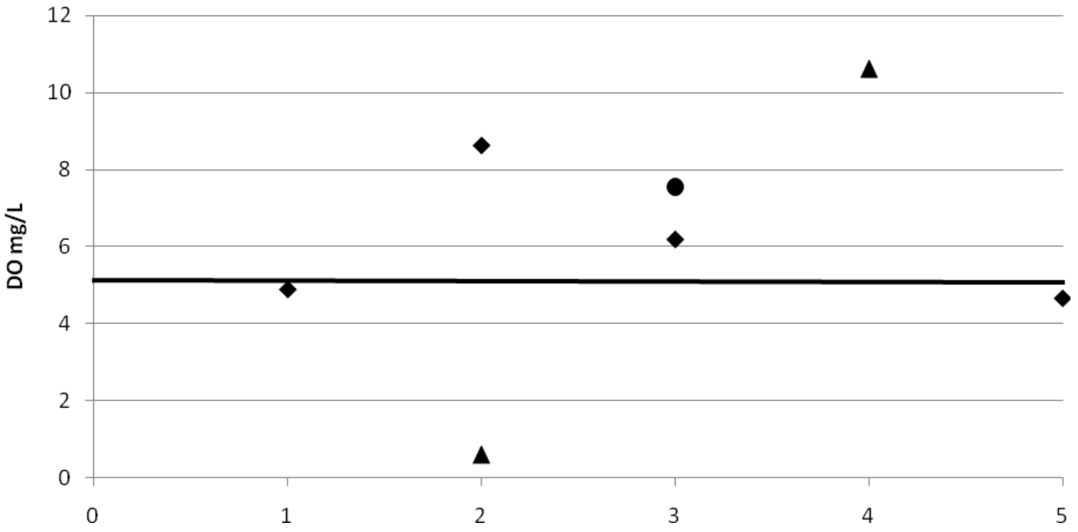

Figure 20: Dissolved oxygen concentrations at five biosites along the Knife River. Triangles represent data from 1996, diamonds represent data from 2006, and the circle represents data from 2007. The bold line at 5 mg/L indicates the threshold level.

Seventeen of 117 DO measures from the STORET database were below the 5mg/L threshold (Figure 21). Low DO concentrations appear at various times throughout the day. Thirteen samples were taken within the 2-hour after sunrise window of which 7 were below 5mg/L (Figure 22). Concentrations at chemsites 1-4 were the lowest mean DO concentrations and chemsites 1 and 2 were below threshold means (Table 13).

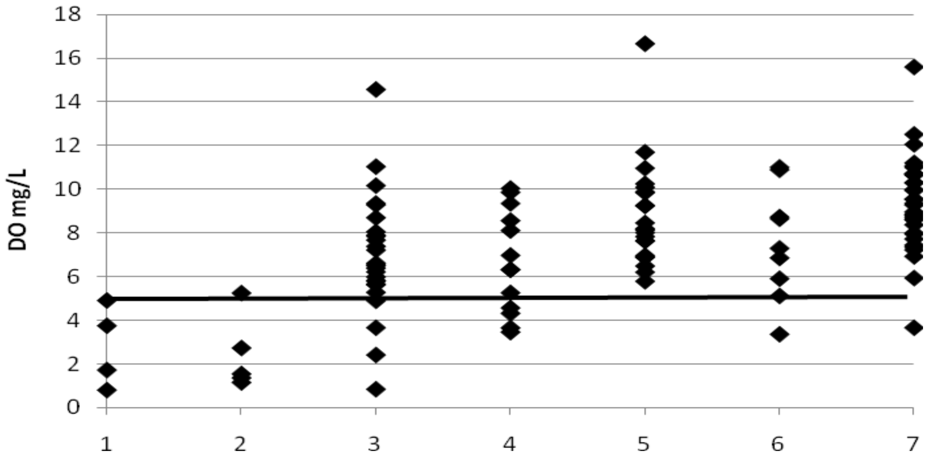

Figure 21: Dissolved oxygen concentrations from STORET at seven chemsites along the Knife River, in 1989 and 2004-2009. DO measurements in STORET are taken between 5am and 8pm from May through October. The bold line at 5 mg/L indicates the threshold level.

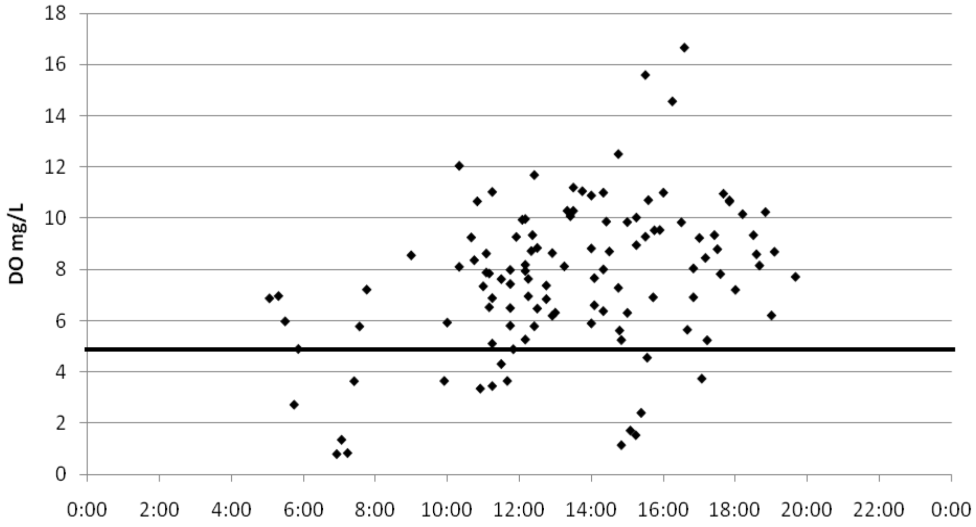

Figure 22: Dissolved oxygen concentrations from STORET by time of day. Measurements at seven chemsites along the Knife River in 1989 and 2004-2009. In September the sun usually rises by 7:30am at the lastest. There are 13 samples taken within the 2-hour after sunrise window. The bold line at 5 mg/L indicates the threshold level.

Spatial/temporal co-occurrence

The DO level at biosite 4 was above the 5mg/L threshold in 1996, the year that fish impairment was listed (Figure 20). Dissolved oxygen concentrations below the 5mg/L threshold during biological sampling were measured at biosites 1 and 5, which were in non-support of the fish IBI standard during 2006 (Figure 20). The DO concentration was above the threshold at biosite 2 in 2006. Macroinvertebrates were assessed in 1996 at biosites 2 and 4 and found to be impaired (low IBI scores); however, only biosite 2 was below the 5mg/L DO threshold.

Table 13: Mean DO concentrations at seven chemsites along the Knife River, in 1989, and 2006-2009.

STORET Sites	*Mean DO*	*Sample Size*
1	2.8	4
2	2.4	5
3	6.9	27
4	6.7	13
5	8.7	24
6	7.5	9
7	9.3	35

Causal Pathway

Wetlands are naturally low in DO because of reduced turbulence and plant decomposition (Kalff 2002). Leaves and macrophytes covering the water surface reduce diffusion of oxygen. Wetlands contain large amounts of organic matter that reduce DO levels through decomposition (biochemical oxygen demand; BOD) by microorganisms. Low DO may therefore be a naturally occurring phenomenon in the headwaters, and DO would be expected to increase downstream as more oxygen diffuses into the water. The mean DO at chemsites 1 and 2 (Table 13) demonstrate that the headwater region has lower DO concentrations than downstream; however, many low DO concentrations were taken throughout the Knife River, thus there must be another causal pathway. An elevated BOD is necessary for a causal pathway linking nutrients as a cause for low DO. BOD was not measured. Nitrogen and phosphorus levels were not elevated, although nitrogen was correlated with the biosite furthest downstream in the NMDS ordination. BOD is not a likely causal pathway for low DO.

