Mud Creek (Snake River Watershed) Stressor Identification Report

A study of local stressors causing a lack of biotic communities in Mud Creek Sub-watershed of the Snake River (St. Croix) 8 Digit HUC Watershed.

Minnesota Pollution Control Agency

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Executive Summary

This report summarizes the key causes, or "stressors," contributing to impaired fish and aquatic macroinvertebrate communities of Mud Creek, a tributary stream to the Snake River located in east central Minnesota. Initially, a comprehensive review of existing biological, chemical, and physical data was performed to create a broad list of candidate causes for these impairments. The initial list of candidate causes was narrowed down after additional data analysis, leaving five candidate causes for the final analysis summarized in this report. The candidate causes evaluated in this report are listed below, along with a brief summary of their impact in this watershed.

Excess deposited and bedded sediments

Deposited and bedded sediments are a very probable stressor contributing to biological impairments in Mud Creek. The stream substrate within the impaired reach consists primarily of fine materials – sand, silt, clay – and there are many signs of streambank instability in the immediate area that are acting as sediment sources. In several locations along the impaired reach, the stream channel appears to be widening due to poor riparian conditions (lack of vegetation) and unregulated cattle activity. This channel transformation appears to be reducing sediment transport capacity of the creek, causing fine sediments to settle out on the streambed. Several symptoms of biological impairment in Mud Creek can be linked to this stressor, including a lack of gravel spawning fish species, lack of insectivorous minnow species, and low numbers of macroinvertebrates from the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT).

Low dissolved oxygen concentrations

Seasonally low dissolved oxygen (DO) concentrations appear to be a stressor to aquatic life throughout the Mud Creek watershed. While DO conditions appear to be suitable in some reaches for much of the year, the data suggests that the months of July, August, and September can bring DO levels that are well below the state water quality standard of 5 mg/L. Biological effects of low dissolved oxygen concentrations in Mud Creek include a lack of intolerant fish and macroinvertebrate taxa and low fish counts.

Degraded riparian habitat

Poor riparian habitat conditions in several reaches of Mud Creek appear to be contributing to the biological impairments. Based on a comparison of habitat data collected throughout the creek, the impaired sites lack adequate cover for fish. There are several types of fish cover that are lacking or missing from the impaired reaches. Those related to riparian corridor degradation include overhanging vegetation and overhead canopy cover.

Loss of watershed connectivity due to ditching

The upper 1/3 of Mud Creek is channelized, along with nearly all of the tributary streams in the watershed. The lack of natural stream habitat is likely limiting fish and macroinvertebrate movement and the overall ecological health of the watershed.

Flow alteration

The contribution of flow alteration to the impaired condition is difficult to evaluate given the lack of long-term flow monitoring data available for this watershed. Extensive ditching of headwaters streams, bogs, and wetlands has been proven to disrupt hydrological processes in other watersheds. The impact of ditching on hydrology in the Mud Creek watershed should be further investigated.

Section I. Background Information/Impairment Details

1.1 Monitoring approach

Water quality and biological monitoring in the Snake River watershed, including the sub-watershed of Mud Creek, has been active for several decades. As part of the MPCA's Intensive Watershed Monitoring (IWM) approach, monitoring activities increased in rigor and intensity during the years of 2006-2009, and focused more on biological monitoring (fish and macroinvertebrates) as a means of assessing stream health. The data collected during this period, as well as historic data obtained prior to 2006, were used to identify stream reaches that were not supporting healthy fish and macroinvertebrate assemblages (Figure 1). Fish and macroinvertebrate data were collected at most biological monitoring stations, and were assessed independently, making it is possible for a given stream reach to be impaired for one or both of these biological indicators.

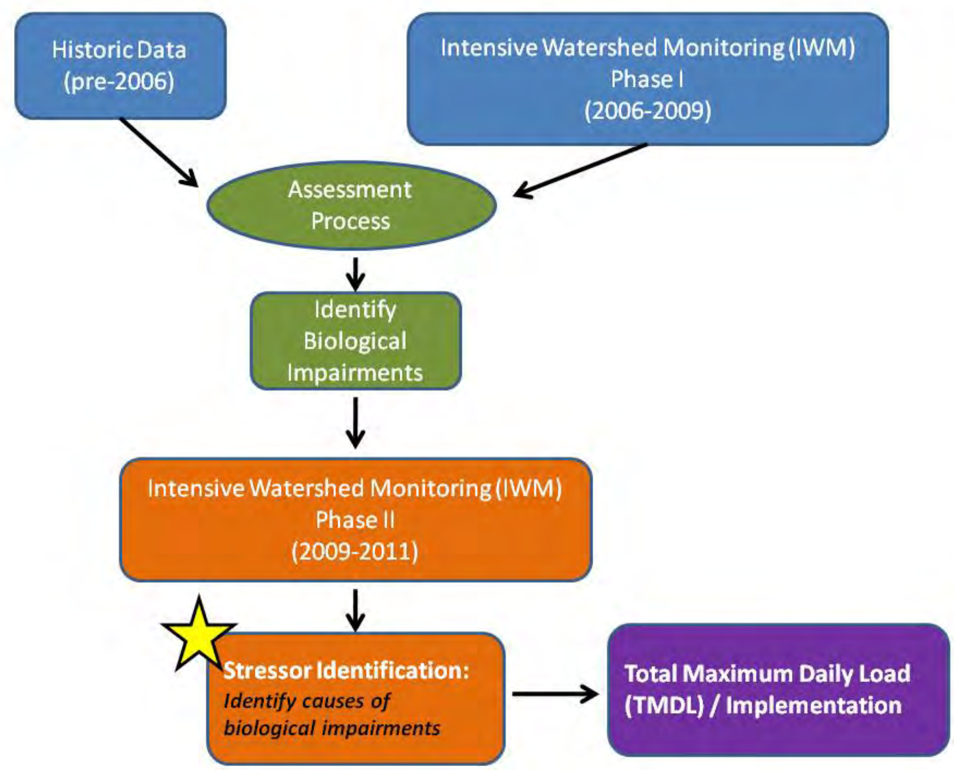


Figure 1. Process map of monitoring, assessment, stressor identification, and TMDL

1.2 Monitoring sites and data collection

A total of 16 monitoring sites (Figure 2) were used to evaluate the biological impairments of Mud Creek and the potential causes and sources contributing to them. Table 1 provides a summary of the monitoring sites and the various parameters collected at each. For the purposes of this stressor ID report, the site identification numbers based on longitudinal position were given to each site, starting with Site 1 near the headwaters and ending with Site 16 near the mouth.

Table 1. List of Mud Creek monitoring stations and parameters collected

Stressor ID Site #	Nearest Road Crossing	X	Y	STORET	BIO ID	Parameters collected
Site 1	300th Ave	46.011065°	-93.137495°	S005-596	N/A	1
Site 2	270th Ave	45.980880°	-93.146719°	S005-848	N/A	1, 4
Site 3	CR 5	45.952416°	-93.164205°	N/A	06SC110	1, 3, 4
Site 4	250th Ave	45.948316°	-93.170207°	N/A	N/A	1
Site 5	CR 5	45.939063°	-93.162861°	N/A	N/A	1, 4
Site 6	230th Ave	45.926720°	-93.159190°	N/A	N/A	1, 4
Site 7	225th St	45.912753°	-93.175590°	S005-597	98SC018	1, 2, 3, 4
Site 8	CR 68	45.897029°	-93.160886°	S005-593	N/A	1, 2, 4
Site 9	near CR 68	45.888789°	-93.162554°	N/A	N/A	4
Site 10	CR 68	45.885720°	-93.144068°	N/A	06SC109	1, 3, 4
Site 11	CR 11	45.869288°	-93.134725°	S005-846	96SC011	1, 2, 3
Site 12	CR 120	45.852981°	-93.142248°	N/A	N/A	1, 4
Site 13	180th Ave	45.846170°	-93.145133°	N/A	N/A	1, 4
Site 14	170th Ave	45.831827°	-93.154408°	S005-847	N/A	1, 2
Site 15	CR 5	45.813795°	-93.167203°	S003-533	06SC107	1, 2, 3, 4
Site 16	CR 17	45.798049°	-93.190141°	N/A	N/A	1