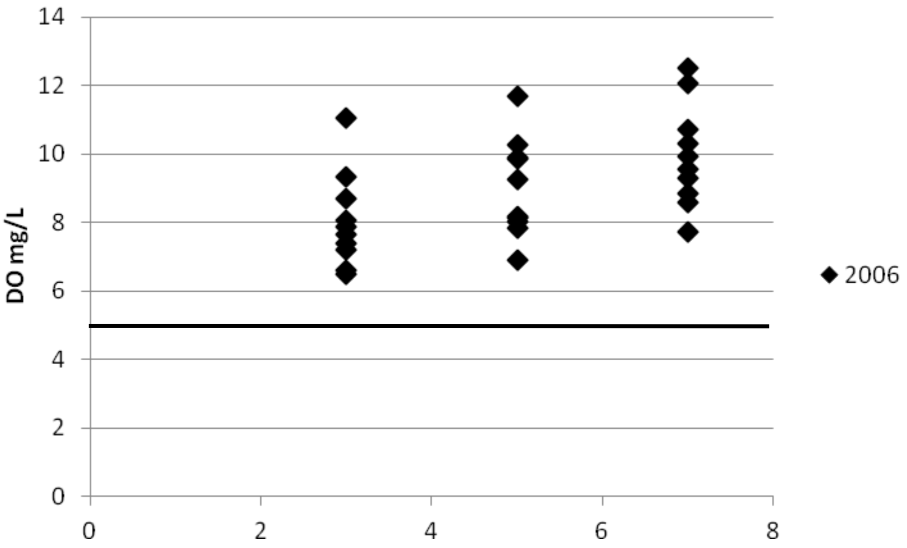

Figure 23: Dissovled oxygen concentrations at three chemsites in 2006 along the Knife River. The bold line at 5 mg/L indicates the threshold level.

Cattle may have access to the Knife River and animal waste or trampling (Trimble and Mendel 1995) are possible causal pathways of low DO. Pastureland makes up about 33% of landuse in the headwaters of the Knife River (Table 4, Figure 3).

Temporal Sequence

Most low DO concentrations were measured in 2009 (Figures 23-26), thus low DO may be a recent stressor. Bioassessment data for 2009 are unavailable, but should be evaluated when they become available.

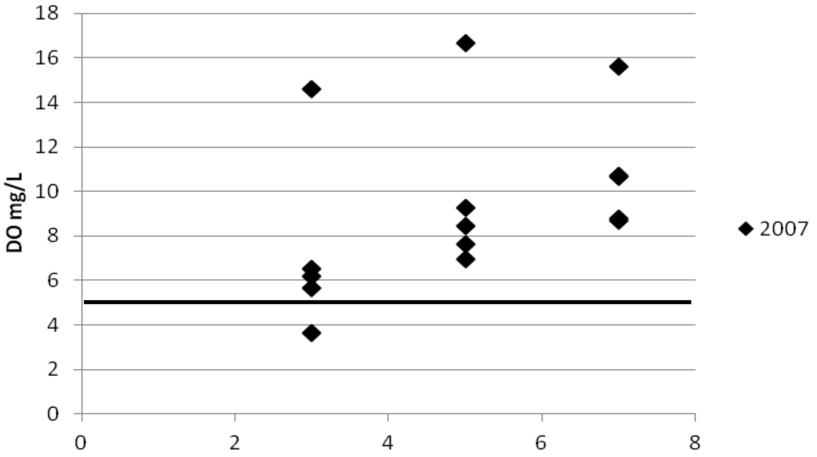

Figure 24: Dissovled oxygen concentrations at three chemsites in 2007 along the Knife River. The bold line at 5 mg/L indicates the threshold level.

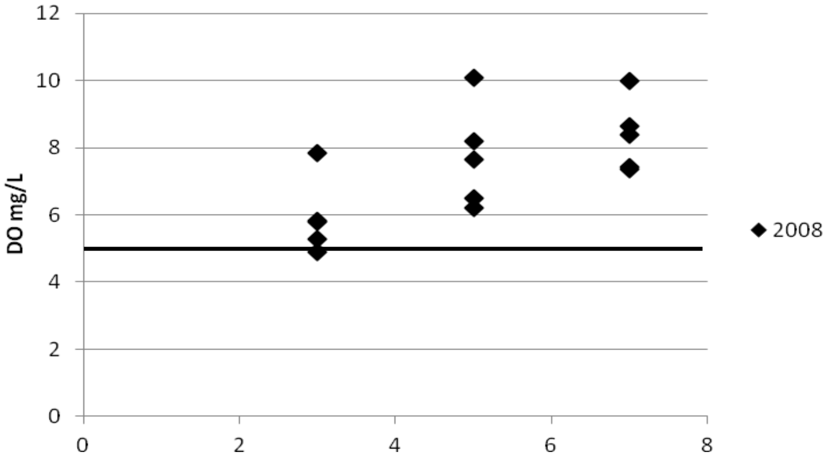

Figure 25: Dissovled oxygen concentrations at three chemsites in 2008 along the Knife River. The bold line at 5 mg/L indicates the threshold level.

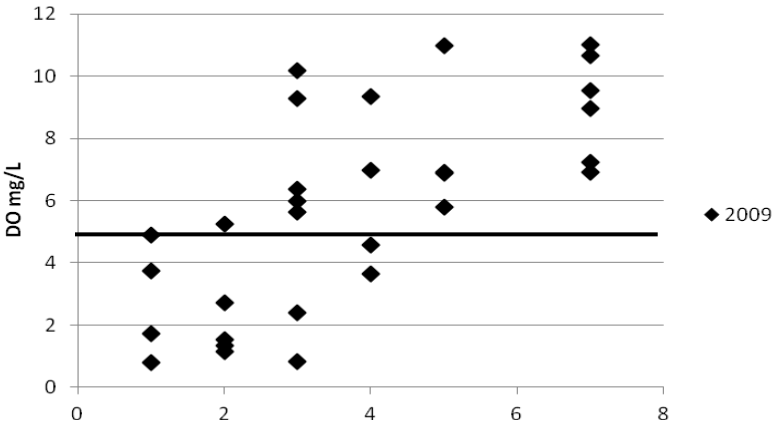

Figure 26: Dissolved oxygen concentrations at six chemsites in 2009 along the Knife River. The bold line at 5 mg/L indicates the threshold level.

Symptoms

Plecoptera counts relative to DO measured at the site did not indicate a response to changing levels of DO (Figure 27). However, this response may be masked by a low number of data points over a narrow range of DO.

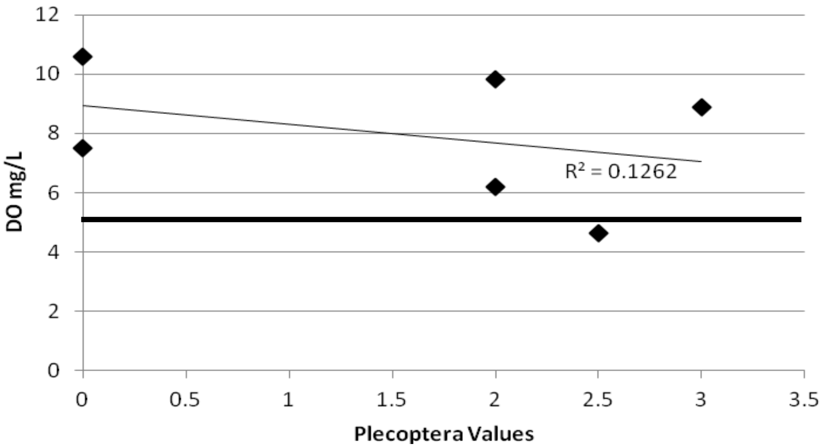

Figure 27: Plecoptera metric values (n=6) and DO concentrations at four biosites in 1996, 2006 and 2007. The bold line at 5 mg/L indicates the threshold level.

Table 14: Types of evidence and scoring for DO. Types of evidence from EPA's CADDIS website.

Types of evidence	Findings	Score
Evidence using data from Knife River		
Spatial Temporal Co-occurrence	Violations of the dissolved oxygen standard are found throughout the Knife River, it is difficult to determine whether IBIs reflect low DO at biomonitoring sites.	0
Evidence of exposure, biological mechanism	The fish and macroinvertebrate communities are exposed to low dissolved oxygen at multiple sites along the Knife River.	++
Causal pathway	The headwaters have the lowest mean DO and are also surrounded by wetlands. There are pasturelands throughout the Knife River Basin, and cattle may have access to the river. There is a wastewater treatment plant in the headwaters area of the Knife River. More data are needed to connect low DO concentrations to either of these pathways.	+
Field evidence of stressor-response	Limited field evidence does not support or weaken DO as a stressor.	0
Field experiments/manipulation of exposure	No known field experiments or manipulations were performed.	NE
Laboratory analysis of site media	No laboratory experiments have been conducted.	NE
Temporal sequence	Limited biological and monitoring data are available to determine temporal sequence of DO.	-
Verified or tested predictions	No predictions were made that can be verified.	NE
Symptoms	There is no declining trend in sensitive macroinvertebrate taxa with decreasing DO concentrations.	-
Evidence using data from other systems		
Mechanistically plausible cause	Low DO is a known cause of biological impairment.	+
Stressor-response in other field studies	Field studies in Minnesota and adjacent states have documented impacts of low dissolved oxygen concentrations on fish community health.	+

Stressor-response in other lab studies	All fish and macroinvertebrates require adequate dissolved oxygen for survival. Laboratory studies have documented the required levels for a variety of species.	+
Stressor-response in ecological models	No ecological modeling data are available.	NE
Manipulation experiments at other sites	No experimental data are available.	NE
Analogous stressors	No analogous stressors are available.	NE
Multiple lines of evidence		
Consistency of evidence	Low dissolved oxygen levels can severely impair the fish and macroinvertebrate communities within a system but the evidence of the effect of dissolved oxygen levels is unclear with the available biological data.	0
Explanatory power of evidence	There is no clear spatial gradient of low dissolved oxygen levels and impaired biotic community. However, dissolved oxygen concentrations may contribute to the abundance of tolerant taxa throughout the Knife River	+

8.1.1 Discussion

Mean DO concentrations increase downstream with the lowest mean DO at biosites 1 and 2 (Table 13). This trend indicates that low DO in the headwaters may be a driver of low DO concentrations found throughout the river. Low DO may be related to the extensive area of wetlands in the headwaters, and therefore, may be naturally occurring. However, another causal pathway, such as bank trampling may be causing declining DO concentrations in other reaches of the Knife River because of sediment oxygen demand (SOD) from fines. Sediment oxygen demand (SOD) is the rate at which dissolved oxygen is removed from the water column during the decomposition of organic matter in streambed sediments.

From 2006-2009 there was an increase in low DO concentrations, with the most occurring in 2009 (Figure 26). Low DO may, therefore, be a more recent trend than for the original macroinvertebrate and fish IBI listings. However, due to the significant number of low readings in 2009, low DO should be considered as a current biological stressor and 2009 DO concentrations should be compared with IBI scores from 2009 when they become available. Chemsites 1, 2, and 4 were not sampled before 2009, so these sites may have had low DO along. More data should be collected within 2 hours after sunrise in compliance with the DO standard.

DO concentrations were below the 5 mg/L threshold at a number of sites but these low concentrations may not correlate with impaired fish IBIs. Fish tend to indicate basin-scale impacts, because they can move away from local stressors into other areas of the basin (Flinders et al. 2007, Norton et al. 2000). However, central mudminnows (*Umbra limi*), a low DO tolerant fish, were the most abundant fish found at biosites 1 and 2 where DO concentrations were lowest.

Macroinvertebrates were found to be impaired in the headwaters region, as well as the middle reaches of the Knife River. IBIs for macroinvertebrates were impaired at biosites 1-4 and low DO concentrations were also recorded at biosites 1-4. Macroinvertebrates are relatively immobile and live in close contact with both the sediments and the water column, thus reflecting impacts at a local scale (Weigel et al. 2003, Brazner et al. 2007, Flinders et al. 2007, Stepnuck et al. 2008). However, although both macroinvertebrates and DO were found to be below thresholds at the same sites, Plecoptera, a DO sensitive macroinvertebrate did not decline when DO levels declined. A greater number of sample sites including more recent data may unveil potential correlations.

There are at least three potential reasons for low DO in the basin. Increased fine sediment in the river may play a role in low DO levels. Embedded sediments can reduce diffusion of oxygen into interstitial areas. Fine sediment may be from a number of sources, such as cattle grazing in riparian, agriculture, or road crossings (see section on bedded sediment).

Increased ammonia can also affect low DO concentrations. As ammonia increases, DO is depleted through nitrification via the following equations:

$$2NH_3^+ + 3O_2 \leftrightarrow 2NO_2^- + 2H^+ + 2H_2O$$

$$NH_4^+ + 1^1/_2\, O_2 \leftrightarrow 2NO_2^{\ -} + 2H^+ + H_2O$$

Cattle may have access to the river, and cow manure is a potential source of ammonia. About 1,035 acres of the Knife River Basin are in beef operations and another 473 acres are in dairy operations (USDA, NRCS 2011).

Lastly, fertilizers can adversely affect DO concentrations. As fertilizer use increases DO concentrations decrease in response to increased primary production. Although nitrogen and phosphorus were not found to be stressors (all recorded levels were below thresholds), fertilizer may still be a contributor in the Knife River Basin since agricultural land is found in the headwaters.

8.2 pH

pH standard

The pH standard for Class 2 waters is 6.5-9.0 (Minnesota Rule 7050.0222).

Effects of high pH in streams

Short-term exposure to elevated pH is rarely lethal, but long-term exposure to pH above 9.5 can damage fish gills, eyes and skin. An increase in pH affects toxicity of other stressors, such as ammonia. As pH increases, unionized ammonia (NH_3) increases. At a pH of 9, the percentage of unionized ammonia is 100 times higher than at a pH of 7. Ammonia can be toxic when organisms are exposed for short durations, thus short-term elevations in pH may result in lethal ammonia concentrations.

Factors impacting pH

High pH can be induced by discharges high in lye or lime, such as some fertilizers or from landfills. Cement, asphalt or soap manufacturing are known sources of high pH, along with runoff from limestone gravel roads. An elevated pH can also be caused by increased photosynthetic activity, where CO_2 is removed and carbonate is favored (Wurts and Durborow 1992). During plant respiration CO_2 concentrations can become high. This CO_2 reacts with water to produce carbonic acid (H_2CO_3), bicarbonate ion (HCO_3^-), and carbonate ion (CO_3^{2-}), which in turn lowers the pH.

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+ \leftrightarrow CO_3^{2-} + H^+$$

When CO_2 is removed during photosynthesis, pH increases, thus pH demonstrates a diurnal cycle much like DO where daytime pH is much higher and nighttime pH is lower.

pH evaluation for the Knife River

Measurements taken during bioassessment did not exceed the standard (Figure 28). However, STORET measurements contained some elevated concentrations (Figure 29). Elevated pH at chemsites 5 and 7 indicate the potential for pH to be a stressor. Only three of 78 measurements were above pH = 9; one at chemsite 5 and two at chemsite 7, with one above 9.5.

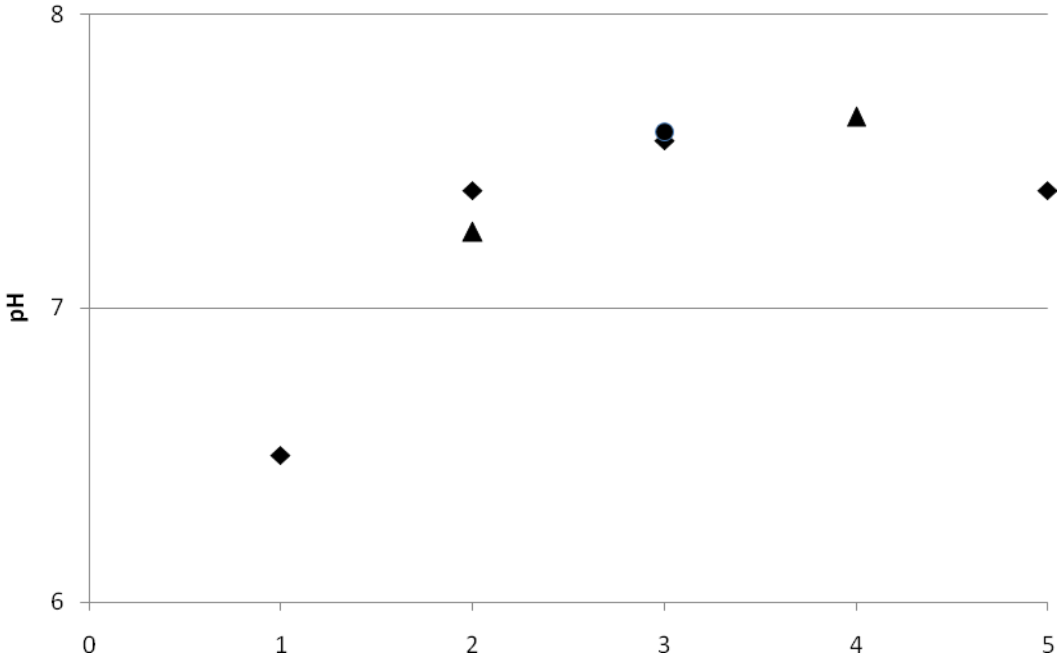

Figure 28. pH values at five biosites along the Knife River. Triangles represent data collected in 1996, diamonds represent data collected in 2006 and the circle represents data collected in 2007.