**** Key: 1-** Dissolved Oxygen profile **2 –** Routine WQ sampling **3 –** Biological / Habitat **4 -** Geomorphology

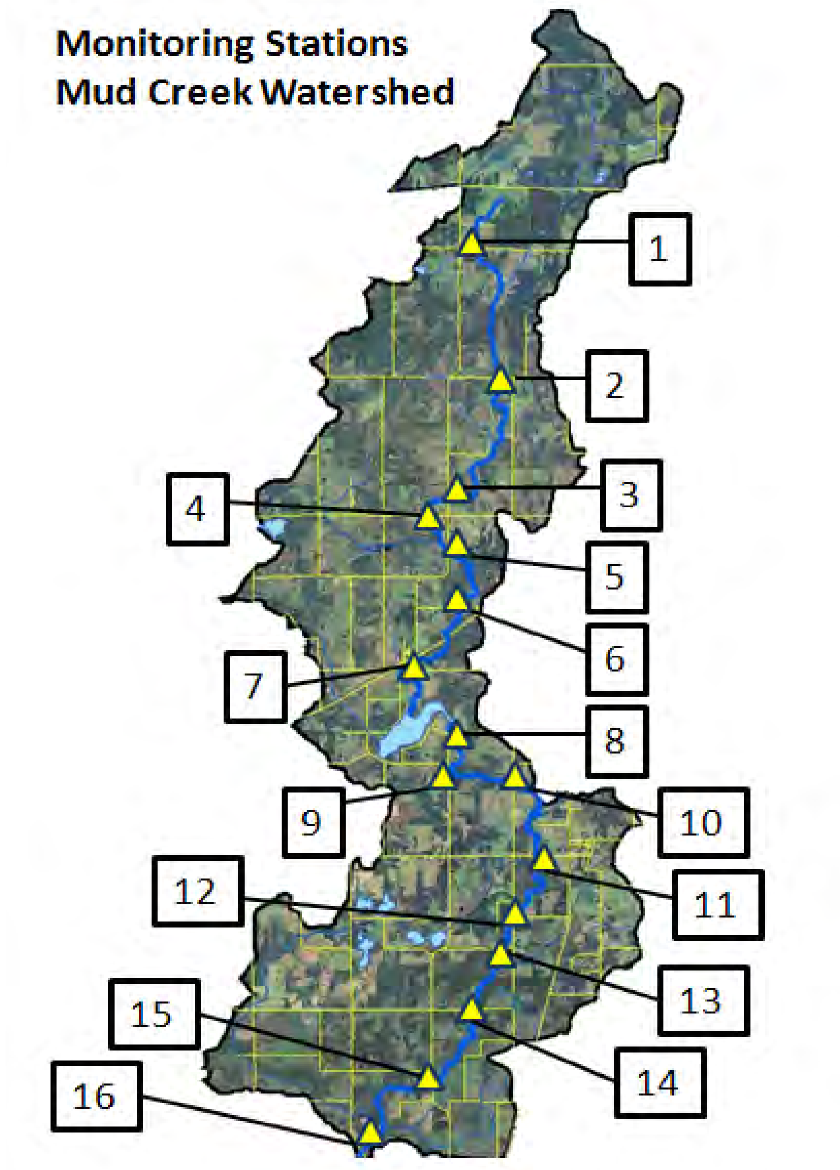


Figure 2. Map of Mud Creek monitoring stations

1.3 Brief description of impairment

Fish and macroinvertebrate Index of Biological Integrity (IBI) scores at several stations on the mainstem of Mud Creek were lower in comparison to streams with similar natural background conditions. As a result, the stream AUID (07030004-566) was added to the Minnesota's list of impaired waters (303d list) in 2002 for fish IBI (F-IBI) and 2004 for macroinvertebrate IBI (M-IBI). See Figure 3 for the location of these stream AUIDs and associated impairments.

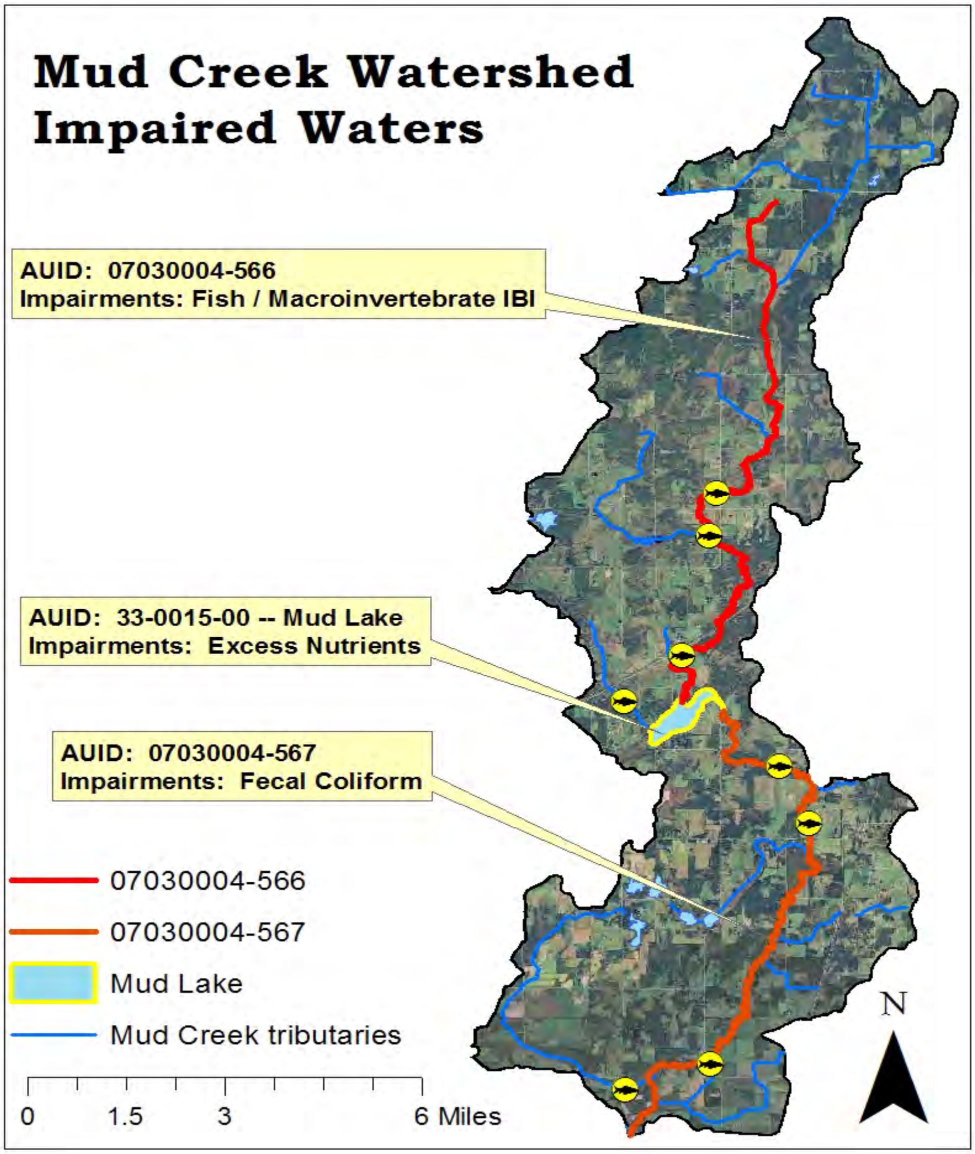


Figure 3. Mud Creek Watershed AUIDs, Impairments, and Biological Monitoring Locations

The spatial extent and severity of biological impairments in this watershed are both fairly limited. Upstream of Mud Lake, F-IBI scores at the two monitoring sites were equal to the impairment threshold, but were considered impaired due to local land-uses that appear to be degrading habitat quality. In addition, the impairment designation for this reach was also supported by M-IBI data, as scores from a monitoring station on this reach were well below the impairment threshold on two separate visits.

Lower Mud Creek (downstream of Mud Lake) is not currently listed as impaired for aquatic life uses. However, this reach is impaired for violating state water quality standards for fecal coliform bacteria. In addition, Mud Lake is currently listed as impaired for excess nutrients.

1.4 Biological monitoring results and metric analysis

Fish IBI (F-IBI) results

The MPCA's biological monitoring stations are divided into various classes based on drainage area, stream gradient, geographical location, and thermal regime (warmwater or coldwater). The eight biological monitoring stations in the Mud Creek watershed fall into three of these fish classes; Northern Headwaters Streams (Class 6), Northern Streams (Class 5), and Low Gradient streams (Class 9). Monitoring station information and F-IBI results are shown in Table 2.

F-IBI results were somewhat variable throughout the watershed, but overall, none of the sites sampled showed a severely degraded fish assemblage. Downstream of Mud Lake, Sites 10 and 15 scored above the upper confidence limit of the F-IBI. Although there was some variability in the results at Site 15 (the 2nd visit scored 20 points lower), the F-IBI results from the stations downstream of Mud Lake are indicative of a relatively healthy fish community.

Upstream of Mud Lake, the F-IBI results at both stations were equal to the impairment threshold, which suggest that the fish assemblage in upper Mud Creek is somewhat degraded compared to high quality sites, but is not severely degraded.