Spatial/temporal co-occurrence

Elevated pH at chemsite 3, 5 and 7 occurred at sites directly downstream of the biomonitoring sites (1,2, 4 and 5) listed as impaired.

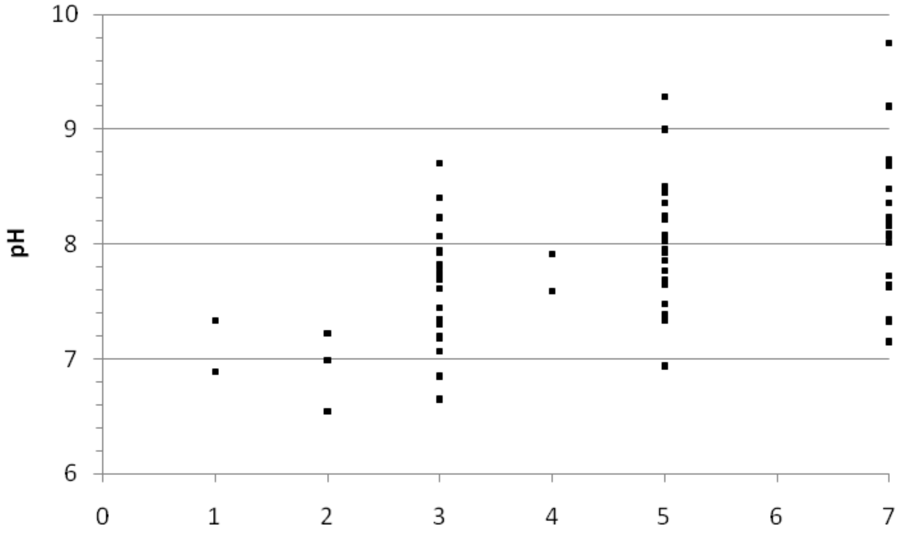

Figure 29: pH values from seven STORET chemsites along the Knife River from 2004-2009.

Causal Pathway

A general trend of increasing pH exists from headwaters of the Knife River to Knife Lake. An increasing pH may be related to natural conditions because the headwaters of the Knife River begin in wetlands where water is naturally more acidic. However, pH above the standard occurs further downstream. There is a landfill in the headwaters area of the Knife River Basin. Agricultural land in the basin may be a source of lime fertilizer. Limestone gravel roads in the Knife Basin are another potential source of elevated pH, but the number of and/or the percent of roads is not known. More data could be gathered to confirm causal pathways of high pH in the Knife River basin.

Field Evidence of Stressor Response

The pH was the only variable significantly correlated with fish IBI scores (p= 0.034, Adjusted R-squared= 0.4263). Fish IBI scores and pH were positively correlated which is the opposite of what would be expected.

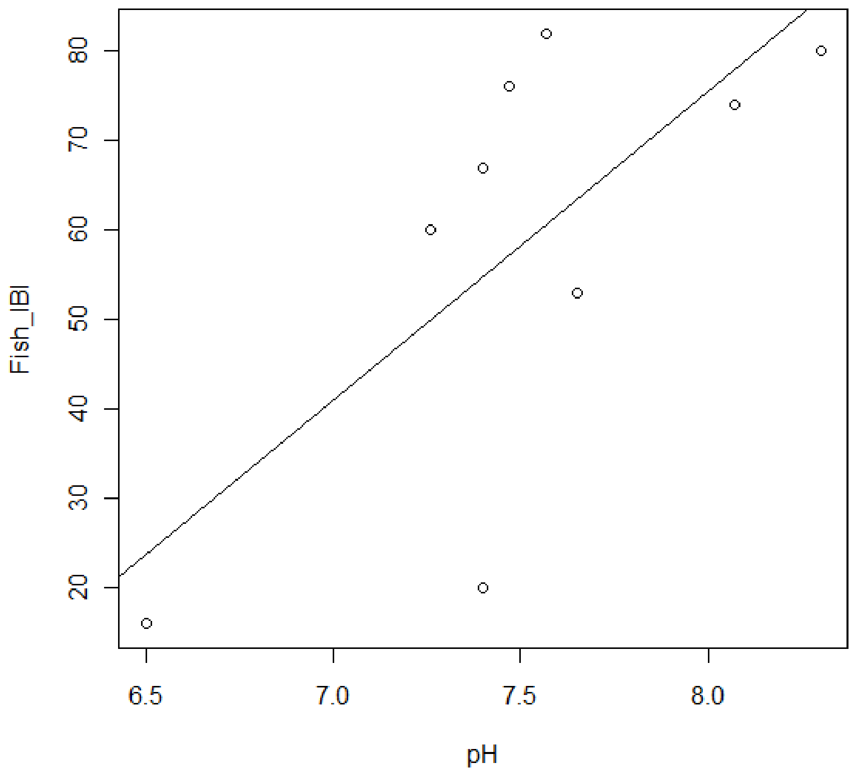

Figure 30: Relationship of pH and fish IBI scores in 2006 at five biosites in the Knife River. Adjusted R-squared= 0.4263 and p-value= 0.034.

Table 15: Types of evidence and scoring for pH. Types of evidence from EPA's CADDIS website.

Types of evidence	Findings	Score
Evidence using data from Knife River		
Spatial Temporal Co-occurrence	Violations of the pH standard are found at chemsites 5 and 7. High pH levels are not found at sites where there is biological impairment.	---
Evidence of exposure, biological mechanism	Evidence of exposure is uncertain.	0
Causal pathway	The presence of all steps in the causal pathway(s) is uncertain.	0
Field evidence of stressor-response	The pH is positively correlated with IBI scores.	-
Field experiments/manipulation of exposure	No known field experiments or manipulations were performed.	NE
Laboratory analysis of site media	No laboratory experiments have been conducted.	NE
Temporal sequence	Limited biological and monitoring data are available to determine temporal sequence of the cause.	-
Verified or tested predictions	No predictions were made that can be verified.	NE
Symptoms	No symptoms have been recorded for high pH.	NE
Evidence using data from other systems		
Mechanistically plausible cause	Elevated pH may cause biological impairment.	+
Stressor-response in other field studies	Limited occurrence of high pH may not effect biota	-
Stressor-response in other lab studies	Toxicity of other stressors such as ammonia increase with increasing pH and are more problematic than the pH	-
Stressor-response in ecological models	No ecological modeling data are available.	NE
Manipulation experiments at other sites	No experimental data are available.	NE
Analogous stressors	No analogous stressors are available.	NE
Multiple lines of evidence		
Consistency of evidence	Biological impairments are inconsistent with elevated pH occurrences.	-
Explanatory power of evidence	There is nothing to explain the inconsistent data.	--

8.2.1 Discussion

There is a trend of increasing pH values from headwaters of the Knife River to the confluence with the Snake River. Sources of this trend are uncertain but may include gravel roads throughout the basin, a landfill in the headwaters, or runoff of lime fertilizer in agricultural areas.

The pH was not elevated at biosites where fish and macroinvertebrate samples were taken, but was instead found to be positively correlated with them. Most fish and macroinvertebrates can tolerate a short duration of elevated pH, but as pH increases ammonia becomes more toxic, so I would expect a negative correlation instead of a positive correlation. The pH and fish IBI scores may be positively correlated simply because the low DO and high fines in the headwaters may be greater stressors to fish communities than pH.

There is not a strong case for pH as a stressor in the Knife River Basin, but due to its occasional exceedance of the standard, and the increased risk of ammonia toxicity, elevated pH may contribute to IBI impairment and further monitoring may be warranted.

8.3 Bedded Sediment / Siltation

Bedded Sediment standard

Bedded sediment refers to organic particles and sand, silt or clay that has settled out of the water column and lined the bed of the river. Bedded sediment is a function of the velocity of stream. There is no Minnesota standard for bedded sediment.

Effects of high siltation in streams

Siltation often causes reduced median sediment size in gravel bed streams. Excess siltation may smother fish eggs and larvae, as gas exchange is reduced or eliminated for eggs and larvae in the streambed. Simple lithophils require clean course substrate to spawn and their numbers may decrease due to fine sediment smothering their eggs. Darters require coarse substrate for all stages of life. Macroinvertebrates that prefer coarse gravel, such as EPT, are reduced (EPA CADDIS). Benthic insectivores may experience a decrease in prey availability due to accumulation of fine sediment.

Factors impacting high bedded sediments

Bedded sediment originates from eroded topsoil or erosion of river banks. Reduced water movement due to channel modification or water withdrawal can cause fine sediment to settle to the streambed. Some causes siltation may include downstream dams, culverts and water withdrawal for irrigation. Other sources of siltation may include deposits from mining or construction. There can also be natural variation in sediment accumulation due to underlying geology and stream gradient.

Bedded Sediment/Siltation evaluation for the Knife River

Since there is no bedded sediment standard, known indicators of siltation will be compared in the Knife River. For example, high values for depth of fines may indicate excess siltation. In the Knife River, the mean depth of fines was much higher in the headwaters but was reduced downstream (Figure 31). Biosites 1 and 2 had the greatest mean depth of fines. Both biosites 1 and 2 have been found to be impaired for fish in 2006, and biosite 2 was impaired for macroinvertebrates in 1996. Neither fish nor macroinvertebrates were impaired at biosite 3 where lower depths of fines were found. Fish and macroinvertebrates were impaired at biosite 4 in 1996, and while the level of fines was not high, levels at biosite 3 and 6 were low and not impaired.

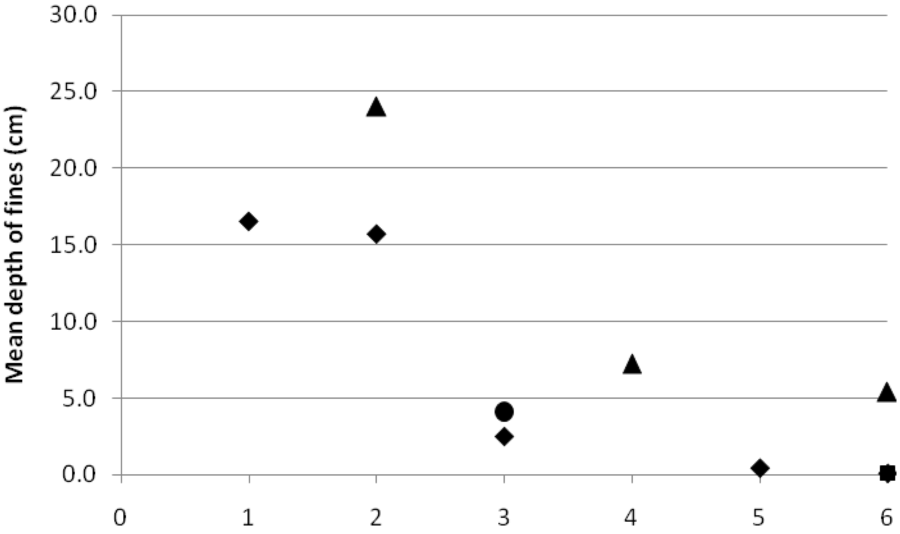

Figure 31: Mean depth of fines at six biosites along the Knife River from the headwaters to the confluence with the Snake River. Triangles represent data from 1996, the square represents data from 2005, diamonds represent data from 2006, and the circle represents data from 2007.

Mean depth of fines is often higher in downstream reaches, because higher gradients in the headwaters allow water to move more fine sediment downstream. The Knife River shows the opposite trend with higher gradients downstream and greater mean depth of fines upstream (Figure 32, Table 16).

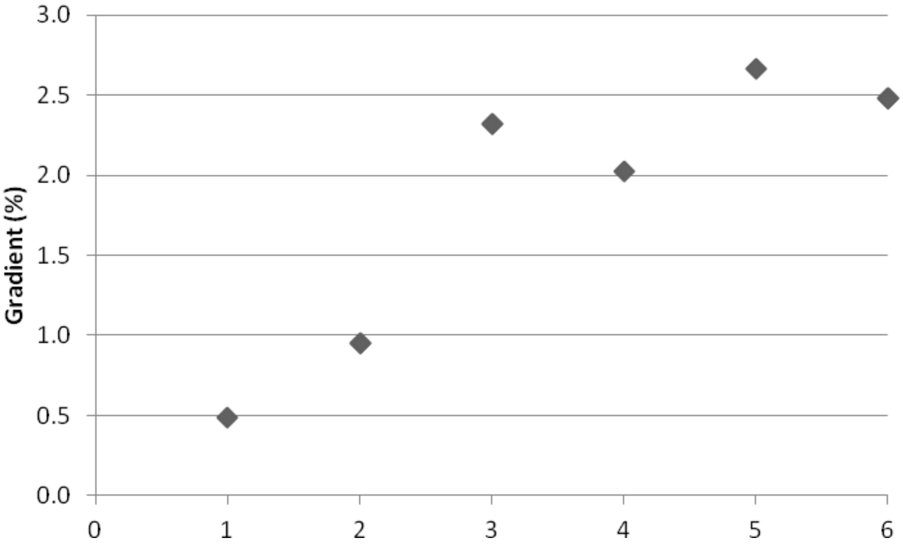

Figure 32: Knife River gradient (%) measured at six biosites from headwaters to the confluence with the Snake River.

Table 16: Habitat data from five biosites along the Knife River.

Biosite Number	*VisitDate*	*Mean Depth of Fines (cm)*	*Width/depth ratio*	*Sinuosity*	*Gradient (%)*
1	07-Jul-06	16.5	8.0	1.2	0.5
2	02-Jul-96	24.0	15.4	1.2	1.0
2	06-Jul-06	15.7	16.3	1.2	1.0
3	18-Jul-06	2.5	23.5	1.1	2.3
3	19-Jun-07	4.1	23.6	1.1	2.3
4	25-Jun-96	7.2	35.8	1.2	2.0
5	19-Jul-06	0.5	30.2	1.3	2.7

The natural gradient of the Knife River (Figure 32) encourages sediments to settle in the headwater areas instead of being flushed downstream because of the way it was formed. Low precipitation in 2006 may also have played a role in allowing sediments to collect in the headwater region. However, given the Knife River gradient there is a potential that excess sediment in the headwaters region is the natural bedded sediment for this river.

Data from 2006 exhibits 100% fines at biosite 1 and 2 (Figure 33) where the Knife River gradient is low, whereas 100% rock substrate is found near the confluence with the Snake River in the unimpaired section of the river (at biosite 6). Data collected in all years indicate a similar trend for percent fines in the Knife River (Figure 33). Percent fines were also associated with biosites 1and 2 in the NMDS analysis (Figure 12).

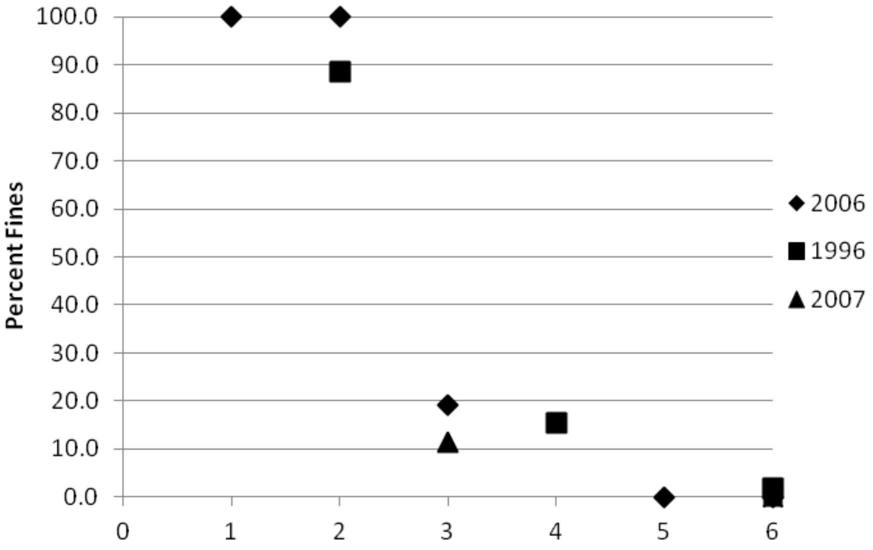

Figure 33: Percent fines at six biosites along Knife River from headwaters to confluence with Snake River.

Table 17: Distribution of particles in the streambed, embeddedness, and percent riffle, pool and run for six biosites along the Knife River.