Table 2. Summary of F-IBI results from Mud Creek monitoring sites, impairment thresholds (standards), and Confidence Limits (C.L.) Sites are arranged from upstream to downstream

Site	Drainage Area (sq. mi)	Fish IBI Class	# of visits	Fish IBI Max	Fish IBI Min	Fish IBI (avg.)	Stdev	Standard	Lower C.L.	Upper C.L.
Site 3	17.0	6	1	40	40	40	n/a	**40**	24	56
Site 7	29.6	6	1	40	40	40	n/a	**40**	24	56
Site 10	40.6	6	1	74	74	74	n/a	**40**	24	56
Site 11*	54.7	9	1	49	49	39	n/a	**40**	30	50
Site 15	65.6	5	2	69	49	59	14.1	**50**	41	59

Fish metric results

The two biological monitoring stations located on the impaired reach (Sites 3 and 7) are both Class 6 sites, and show similar symptoms in terms of fish impairment. The set of fish metrics used to evaluate Class 6 sites is shown in Figure 2, along with the metric scores (0-10 scale) for each site. Results from Site 10, located further downstream, were included in the figure for comparison purposes, as this site is also Class 6 and scored well above the impairment threshold. Generally, the fish community at the impaired sites was dominated by species with high tolerance to various forms of habitat degradation and environmental stress. Not surprisingly, these sites also lacked the sensitive fish species that are seen in less disturbed watersheds in the St. Croix River basin.

In addition, both of the impaired sites have low scores in the fish metrics that are closely tied to substrate quality. The metric *SLithop* pertains to the amount of simple lithophils, or gravel spawning fish species, present at a site. Both of the impaired sites scored low in this metric, especially Site 7 (Table 3). The metric *InsectCypPct* measures the relative abundance (%) of individuals that are insectivorours Cyprinidae (minnow) species. Fish species of this metric that are common to the St. Croix River basin include longnose dace and hornyhead chub. Quality benthic (streambed) habitats are required to support these fish species, as most of the aquatic insects they depend on for food utilize this area of the stream channel for refugia and reproduction. Insectivorous minnow species were completely absent from the two impaired sites, while Site 10 scored high in this metric (9/10) with around 19 percent of the total catch at that station being insectivorous minnows (Table 3).

Table 3. Fish Metric Scores for Class 6 monitoring sites on Mud Creek. Sites 3 and 7 are located on the impaired reach. Scale for scores is 0 (very poor) to 10 (excellent)

Metric Name *	Site 3	Site 7	Site 10
DarterSculp	5	5	5
Hdw-Tol	0	0	0
InsectCypPct	0	0	9
Insect-TolTxPct	8.5	10	8.7
Minnows-TolPct	2.5	0.5	10
NumPerMeter-Tolerant	2.4	0.5	10
PioneerTxPct	7.2	9.6	4.9
Sensitive	0	2.5	7.5
SLithop	4.7	2.3	10
TolTxPct	10	10	8.4
Total Fish IBI Score*	40.3	40.5	73.6

Severity of Impact **	
0 to 2.0	High
2.1 to 4.0	Moderate
4.1 to 4.9	Low
5 and above	Very Low / None

* For Metric Descriptions, see Appendix D.

** Scale based on partitioning of biological metric scores. Lower scores represent more "stress" or "impact" on the fish species within the metric.

*** Fish IBI score scale is 0 – 100.

Macroinvertebrate IBI (M-IBI) results

Site classes for macroinvertebrate monitoring are broken down in similar fashion to the fish classes, using stream features such as drainage area, gradient, and ecological setting. The biological monitoring sites on Mud Creek fall into two classifications--Northern Forest Streams Glide-Pool (Class 4), and Northern Forest Streams Riffle-Run (Class 3). The main difference between these two classifications is stream gradient and available habitat types, with Class 3 sites showing more riffle-run habitat (moderate to high gradient) and Class 4 having more glide-pool features (low gradient).

M-IBI scores were below established impairment thresholds at two Mud Creek stations, Site 3 and Site 10 (Table 4). The M-IBI score at Site 10 was very close to the threshold and well above the lower confidence limit. The F-IBI score at this site was well above the impairment threshold, so it was decided that this station would not be listed for M-IBI impairment. On the other hand, Site 3 was sampled twice for macroinvertebrates and scored at the lower end of the confidence limit both times. The AUID that this site is located on (07030004-566) was already listed for an F-IBI impairment and a macroinvertebrate listing was added in 2004.

Table 4. Summary of M-IBI results from Mud Creek monitoring sites along the impairment thresholds (standard) and Confidence Limits (C.L.)

Site	Drainage Area (sq. mi)	Invert Class	# of visits	M-IBI Max	M-IBI Min	M-IBI (avg.)	Stdev	Standard	Lower C.L.	Upper C.L.
Site 3	17.0	4	2	**42.2**	**39.2**	**40.7**	2.1	52.4	66.0	38.8
Site 7	29.6	4	1	59.2	59.2	59.2	n/a	52.4	66.0	38.8
Site 10	40.6	3	1	47.9	47.9	47.9	n/a	50.3	62.9	37.7
Site 11	54.7	4	1	68.3	68.3	68.3	n/a	52.4	66.0	38.8
Site 15	65.6	4	2	55.7	62.7	59.2	4.9	52.4	66.0	38.8

The M-IBI metrics with the lowest scores in the impaired reach are those dealing with overall tolerance to disturbance, filter feeding, and Tricoptera (caddisfly) richness. In two sampling visits to Site 3, there were no pollution intolerant invertebrates collected. Most of the other sites in the watershed scored relatively well in this metric, so the lack of intolerant macroinvertebrates at Site 3 is somewhat of a localized impairment symptom. The lack of collector and filter-feeding taxa at Site 3 drove down scores for the *Collector-filtererPCT* metric. Lower scores in this particular metric seemed to be a trend across many of the sites in the Mud Creek watershed, and may be indicative of stressors related to suspended and/or bedded sediment.

MetricName	Site 3 (1st visit)	Site 3 (2nd visit)	Site 7	Site 11	Site 15 (1st visit)	Site 15 (2nd visit)
ClingerCh	4.7	6.0	5.3	6.0	6.7	6.7
Collector-filtererPct	1.4	0.3	0.8	1.0	1.3	1.5
DomFiveCHPct	7.8	3.7	5.2	5.0	4.1	6.8
HBI_MN	5.4	4.2	4.9	8.4	6.2	6.9
Intolerant2Ch	0.0	0.0	5.0	7.9	5.0	7.9
POET	5.7	4.3	8.6	7.9	7.1	7.9
PredatorCh	5.7	6.4	10.0	10.0	10.0	10.0
TaxaCountAllChir	7.7	7.7	10.0	10.0	8.5	10.0
TrichopteraChTxPct	2.7	2.7	4.4	6.6	3.8	2.3
TrichwoHydroPct	1.1	3.8	5.1	5.5	2.9	2.8
M-IBI Total Score	42.1	39.2	59.2	68.3	55.7	62.7
+/- to imp. Threshold	-10.3	-13.2	6.8	15.9	3.3	10.3

Severity of Impact**
0 to 2.0
2.1 to 4.0
4.1 to 5.4
5.5 and above

Table 5. Fish Metric Scores for Class 4 Monitoring Sites. Sites 3 and 7 are located on the impaired reach of the creek. Scale of Metric Scores is 0 (very poor) to 10 (excellent).

** Scale based on partitioning of biological metric scores. Lower scores represent more "stress" or "impact" on the invertebrate species within that metric.

The lack of Trichoptera (caddisfly) richness at the impaired site (Site 3) can also be observed throughout most of the watershed. There are many varieties of caddisflies and each of them has specific habitat requirements. Later in the Stressor ID process the caddisfly metrics will be further examined to determine which species are missing or occurring less frequently.

Section II. Stressor Identification

2.1 Organization framework of Stressor Identification

The Stressor Identification process (SID) is used in this report to weigh evidence for or against various candidate causes of biological impairment (see Cormier et al., 2000). The SID process is prompted by biological assessment data indicating that a biological impairment has occurred. Through a review of available data, stressor scenarios are developed that may accurately characterize the impairment, the cause, and the sources/pathways of the various stressors (Figure 4). Confidence in the results often depends on the quality of data available to the SID process. In some cases, additional data collection may be necessary to accurately identify the stressor(s).

SID draws upon a broad variety of disciplines, such as aquatic ecology, geology, geomorphology, chemistry, land-use analysis, and toxicology. Strength of evidence (SOE) analysis is used to develop cases in support of, or against various candidate causes. Typically, the majority of the information used in the SOE analysis is from the study watershed, although evidence from other case studies or scientific literature can also be drawn upon in the SID process.

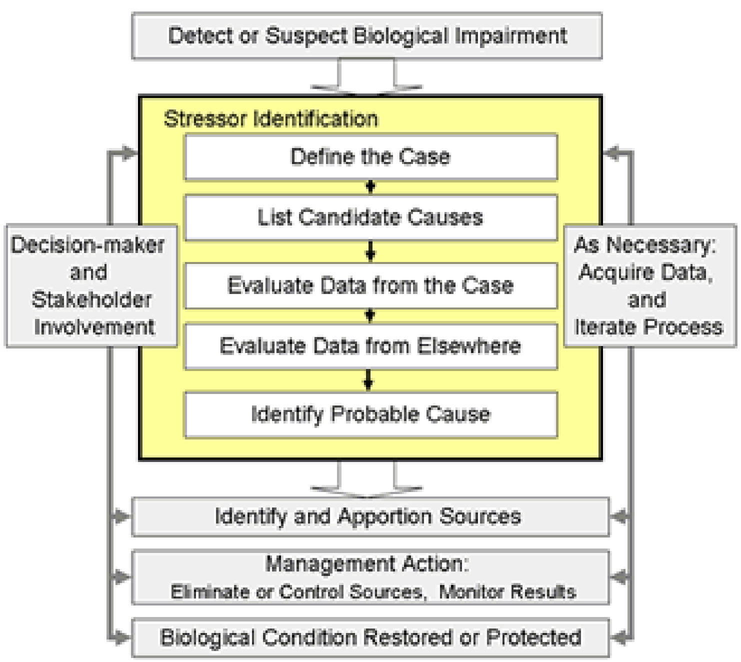


Figure 4. Conceptual Model of Stressor Identification (SID) Process

Completion of the SID process does not result in a finished Total Maximum Daily Load (TMDL). The product of the SID process is the identification the stressor(s) for which the TMDL load allocation will be developed. For example, the SI process may help investigators identify excess fine sediment as the cause of biological impairment, but a separate effort is then required to determine the TMDL and implementation goals needed to address and correct the impaired condition.

.2.2 Stressor ID Reconnaissance (SIDR) results/list candidate causes

This section of the report will summarize the results of the Stressor ID Reconnaissance (SIDR). The SIDR is comprehensive evaluation of the watershed characteristics (land-use, topography, geomorphology) and the linkages between those features and the known impairments. In general, the SIDR focuses on five major watershed components; water chemistry, biology, hydrology, geomorphology, and connectivity. The results of the SIDR will be used to develop a list of candidate causes for stream impairments and establish causal pathways between stressor sources and negative impacts to the streams of the watershed.

2.2.1 SIDR Step 1: Watershed/stream characterization

Mud Creek, located within Southwest Kanabec and southeast Pine Counties, is a low gradient stream that flows in a southerly direction over its course for approximately twenty three miles to its confluence with the Snake River near Grasston, MN (Feist, 2008). The headwaters of Mud Creek and most of the tributary its tributary streams were channelized prior to 1939 based on analysis of old aerial photos. The mainstem of Mud Creek returns to a "natural channel" form about 0.5 river miles downstream of 270th Ave, and remains mostly un-ditched for the remainder of its course downstream to the confluence with the Snake River.

The Mud Creek watershed falls within the ***Central Wisconsin and Minnesota Thin Loess and Till*** Major Land Resource Area (MLRA) classification according to the NRCS. The landscape of this region is characterized by gently undulating to rolling, loess-mantled till plains, drumlin fields, and end moraines mixed with outwash plains associated with major glacial drainageway swamps, and bogs (NRCS).

Land cover in the Mud Creek watershed is predominantly pastured rangeland with scattered areas of forest, shrub, and wetland throughout (Figure 5). Urban and developed areas are scarce within the watershed, with the cities of Quamba (population: 123) and Henriette (population: 61) being the only incorporated communities. Watershed land-cover/land-use is fairly homogenous throughout, with the only noteworthy difference being that there is more cultivated cropland in the lower Mud Creek sub-watershed.

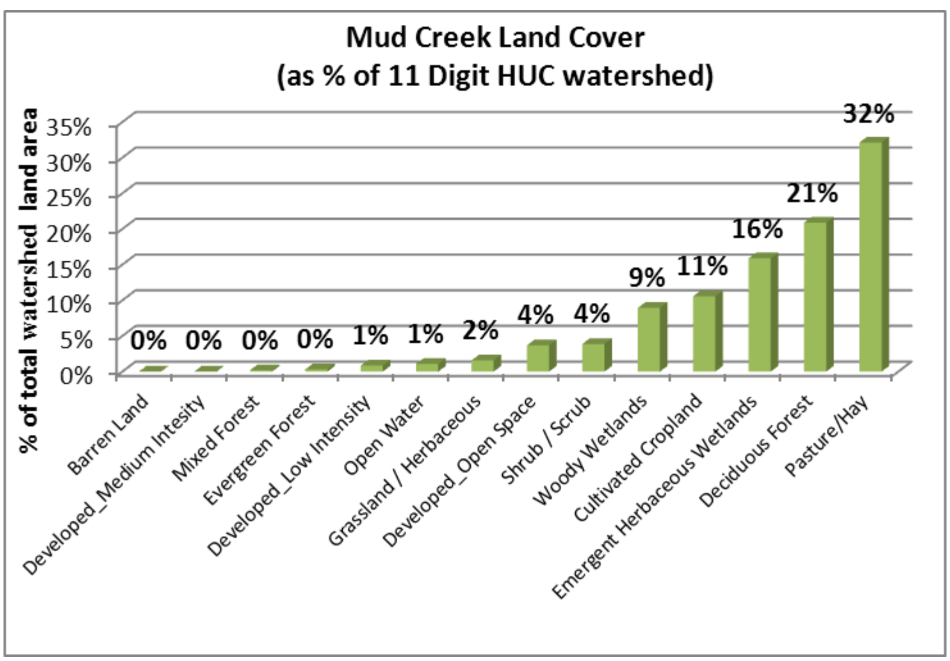


Figure 5. Mud Creek HUC 11 Watershed land cover

Point-source pollution does not appear to be a threat to aquatic life in the Mud Creek watershed. There are only two permitted point-sources; a stormwater permit and a wastewater treatment plant (WWTP) for the city of Grasston, Minnesota. The WWTP discharges directly to the Snake River and therefore has no direct impact on water quality of Mud Creek.

2.2.2 Stream channel and valley characterization

A desktop stream and valley typing exercise was completed as part of the SIDR using the methodology outlined in *Applied River Morphology* (Rosgen, 1996). Although further fieldwork is recommended to verify the results of the desktop exercise, major breakpoints in stream and valley type were identified based on stream channel pattern, width, slope, and valley type (Figure 6). The valley types in the watershed are predominantly X and VIII, which both offer extensive floodplains and valley walls with very gradual slopes. The most common channel types observed were E and C, while some B type channels were observed in a few short reaches where gradient increased and valley width narrowed. Descriptions of these stream and valley types are provided in Table 6.

Table 6. Valley and stream types found in the Mud Creek Watershed

Valley Type	Description
VIII	Wide, gentle valley slope with a well-developed floodplain adjacent to river terraces.
X	Very broad and gentle slopes, associated with extensive floodplains. Constructed with alluvial materials originating from both riverine and lacustrine deposition processes.
Stream Type	**Description**
E	Moderate to high sinuosity, gentle to moderately steep channel gradients, and very low channel width to depth ratios
C	Slightly entrenched, meandering, riffle-pool channel with a well-developed floodplain
B	Moderately entrenched, gradient 2-4%, often found within gentle to rolling slopes in narrow, colluvial or structurally controlled valleys.
Ditch	Trapezoidal agricultural drainage ditch