Biosite Number	*VisitDate*	*%Fines*	*%Rock*	*%Boulder*	*%Embed*	*%Riffle*	*%Pool*	*%Run*
1	07-Jul-06	100.0	0.0	0.0			18.7	81.3
2	02-Jul-96	88.5	0.0	0.0		0.0	100.0	0.0
2	06-Jul-06	100.0	0.0	0.0			35.5	64.7
3	18-Jul-06	19.2	80.8	18.6	30.5	15.8	18.5	65.7
3	19-Jun-07	11.5	88.5	32.5	39.8	18.3	19.6	66.0
4	25-Jun-96	15.4	84.6	8.1	37.5	11.2	66.1	22.8
5	19-Jul-06	0.0	100.0	15.0	11.7	41.8	24.7	33.4
6	18-Sep-96	1.8	98.2	23.2	16.4	29.2	16.5	54.4
6	19-Jul-05	0.0	100.0	13.8	26.0	10.4	42.3	39.7
6	11-Jul-06	0.0	100.0	18.9	13.0	26.2	32.1	41.6

Table 18: Geosite data from Rosgen level 2 assessment and RiverMorph calculations.

Geosite Number	*Classification*	*Width/depth ratio*	*Entrenchment ratio*	*Sinuosity*	*Slope*	*Visit date*
1	C4	23.86	3.95	1.19	0.00155	16-Jul-09
2	C3	21.57	5.31	1.54	0.00333	21-Aug-09
3*	C4c-	41.57	5.35	1.54	0.00053	21-Sep-09
4*	C3	36.45	4.79	1.24	0.00162	14-Jul-09

* These geosites are located below the impaired section of the Knife River.

A moderate amount of boulder-sized substrate appears to be available downstream from biosite 2, with the greatest amount available at biosite 3, where biota were not impaired (Table 17). Embeddedness peaked at biosites 3 and 4 as the transition from fine to rocky substrate occurs.

A high entrenchment ratio indicates lower entrenchment in a single thread channel (Rosgen 1996). A river channel is considered entrenched with an entrenchment ratio < 1.4 (±0.2) (Rosgen 1997). As the ratio increases above 1.0, the streambank height increases and a larger magnitude flood is required for the river to overflow the banks. Entrenched streams are associated with bank erosion. Knife River entrenchment ratios are all high and therefore the sedimentation is not indicative of bank erosion. All Knife River width/depth ratios determined at geosites 1-4 are considered moderate to high (>12).

The Knife River is a “C” channel according to a Rosgen level II assessment. Channels characterized as “C” are sinuous, low relief channels with well-developed floodplains (Rosgen 1996). Sinuosity above 1.4 is considered high, whereas a sinuosity below 1.2 is low. Geosites 2 and 3 have high sinuosity and geosite 1 has low sinuosity. Type “C” channels can be altered significantly via changes in bank stability, watershed condition or flow regime. A C3 channel (geosites 2 and 4) is dominated by cobble-sized channel material, whereas a C4 channel (geosites 1 and 3) is dominated by gravel.

In the Knife River, geosites 1 and 3 are classed as C4 channels (Table 18); highly sensitive to disturbance. Some C4 channel has a high sediment supply, very high streambank erosion potential and very high vegetation influence (Rosgen 1994). A disturbed C4 channel has a good recovery potential. Geosites 2 and 4 are classed as C3 channels; moderately sensitive to disturbance. The C3 channel has a moderate sediment supply, moderate streambank erosion potential and very high vegetation influence. A disturbed C3 channel has a good recovery potential. Very coarse gravel is the dominant channel material in both riffle and reach cross-sections of geosite 1 where there is a D_{50} of 49 for riffle sections and 38 for reach sections. Very coarse gravel is the dominant channel material in riffle cross-sections of geosite 2 with a D_{50} of 59 and fine gravel is the dominant channel material in reach cross-sections with a D_{50} of 5. Small cobble is the dominant channel material in both riffle and reach cross sections of geosite 3 with a D_{50} of 90 in riffle sections and 105 in the reach cross-section. Coarse gravel is the dominate channel material found at geosite 4 with a D_{50} of 53 in the riffle cross sections and a D_{50} of 63 in the reach cross-sections. Gravel substrate is preferred by many fish and macroinvertebrates including lithophilic spawners and EPT. The midstream reach of the Knife Rivers appears to have favorable habitat features.

Spatial temporal co-occurrence

Habitat and behavioral designations explain the mode of existence of benthic macroinvertebrates. Clinger taxa remain stationary in the streambed in flowing water and are expected to decrease in response to a stressor (Merritt et al. 1996). Data collected in the Knife River indicates a decreasing trend for clinger taxa with increasing proximity to mean depth of fines in the headwaters region (Figure 34).

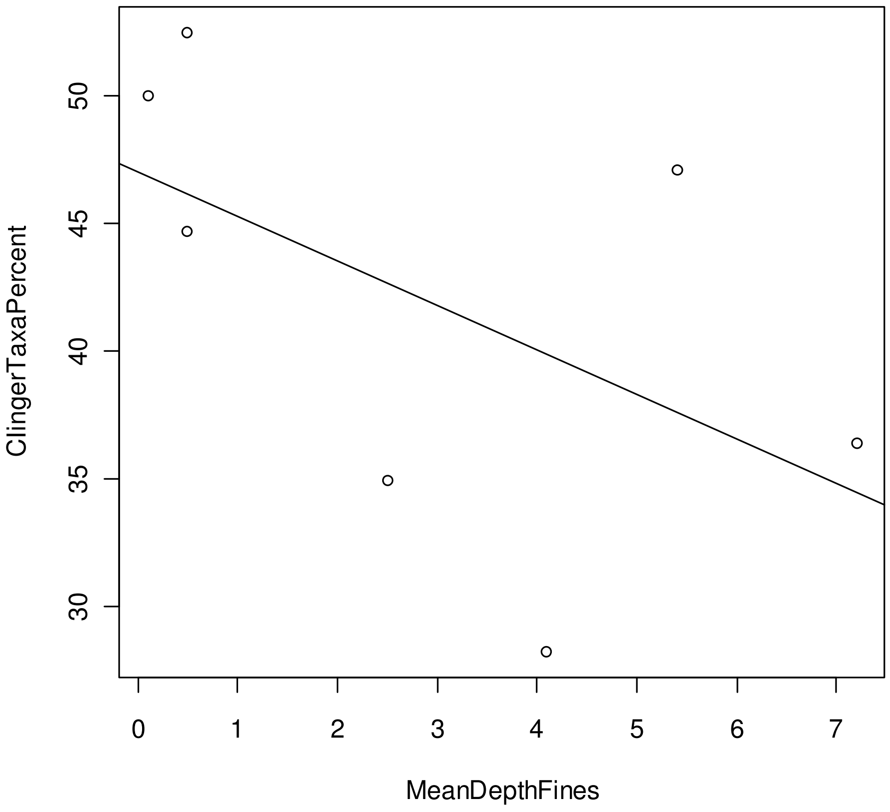

Figure 34: Percent clinger taxa relative to mean depth of fines at biosites 3-6 along the Knife River. Adjusted R-squared = 0.145, and p-value= 0.2147.

Percent simple lithophilic fish indicate a negative relationship with depth of fines due to their reliance on rocky substrates for spawning. In the Knife River, the mean depth of fines was negatively correlated to the percent simple lithophilic species (p-value = 0.002516, Adjusted R-squared = 0.7149) (Figure 35). A lower percent of lithophilic spawners were found where there was higher depth of fines, suggesting that bedded sediment may be a stressor in the Knife River Basin. Small sample size and the effects of multiple stressors may mask this trend for percent benthic invertivores and sensitive fish in the Knife River (data not shown).