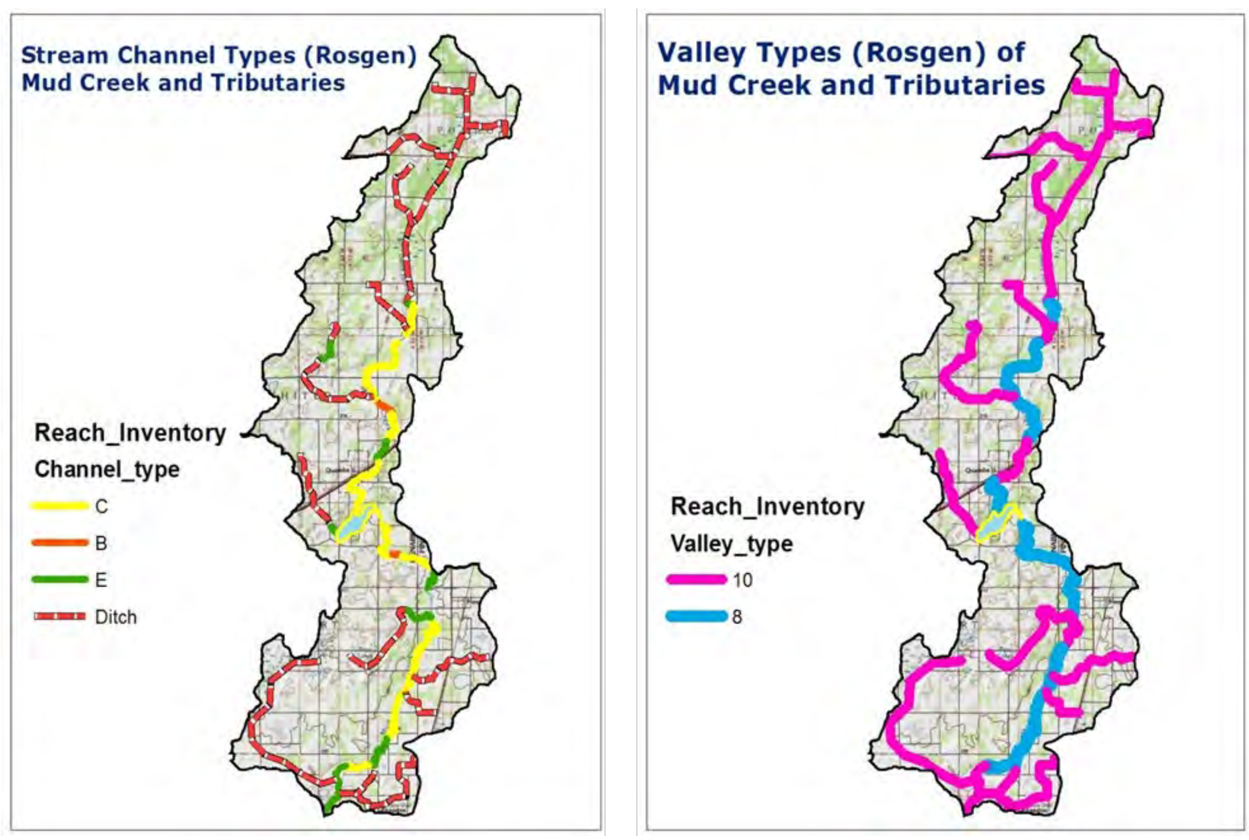


Figure 6. Maps of stream and valley types in the Mud Creek Watershed

2.2.3 SIDR Step 2: Screening for potential physical, chemical, and biological stressors

Overview

Rosgen (2006) developed a series of worksheets to evaluate and compile land-use activities and their effects on sediment supply and channel stability. For the purposes of this Stressor ID study, several of these worksheets were modified slightly to focus on a comprehensive set of potential stressors to aquatic life; including, but not limited to sediment. Completion of these worksheets involved summarizing available water chemistry data, reviewing field reconnaissance data (pictures, notes, and field data), aerial photo analysis, and compiling relevant GIS layers. The results, summarized below, will be used to develop a set of candidate causes for the impairment, each of which will be further evaluated in the next section of this report.

SIDR results-physical stressor

The land-uses identified as having the most impact to physical integrity (e.g. channel stability) of Mud Creek were channelization, animal agriculture (grazing), and row-crop agriculture. The presence of active logging, gravel roads, and urban/residential development is likely affecting sediment supply and channel stability on some level as well, but these potential sources are not very common in the watershed.

The effects of these land-uses on physical habitat are mostly related to riparian habitat quality and channel stability. During the desktop analysis of stream and valley types, it appeared that wide E or C channels occurred frequently in reaches with where the riparian corridor had been converted from prairie or forest to cattle pasture. It is possible that these channels underwent a transition from E channels (low width to depth ratio) to C channel type through channel widening as riparian vegetation changed from forest/perennial grasses to pasture. Several examples of over-widened reaches of Mud Creek are shown in Figure 7, as well as a channel evolution model developed by Rosgen (1996) showing the transition from E to C channel type that is often seen with this type of land management.

The impact of these land-uses on channel stability were broken down into several categories during the completion of the SIDR worksheet; (1) Direct impacts that destabilize the channel; (2) Altered stream-channel dimension, pattern, and profile; (3) excess sediment deposition; (4) large woody debris (LWD) in the stream-channel; (5) streambed scour / channel incision. Each of these impacts are related to channel stability, however, the results of each of these processes affect aquatic life in different ways. All of these potential problems will be evaluated in detail in the Section 3 of this report to determine the specific stressors that are most likely resulting in the impaired fish and macroinvertebrate assemblages.

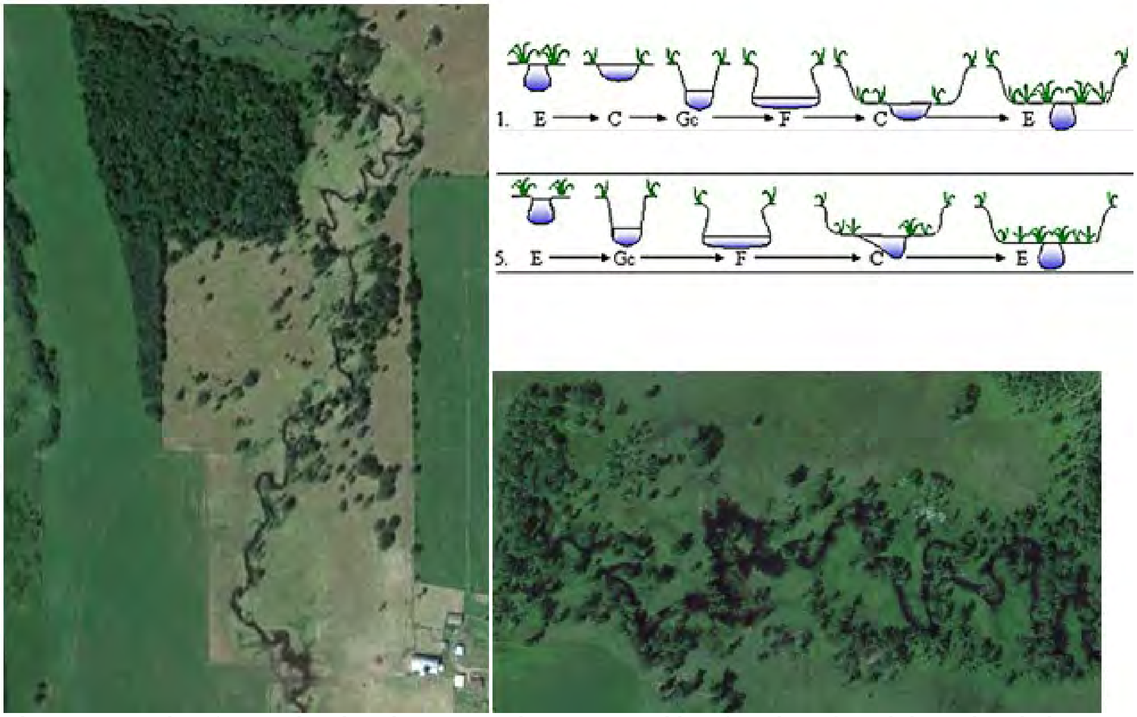


Figure 7. Examples of unregulated cattle access to the stream corridor of Mud Creek, and channel evolution patterns commonly associated with this type of land management

Stream-flow and stream-power changes were also identified as potential physical stressors in the Mud Creek watershed. Given the amount of channelization (ditching) through wetlands and bogs in the watershed, it can be concluded that wetland function has been reduced and the hydrological pathways and processes have been altered from their natural state. Changes in flow regime can have a significant impact stream-power and sediment dynamics, which ultimately affect channel stability and in-stream habitat for fish and macroinvertebrates.

Loss of connectivity was also identified as a potential contributor to biological impairments. Although most of the road crossings and culverts in the watershed are suitable for fish passage, the ditching of the headwaters and many of the tributaries greatly diminishes the available habitat for fish to utilize as refugia or spawning/rearing areas.

For the complete worksheet covering all of the potential physical stressors that were considered during the SIDR screening process, refer to Appendix A. Included in this table is a short summary of the available data and the decisions stemming from the review.

SIDR results-Water chemistry stressors

Low dissolved oxygen (DO) and increased nutrient loading (phosphorous) were identified as the two main water chemistry stressors that may be contributing to biological impairments in Mud Creek. DO concentrations below the state water quality standard of 5.0 mg/L were frequently observed at monitoring sites both upstream and downstream of Mud Lake, especially in the month of August. Total phosphorous (TP) concentrations above the draft river nutrient criteria of 0.1 mg/L were observed regularly both above Mud Lake and near the outlet to the Snake River. These elevated TP concentrations are currently being addressed through the Mud Lake Excess Nutrients TMDL, but will also be considered as a potential factor in the biological impairments due to the low DO concerns.

No other water quality parameters appear to be problematic for supporting aquatic life in Mud Creek. A summary of the water chemistry data that was evaluated can be found in

Appendix A. The table used to identify the potential sources of elevated nutrients and low DO can also be found in this appendix.

SIDR results-Biological stressors

It is unlikely that a biological agent is contributing to fish and macroinvertebrate impairments in Mud Creek. According to the MDNR List of Infested Waters (updated 10/2011), there are no lakes or streams in the Mud Creek watershed designated as infested with invasive species. The fish and macroinvertebrate taxa list from sampling efforts did not contain any species that were non-native or stocked intentionally or illegally. Based on this information, it does not appear that a stressor of biological nature is responsible for the low fish and macroinvertebrate IBI scores observed.

2.3 SIDR summary/list of candidate causes for impairment

Completion of the SIDR resulted in several remaining candidate causes for impairment and eliminated others based on a review of available data. In some cases, best professional judgment was used when data for specific parameters were lacking, but this approach was only used for stressors that were very unlikely given the watershed conditions (e.g toxicity due to heavy metals). The SIDR effort also identified several data gaps that required further work in order to develop evidence for or against certain stressors.

Listed below in Table 7 are the candidate causes that emerged as potential contributors to the impaired fish and macroinvertebrate assemblages in Mud Creek. Also listed are the candidate causes in which significant data gaps are evident. These particular candidate causes cannot be removed from consideration until additional data is collected. The candidate causes that were eliminated can be found in Appendix A, along with a brief summary of the data or other logic that was used to eliminate them.

Table 7. List of remaining candidate causes for biological impairments in Mud Creek

Candidate Cause for Impairment
Deposited and bedded sediments (DBS)
Low Dissolved Oxygen
Altered Flow Regime
Loss of Connectivity
Loss of Riparian Habitat

Section III. Causal Analysis/Strength of Evidence

3.1 Candidate cause 1-excess deposited and bedded sediments (DBS)

Deposited and bedded sediments (DBS) are mineral and organic particles that settle out of the water column and collect on the streambed. DBS is one of the leading causes of biological impairments in rivers and streams of the United States (Berry et al., 2003). Numerous Stressor Identification studies involving biologically impaired Minnesota streams have identified DBS as a primary cause of impairment (Jasperson, 2010; Felix et al., 2009; U.S. EPA and MPCA, 2004; EOR, Inc., 2009.)

The presence of excess DBS in riverine habitats has been proven to adversely impact fish and macroinvertebrate species that depend on clean, coarse stream substrates for feeding, refugia, and/or reproduction (Newcombe et al., 1991). Aquatic macroinvertebrates are generally affected in several ways, including: (1) loss of certain taxa due to changes in substrate composition (Erman and Ligon, 1988); (2) increase in drift (avoidance) due to sediment deposition or substrate instability (Rosenberg and Wiens 1978); and (3) changes in the quality and abundance of food sources such as periphyton and other prey items. Fish communities are typically influenced via: (1) a reduction in spawning habitat or egg survival (Chapman 1988) and/or (2) a reduction in prey items as a result of decreases in primary production and benthic productivity (Bruton 1985; Gray and Ward 1982).

Conceptual model

The conceptual model for excess DBS is shown in Figure 8. This is a generalized model, and several of the sources and pathways depicted are not applicable in the Mud Creek watershed. The most likely sources of excess DBS in Mud Creek are current and legacy effects from agriculture and logging activities in the watershed, and active streambank erosion in the near-channel area of the stream.

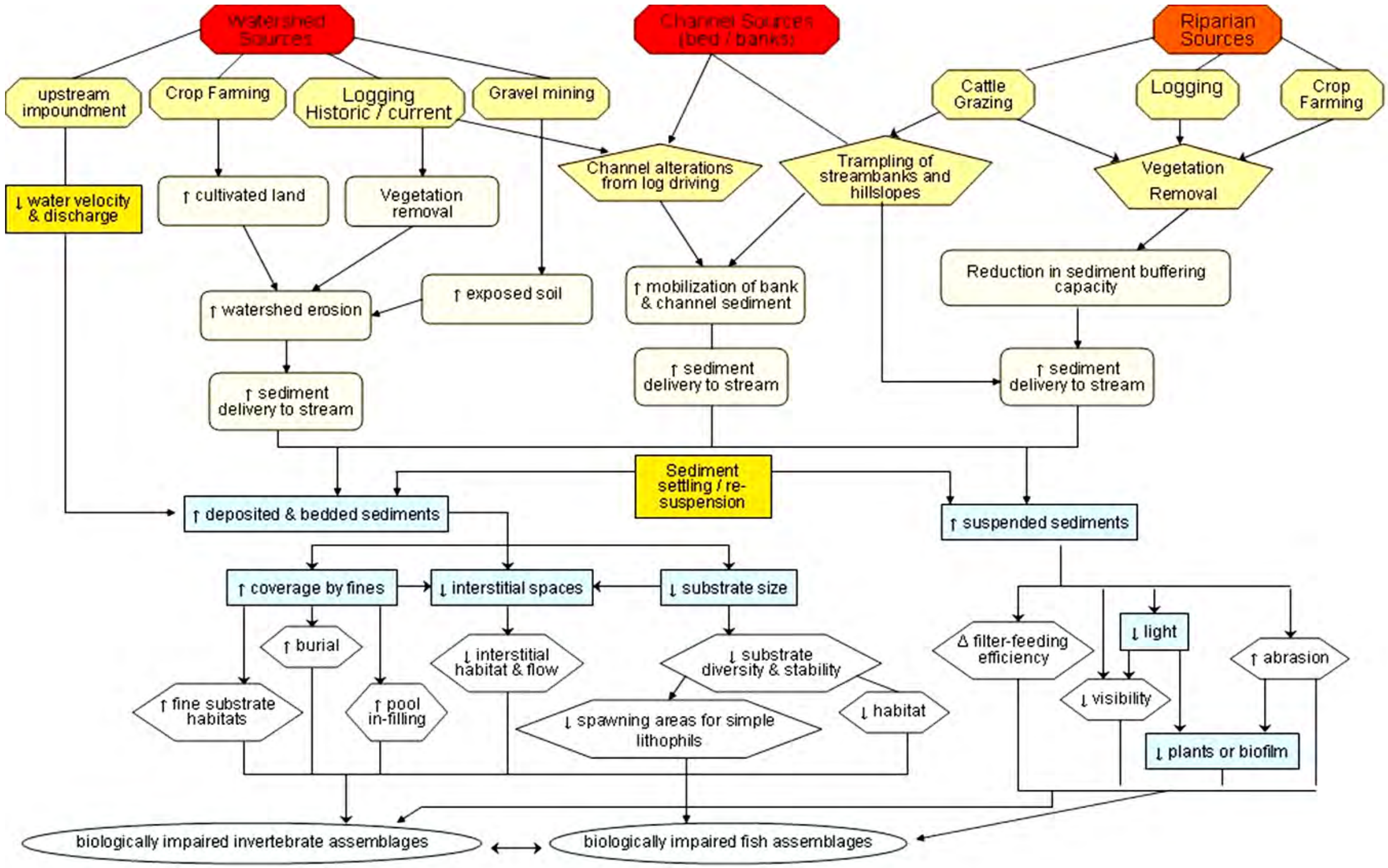


Figure 8. Conceptual model for deposited and bedded sediments as a stressor causing biological impairment

Channel widening/bank instability

Removal of riparian vegetation can lead to an increase in width-depth ratio, channel braiding, and the loss of undercut banks that can serve as cover for fish (Behnke and Raleigh 1978, Marcuson 1977; Rosgen, 1996). Cattle activity in or near the stream has also been shown to cause widening of the stream channel and higher erosion rates (Behnke and Raleigh, 1978; Ohmart, 1996; Kauffman and Krueger, 1984).

In several reaches of Mud Creek (Figure 9), it appears that riparian disturbance has contributed to stream channel widening and instability. Based on stream reconnaissance efforts and aerial photo analysis, it does not appear that cattle are fenced off from the stream in any locations where grazing occurs in the riparian corridor. Cattle grazing near the stream channel have reduced the rigor and diversity of plant species within the stream corridor, leaving stream banks and riparian terrain more susceptible to sediment loss.

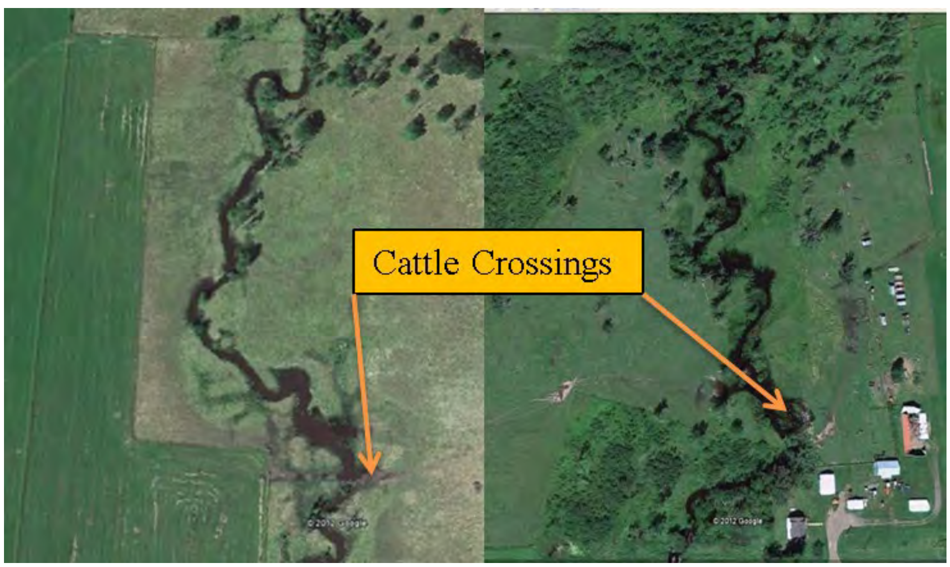


Figure 9. Areas of channel widening and sedimentation due to cattle grazing and accessing the Riparian Corridor

Areas of stream channel instability were observed throughout the length of Mud Creek (Figure 10). Unstable or eroding banks are likely increasing the amount of DBS found on the streambed, as sediment enters the stream in quantities that cannot be effectively transported downstream. Although some of these areas have land-uses within the immediate riparian corridor that are causing streambanks to be unstable (e.g. cattle grazing), there appears to be unstable banks in areas where there is little to no anthropogenic disturbance in the immediate area. This suggests that the alteration of other processes in the watershed beyond the immediate stream corridor, such as flow alteration and/or stream channelization, may also play a role.