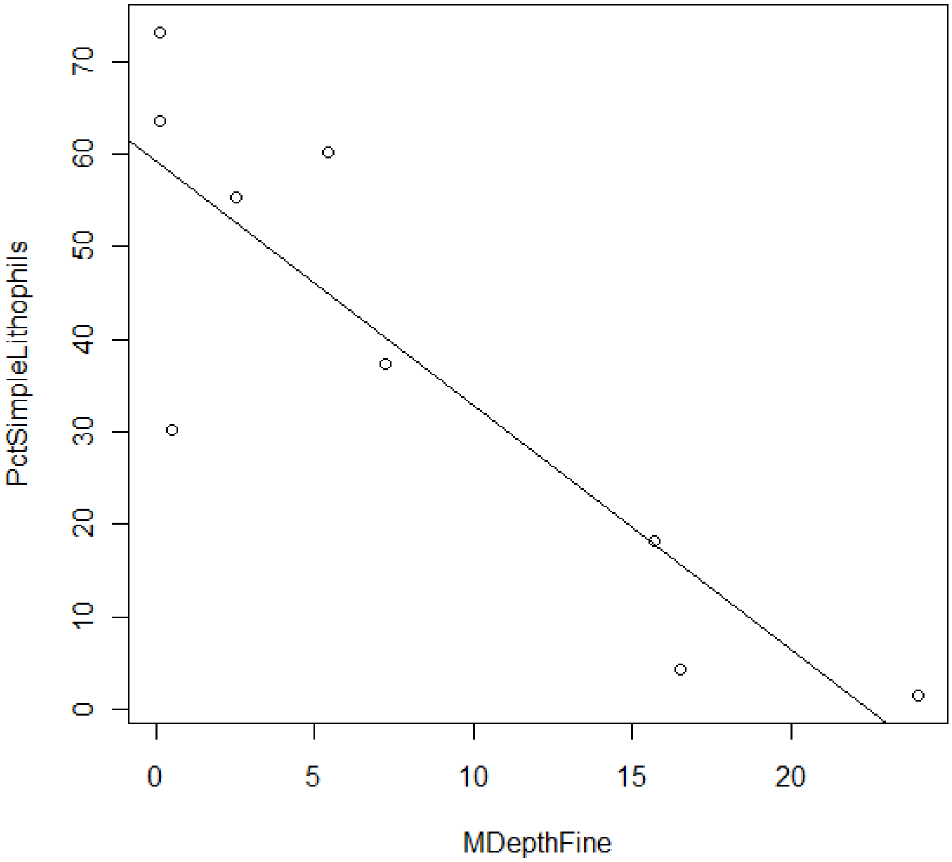

Figure 35: Percent simple lithophils relative to mean depth of fines at six biosites along the Knife River. Adjusted R-squared = 0.7149, and p-value = 0.002516.

The change in proportion of pools in a river is another measurement that can be used to determine excess siltation. As more siltation occurs and bedded sediment increases, pools are expected to fill in and the proportion of pools should decrease. Biosites 2 and 3 have been monitored twice. The percentage of pools decreased at biosite 2 from 100% in 1996 to 35.5% in 2006 (Table 17), which may indicate that pool filling is indeed occurring. However, the percentage of pools increased from 18.5% in 2006 to 19.6% in 2007 at biosite 3. Data spanning 2006-2007 may not accurately assess loss in pool features since 2006 was a drought year.

Table 19: Percent woody debris (PctWoody), emergent (PctEmerMac), and submergent macrophytes (PctSubMac) in the Knife River between 1996-2006.

Biosite Number	*PctWoody*	*PctEmerMac*	*PctSubMac*
1	3.6	36.8	7.9
2	0.0	25.0	75.4
2	0.0	28.2	73.2
3	4.3	10.4	10.7
3	7.5	7.1	11.1
4	1.5	0.4	17.3
5	0.8	0.4	2.3
6	1.1	0.4	5.7
6	1.9	0.0	2.3
6	0.4	0.0	0.0

Causal Pathway

Bedded sediment is associated with slow moving water. Wetland plants and emergent vegetation slow water flow and facilitate siltation. A high percentage of emergent and submergent macrophytes were found at biosites 1 and 2 (Table 19); the two biosites that had the highest percentage of fines.

Sediment also enters rivers via runoff from pastureland and agriculture. Pastureland is the dominant landuse (33%) in the drainage of biosites 1 and 2 (Table 4), and agriculture was correlated with biosites 1 and 2 in the NMDS analysis (Figure 12). Grazing in riparian areas may cause bank trampling and may lead to bedded sediments.

Table 20: Types of evidence and scoring for bedded sediment. Types of evidence from EPA's CADDIS website.

Types of evidence	Findings	Score
Evidence using data from Knife River		
Spatial Temporal Co-occurrence	More fine materials are found in the headwaters where macroinvertebrates are impaired.	+
Evidence of exposure, biological mechanism	More fine sediment occurs in the headwaters and the impaired site is exposed.	+
Causal pathway	Multiple causal pathways occur for sedimentation	+
Field evidence of stressor-response	Lithophilic fishes decrease as depth of fines increases	++
Field experiments/manipulation of exposure	No know field experiments or manipulations were performed.	NE
Laboratory analysis of site media	No laboratory experiments have been conducted.	NE
Temporal sequence	Limited biological and monitoring data are available to determine temporal sequence of the cause.	-
Verified or tested predictions	No predictions were made that can be verified.	NE
Symptoms	A decrease in simple lithophils occurs at sites with more fine sediment.	+
Evidence using data from other systems		
Mechanistically plausible cause	Sediment is a known cause of biological impairment.	+
Stressor-response in other field studies	Field studies in Minnesota and adjacent states have documented the negative impacts of sedimentation on fish and macroinvertebrate health.	+

Stressor-response in other lab studies	Sediment is known to impact fish and macroinvertebrate health.	+
Stressor-response in ecological models	No ecological modeling data are available.	NE
Manipulation experiments at other sites	No experimental data are available.	NE
Analogous stressors	No analogous stressors are available.	NE
Multiple lines of evidence		
Consistency of evidence	Bedded sediment can severely impair the fish and macroinvertebrate communities within a system and the evidence of the effect of bedded sediments is consistent with the available biological data.	++
Explanatory power of evidence	There is a clear gradient of high fines and impaired biotic community.	++

8.3.1 Discussion

Increased sediment in the Knife River Basin may be linked to other stressors. Higher percentages of macrophytes were associated with the headwaters region where there is more fine sediment. Dissolved oxygen is lower in poorly aerated sediments and ammonia forms in anoxic conditions. Coupling of these stressors is likely impacting biota.

The depth of fine sediment may have been high due to low streamflow in samples taken in 2006 (Brouder 2001), which was a drought year. Sediment accumulation is a function of stream velocity, so reduced flows in 2006 may have encouraged sediment accumulation. Long-term data collection may demonstrate whether IBI scores and percent fines are correlated despite the variation in precipitation.

Sensitive fish and macroinvertebrates decreased in areas where there was more fine sediment. Simple lithophilic spawners require gravel substrate for their eggs to develop and clinger taxa require larger substrates to cling onto in flowing water. Both decreased as percent fines increased in the Knife River Basin.

Percent fines were correlated with the headwater sites, whereas increasing gradient, riffles and forest land use were correlated with sites downstream in the NDMS analysis. High percent fines are likely influenced by the surrounding land area and increase with decreasing gradient, decreasing forested land and decreasing riffle habitat. Although there is a correlation between fish species abundance, urban, agricultural, and percent fines, whether species abundance changes in relation to these land uses or I f they are simply co-occurring due to their normal presence in areas with low gradient is not known. Both low gradient and high percent fines are characteristic of wetlands in the headwaters of the Knife River, and therefore, the higher percent fines may be related to the presence of wetlands, and not related to fish species presence. However, human induced landscape changes are likely the cause of sedimentation in the Knife River basin since sediment from agriculture is a leading cause of impairment nationwide (EPA 1993, 2007).

Knife Lake may influence taxa composition especially at biosite 5. The transition from lentic to lotic conditions may favor more generalist species, which also tend to be more tolerant. This study could not address the transition from upstream to downstream of Knife Lake or the effects of the dam on composition or richness. However, dams interrupt the normal flow regime, trap sediment upstream, and transport sediment downstream. Fish migration is interrupted and upstream riffle/runs may change to pool/glides. The river downstream of the dam is unimpaired, whereas the entire upper stretch is classified as impaired. The dam may hold sediment from the agricultural regions in the watershed and limit sedimentation in the lower Knife River.

Bedded sediment begins as suspended sediment in the water column. There are standards for suspended sediment but not for bedded sediment. Timing of sampling may not correspond to active grazing in the riparian or agricultural practices, and therefore, suspended sediment did not appear to be a stressor. Suspended sediment is measured infrequently, thus below threshold values may not show temporal disturbances. More suspended sediment data should be collected during high flows after a large rainfall or snowmelt.

Extensive landscape transformation such as past riparian grazing (Magner et al. 2008), loss of wetlands, increased tile drainage or a change in vegetation may be responsible for past sediment changes, resulting in current bedded sediment conditions (Magner and Steffen 2000). Regardless, measureable standards for bedded sediment are needed to assess and list a waterway for impairment based on bedded sediment load as well as suspended sediment.

9. Conclusions

The Knife River SI, which I conducted, identified three potential stressors that may impact the biota in the Knife River; low DO, high pH, and excess bedded sediment. An important step in the SI process is to assess data gaps and collect additional data. More data are needed in the Knife River Basin before TMDL implementation. Natural background conditions may be a factor in the impaired DO concentrations in Knife River, therefore, additional monitoring is required to determine the influence of a background condition, such as wetlands influencing low DO in the headwaters. Also, since bedded sediment was found to be a potential stressor, suspended sediment should be re-evaluated for its potential as a stressor. As new data becomes available they should be utilized to corroborate or dismiss the findings presented here.

Dissolved oxygen concentrations were below the class 2B standard on multiple occasions in the upstream four biosites along Knife River. Mean DO concentrations were below the 5mg/L standard at chemsites 1 and 2, and only chemsite 5 had no recorded DO concentrations below the threshold. Low DO concentrations indicate that DO is a likely stressor to the biological community. However, more sampling should be conducted to meet the minimum of 20 samples taken within 2 hours of sunrise to determine compliance with the standard. Low DO concentrations measured along the Knife River may be due to multiple causal pathways including stagnant water, excess sediment, oxidation of ammonia, or wetlands in the headwaters that naturally supply water with low DO. Collection of BOD samples would be helpful to determine depletion of DO due to decomposition by microorganisms. Many of the threshold violations were from 2009, and therefore, low DO may be a recent problem and should be compared to biological data from the same timeframe when they become available.

Increasing pH in the Knife River from the headwaters to the confluence with the Snake River may cause pH to be a biotic stressor. The pH at chemsites 5 and 7 were above the threshold of 9.5 in three instances. High pH values should be monitored for their effects on biota. Knife River pH should be further monitored to determine the potential as a stressor to IBI scores due to its secondary effect of increasing the toxicity of ammonia.

The accumulation of fine sediment in the streambed may negatively affect the biological communities in the Knife River. Mean depth of fines was higher in the headwaters and was reduced downstream. A change in gradient may play a role in fines accumulating in the headwaters since gradient was lowest in the headwaters and highest at the confluence with the Snake River. Both clinger taxa and simple lithophilic spawners decreased where there was higher depth of fines. Finally, the percent of pools at biosite 2 decreased from 100% to 35.5% from 1996 to 2006 indicating that pool filling may have occurred. Coarse sediment found at some sites likely indicates that the former state of the Knife River had less bedded sediment. Agricultural activity is likely a cause of anthropogenic sedimentation in the basin.

9.1 Improvements Upon the SI Process

The CADDIS tool designed by the EPA is an excellent guideline for proceeding through the SI process. Detailed instructions and examples are useful for streamlining the process. As with any new development there are additions that would enhance the user experience of the SI process and create a more uniform approach. Some challenges I experienced with the CADDIS process, suggestions for improvement, and data gaps are noted in the section below.

The SI could be improved in three ways: with the help of professionals in multiple disciples, improvement upon standards that could link more possible stressors, such as bedded sediment to a TMDL, and collection of additional data to fill in essential "data gaps". Overall the SI process offers a simple and streamlined approach to stressor determination that is useful for TMDL development.

First, due to the interdisciplinary nature of the SI process, expertise in a number of fields is needed to accurately identify stressors. Therefore, the SI process would be most accurate when professionals in a range of disciplines are involved, such as geomorphology, hydrology, biology, statistics, chemistry, and toxicology. Professionals in each discipline may be able to add insight that may be overlooked by someone attempting the entire process alone, thus I recommend that for future SI processes people from a number of fields should be consulted.

Secondly, non-traditional stressors that are identified in the SI process are not assessable by a TMDL. The intent of the SI process is to identify the stressor(s) that should result in TMDL development. Unfortunately some stressors indicated by the SI process do not fit the TMDL format. For example, in the Knife River SI bedded sediment was found to be a likely stressor, but TMDLs can only be developed for suspended sediment, not for bedded sediment. Therefore, if the SI process is to be an effective precursor to the TMDL, all possible stressors should be accounted for through the TMDL process.

Often assessments are only started after a reach is determined to be impaired and mechanisms that were originally responsible for impairment may no longer be active (Anderson et al. 2006). Unfortunately, as in the case of the Knife River, the dam at Knife Lake may be enough to prevent key biota from returning to the upper stretches of the river even if conditions do improve. This makes legacy effects, as well as improved conditions difficult to assess.

A series of “data gaps” in current data collection procedures is noted in the following paragraphs. More information would be useful in determining accurate and thorough cases for stressors in the Knife River Basin.

A data gap exists in biomonitoring frequency. Many sites in the Knife River Basin have only been sampled once, and only a few sites are sampled in each year that data were collected. Minnesota operates on “independent applicability” which means that a single impaired biological score results in a TMDL listing. More rigorous analysis, such as returning for further sampling at previous biomonitoring sites in subsequent years to confirm impairment should occur to avoid development of an SI or TMDL that may be unnecessary years later if a site is later found not to be impaired or is found to have a natural background condition. Data collected from the same location as past biomonitoring is also beneficial to establish trends and changing conditions. Without data from multiple years there is little basis for comparison to evaluate whether the river and biota are changing.

A second data gap exists in hydrological data collection during the biomonitoring process. A flow measurement is recorded for the reach during biomonitoring, but these data are of limited value. There is no flow gauge on the Knife River, thus flow gauge data was evaluated from the Snake River. Although flow data from the Snake River may show similar trends to the Knife River, utilizing the Snake River gauge does not allow for hydrological analysis on potential flow regime changes within the Knife River. Long-term hydrologic records are not available in the Knife River, which makes decisions about changes in flow regime difficult to assess. It would be helpful to have at least one flow gauge on the Knife River that could be checked during biomonitoring.

There is a third data gap in data collection consistency. Biological sampling includes many variables, such as climatic conditions, species migrations, and reproduction cycles that may influence the IBI scores. Ideally all sites would be sampled at the same time/day or at least in the same week and this is not case with Knife River data. For comparison, samples taken in the same month from year to year would provide more consistency. Additionally, if geomorphology and channel stability measurements were taken at the time of biological monitoring, they could provide a record of channel stability and aid in prescribing remediation (Asmus et al. 2009).

A fourth data gap is in the lack of geomorphology data collected. Only four sites were sampled in the Knife River and only two of them were above impaired sections on the river. Geomorphology data collection collected simultaneously at biosites would be more informative. When LiDAR becomes available across the state, valley shape should be evaluated to determine the expected channel shape.

9.2 Incorporating the Watershed Assessment Tool

The watershed assessment tool (WAT) created by the Minnesota Department of Natural Resources (DNR) was publicly released in the fall of 2011. The WAT can be utilized to assess watershed health based on five ecological components; hydrology, connectivity, biology, geomorphology, and water quality. Each of the 81 major watersheds in Minnesota receives a score for each of the five ecological components with this tool. These components scores are then summed to create a final "health" score for each of the major watersheds. The WAT may be an important addition to the SI process in the future, helping inform where major impairments are located within the watershed and what might be causing them.

The WAT may be extremely helpful in the SI process, especially during the initial phase of gathering information. Since each of the five components includes three to five indices that are scored separately and then combined to create each component score, it is possible to evaluate not only the score for each ecological component but also the scores for each of the indices that make up a component. One could look at the ecological components to determine which are most impacted and then evaluate the indices making up those components. For example, if the connectivity component of the WAT received the lowest scores then the indices that make up the connectivity score should be evaluated to determine which index is most impacted. If the aquatic connectivity is the most impacted index, then using an interactive map, the number and placement of bridges and culverts or dams in a watershed of interest could be determined. This information is useful as a starting point at the beginning of an SI.

The WAT could also be useful in determining future bioassessment sites. The WAT may be of use to help select new sites for bioassessment based on natural or anthropogenic features. Potential stressors could be identified using the indices that indicate impairment and may provide insight into where additional sampling should occur. Choosing sampling sites based on features of potential impairment could help pinpoint or negate a particular stressor's presence in the watershed.

Utilizing the WAT during a SI has some advantages over relying solely on data collected at designated sites, as it is at a watershed-wide scale. Landscape influence can be better accounted for in the watershed-wide approach, whereas tradition biomonitoring does not inform about landscape-wide stressors.

Secondly, the WAT could help to provide a baseline for monitoring changes in present and future conditions. The WAT covers a greater scope of data than PCA bioassessment protocol, and therefore, many of the current trends in watershed health shown by the WAT could be valuable to compare to future changes.

A third advantage of using the WAT in preliminary SI assessment would be to find stressors that are not usually sampled for during current biomonitoring practices. For example, currently the PCA does not usually sample for pesticides, herbicides, or other toxic chemicals during basic sampling. The WAT could be used to further identify potential sources of impairment that might lead to additional chemical assessment. For example, in the water quality component of the WAT, the point sources index might reveal a high number of feedlots, or superfund sites, which might be cause for extra sampling in those areas. The non-point source index may reveal large chemical or nutrient applications in the watershed that could then be assessed.

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