Figure 10. Examples of streambank instability and mass wasting in the Mud Creek Watershed (Photos are from Sites 6 (left) and Site 3 (right))

DBS evaluation for Mud Creek

Several data sources were available for evaluating the presence of deposited and bedded sediments (DBS) in the Mud Creek watershed. Quantitative substrate data were available through the MPCA's biological monitoring habitat assessment and through the results of geomorphic surveys conducted at select stream reaches. Qualitative data were also used in this analysis based on the protocols of the Pfankuch Stability Index (PSI), first developed by (Pfankuch, 1975), and later modified by Rosgen (2001).

Results from pebble counts collected using Wolman (1954) method are shown in Figure 11. Most monitoring stations upstream of Mud Lake had stream substrates that were dominated by fine sediment (predominantly sand). Downstream of Mud Lake, gravel and cobble substrate types were more abundant than sand and silt, a trend that was generally consistent across all data sources, both qualitative and quantitative. Sites 3 and 6 upstream of the lake appear to be the most heavily impacted by excessive amounts of DBS, as the % of fine sediments within those two reaches were about 97 percent and 98 percent, respectively.

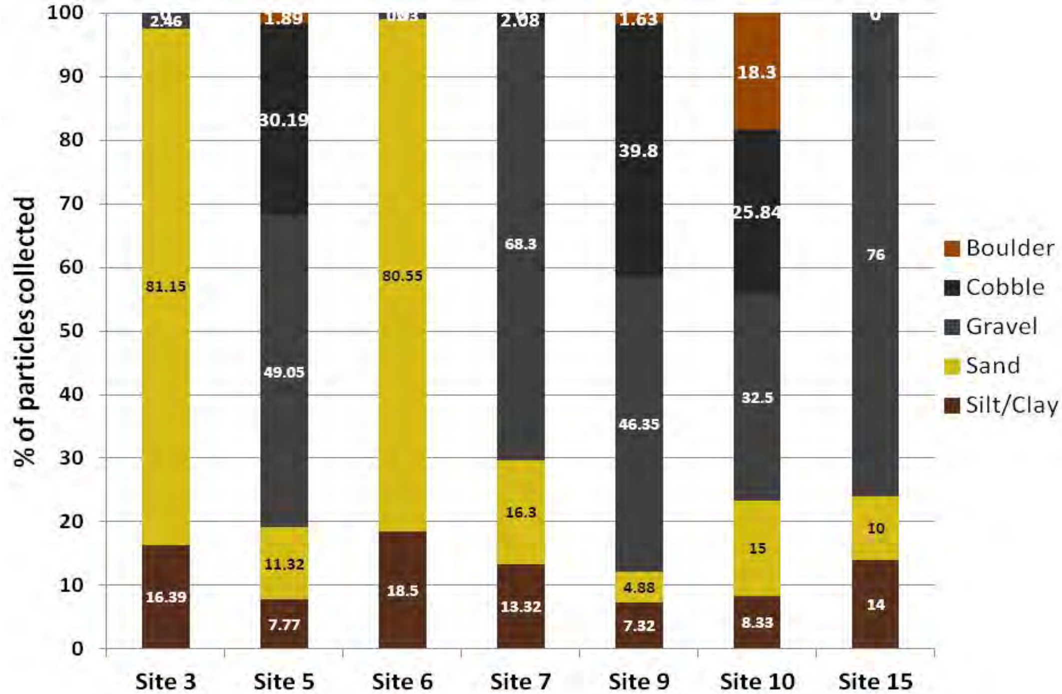


Figure 11. Results of Wolman (source) pebble counts collected at riffles within Mud Creek

Both anthropogenic disturbances and natural background conditions are likely responsible for the abundance of fine sediment at Sites 3 and 6. Natural differences in stream gradient are quite large between several of the Mud Creek biomonitoring stations. Sites 3 and 6 are low gradient sites compared to Sites 5, 9, and 10. A comparison of stream gradient and percent fine substrate using quantitative habitat data shows the relationship between these two parameters (Figure 12). Based on the quantitative habitat data, those stations with lower gradients (Sites 3, 7, 11, and 15) have higher percentages of fine materials on the substrate compared to Site 10, which has two times more gradient and higher stream power to move sediment.

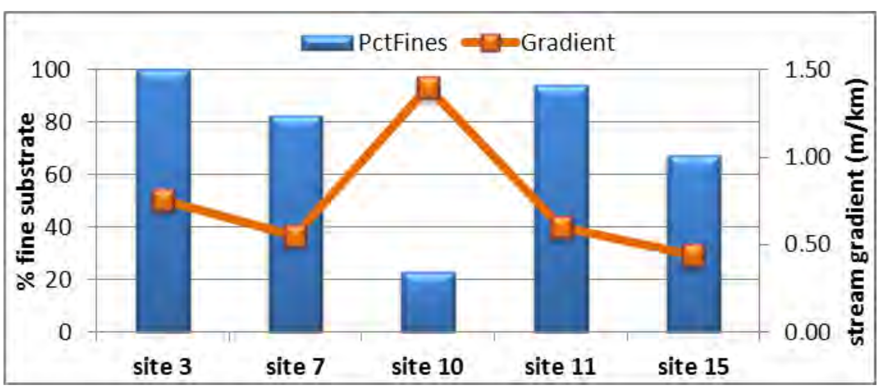


Figure 12. Percent fine substrate and stream gradient at Mud Creek monitoring stations

Differences in channel stability also factor into the amount of DBS observed at Mud Creek monitoring sites. The Pfankuch Stability Index (PSI) was used to evaluate the condition and stability of the stream channel at nine sites along the length of the creek. The PSI focuses on three specific regions of the stream channel (upper banks, lower banks, stream bottom) and provides a general stability rating based on the cumulative scores. Results from 10 PSI assessments on are shown in Table 8, including the cumulative scores and sub-scores for each channel region (i.e. upper banks, lower banks, etc.). Overall stability ratings ranged from poor to good across a variety of channel types that were visited in the watershed. The three sites that were rated "poor" scored poorly in the "stream bottom" metrics that pertain to scouring and sediment deposition, especially Sites 3 and 6 within the biologically impaired reach (Table 8). These PSI scores support elevated DBS as a stressor in the upper Mud Creek watershed.

Table 8. Results of PSI data collection at Mud Creek monitoring sites. (Higher PSI scores indicated at higher degree of streambank/streambed instability)

	Upper Banks Total	Lower Banks Total	Stream Bottom (subtrate) Total	Grand Total	Channel Type	Stability Rating
	range 10 - 40	*range 13 - 52*	*range 15 - 60*	*range 38 - 152*		
Site 2	22	29	49	100	***E5***	**POOR**
Site 3	29	39	52	120	***C5***	**POOR**
Site 5	21	28	28	77	***B4***	**FAIR**
Site 6	23	37	56	116	***C5***	**POOR**
Site 7	23	30	42	95	***E4 / E5***	**FAIR**
Site 8	26.5	28	37	91.5	***C4***	**FAIR**
Site 9	20	26	30	76	***C4***	**GOOD**
Site 10	22	30	26	78	***C4***	**GOOD**
Site 14	26	28	42	96	***C5***	**FAIR**
Site 15	23	30	39	92	***E4 / E5***	**FAIR**

Biological response to DBS

As mentioned in the introduction to this stressor, elevated levels of DBS can be particularly harmful to certain fish and macroinvertebrate species that depend on coarse stream substrates. Table 9 highlights several key biological metrics that are likely to respond in a predictable way to increases in DBS. The fish and macroinvertebrate species included in these metrics have certain reproductive, trophic, and habitat suitability traits that are directly affected as benthic habitats become influenced by sedimentation. Sedimentation can also have more general impacts on a biotic community, such as limiting overall species diversity or reducing the number of sensitive organisms in the assemblage.

Table 9. A selection of biological metrics that be responsive to increases or decreases in DBS

Metric	Metric Description	Expected Response to increase in DBS
Fish		
Insect-TolTxPctPct	Relative abundance (%) of taxa that are insectivorous (excludes tolerants)	***Decrease***
InsectCypPct	Relative abundance (%) of individuals that are insectivorous Cyprinidae species	***Decrease***
SLithop	Taxa richness of simple lithophilic spawning species	***Decrease***
DarterSculp	Taxa richness of darter and sculpin species	***Decrease***
Macroinvertebrates		
ClingerCh	Taxa richness of clingers	***Decrease***
Intolerant2Ch	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, using MN tolerance values	***Decrease***
POET	Taxa richness of Plecoptera, Odonata, Ephemeroptera, & Trichoptera (baetid taxa treated as one taxon)	***Decrease***
TrichopteraChTxPct	Relative percentage of taxa belonging to Trichoptera	***Decrease***
TrichwoHydroPct	Relative abundance (%) of non-hydropsychid Trichoptera individuals in subsample	***Decrease***

Fish

The fish assemblages within the impaired reach show several symptoms of stress from DBS. Sites 3 and 7 scored a 0.0 (out of 10.0) for the metric ***InsectCypPct*** which measures the relative abundance of fish that are insectivorous Cyprinidae (minnow) species. In comparison, Site 10 of the same fish class (Northern Headwaters Streams) scored a 9.0, largely due to a healthy population of hornyhead chub (*Nocomis biguttatus*) at this monitoring location. Hornyhead chub were not observed at Sites 3 and 7. Schmidt (2008) reported on the decline of the hornyhead chub in Minnesota and potential linkages between this decline and overharvest and degraded habitat conditions. In his evaluation of hornyhead chub populations in several regions of Minnesota, Schmidt found that they prefer riffle/run habitats comprised of sand, gravel, and cobble that were lightly embedded. It is possible that this fish species, as well as others that prefer the same habitat type, are absent from Site 3 due to the abundance of fine sediment and lack of riffle habitat at that monitoring location.

All Class 6 fish monitoring sites, including those on the impaired reach, recorded adequate scores in fish metrics ***Insect-TolTxPctPct*** and ***DarterSculp*** (Table 10--see Appendix D for metric definitions). Although excess DBS has been known to negatively affect these fish metrics, the cause and effect relationship was not observed to a significant extent in Mud Creek. These results do not support the case for excess DBS as a stressor, but are not enough to completely refute the possibility that DBS still plays a role in the impaired biological community.

Table 10. Metric scores for Class 6 fish station on Mud Creek

	Metric Score (0-10)		
Metric Name	**Site 3**	**Site 7**	**Site 10**
Insect-TolTxPctPct	8.5	10.0	8.7
InsectCypPct	0.0	0.0	9.0
SLithop	4.7	2.3	10.0
DarterSculp	5.0	5.0	5.0

Scores for the reproductive metric ***SLithop*** indicate that gravel spawning fish taxa were less common at Sites 3 and Site 7 within the impaired reach of Mud Creek (table 10). Fish species with this reproductive trait were much more common at Site 10, which has larger amounts of coarse substrate available for spawning of this type. As shown in Figure 11, gravel and other coarse substrate types are almost non-existent at Site 3, and the percentage of fine substrate was also quite high at Site 7 when looking at the results of the quantitative habitat assessment data (Figure 12). The metric SLithop appears to be responsive (negatively) to increased amounts of DBS, which supports the case for this stressor.

Macroinvertebrates

The macroinvertebrate metric ***ClingerCh*** typically responds negatively to increases in DBS. "Clinger" macroinvertebrates are those that attach themselves to the stream bottom or other objects in the stream, and can remain attached in swiftly flowing water. Clingers are often found in riffle habitat composed of coarse substrates such as cobble, boulder, or large gravel. As fine sediment accumulates on the streambed, the suitable surfaces for clingers to utilize become limited, and their numbers typically decline (Relyea et al., 2012).

Scores for the metric ***ClingerCh*** were fair across most of the Mud Creek monitoring stations. The lowest score was 4.7 out of 10, which was recorded at Site 3. This result agrees with the expectation that the lowest score for this metric should occur at the site with the highest percentage of fine sediment on the stream bottom. However, during a repeat visit to Site 3 the score for this metric was somewhat higher (6.0/10), and comparable to the rest of the sites on Mud Creek. Based on these results, it does not appear that the metric ***ClingerCh*** is very sensitive to the presence of fine sediment in this particular case.

Table 11. Scores for macroinvertebrate metrics that are commonly affected by deposited and bedded sediments (DBS). See Appendix D for metric descriptions

	Metric Score (0-10)					
Metric Name	**Site 3 ***	**Site 3 * (2nd visit)**	**Site 7 ***	**Site 11**	**Site 15**	**Site 15 (2nd visit)**
ClingerCh	**4.7**	**6.0**	**5.3**	**6.0**	**6.7**	**6.7**
Intolerant2Ch	**0.0**	**0.0**	**5.0**	**7.9**	**5.0**	**7.9**
POET	**5.7**	**4.3**	**8.6**	**7.9**	**7.1**	**7.9**
TrichopteraChTxPct	**2.7**	**2.7**	**4.4**	**6.6**	**3.8**	**2.3**
TrichwoHydroPct	**1.1**	**3.8**	**5.1**	**5.5**	**2.9**	**2.8**

* Site located on impaired reach of Mud Creek

In addition to the effects on clinger macroinvertebrates, excess DBS accumulation has been shown to cause undesirable changes in macroinvertebrate community composition by favoring some taxa at the expense of others (Waters, 1995; Wood & Armitage, 1997). Many taxa from the Ephemeroptera, Plecoptera and Trichoptera (EPT) orders, which provide the most productive and available food for stream fishes, are particularly affected by sedimentation. The metric ***POET*** is based on the taxa richness of **P**lecoptera (stoneflies), **O**donata (dragonflies), **E**phemeroptera (mayflies), and **T**richoptera. Site 3 scored lower than the rest of the Class 6 monitoring sites in the POET metric. This may be an indication that the high levels of DBS at this site are limiting the diversity of POET taxa.

In addition to low POET diversity, intolerant macroinvertebrate taxa were essentially non-existent at Site 3. Metric scores for ***Intolerant2Ch*** were 0.0 for both visits to this site. The other comparable monitoring stations on Mud Creek had adequate scores in this metric (5.0–7.9), so the lack of intolerant taxa at Site 3 appears to be a localized problem. The major difference between Site 3 and the other monitoring stations is the amount of DBS present, so there is a high level of spatial co-occurrence between this candidate stressor and the ***Intolerant2Ch*** metric.

Strength of evidence summary

Most of the evidence compiled supports DBS as a candidate cause for the macroinvertebrate impairment (Table 12). There is good spatial co-occurrence agreement between biological effect and DBS using relevant metrics, although the relationship between clinger taxa and sedimentation is not as strong as expected.

Table 12. Strength of Evidence (SOE) scores for Candidate Cause 1-Deposited and bedded sediments

Types of Evidence	07030004-566 (F-IBI / M-IBI Impairments)
Spatial/temporal co-occurrence	+
Temporal sequence	0
Field evidence of stressor-response	+
Causal pathway	++
Evidence of exposure, biological mechanism	+
Field experiments /manipulation of exposure	NE
Laboratory analysis of site media	NE
Verified or tested predictions	+
Symptoms	+
Mechanistically plausible cause	+
Stressor-response in other lab studies	NE
Stressor-response in other field studies	++
Stressor-response in ecological models	NE
Manipulation experiments at other sites	NE
Analogous stressors	++
Consistency of evidence	**+**
Explanatory power of evidence	**0**

3.2 Candidate cause 2-Habitat loss from riparian corridor disturbance

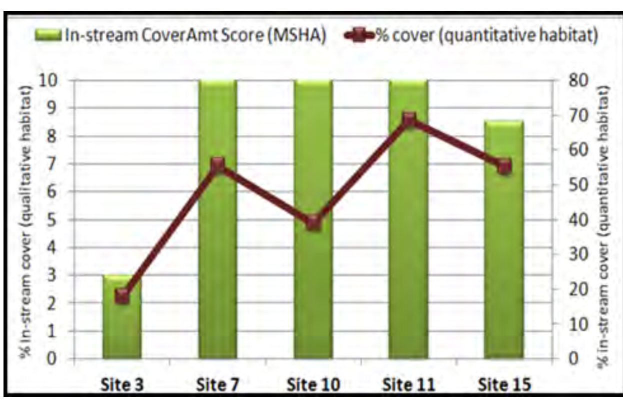
The riparian zone of a stream is generally defined as the transition area between aquatic ecosystems and adjacent upland terrestrial ecosystem (Gregory et al, 1991). High quality, undisturbed riparian corridors provide shading from solar radiation, filtration of overland runoff, mitigation of bank erosion, and inputs of detritus and organic matter that are critical to supporting aquatic life (Cummins and Spengler, 1978; Li and Shen, 1973). Riparian corridor degradation has already been cited as a likely source for additional sediment loading to the creek (see Candidate Cause 1). This section will evaluate the linkages between riparian corridor degradation and in-stream habitat, specifically fish cover and macrophyte abundance.

Mud Creek riparian assessments

A variety of land-uses and land cover alterations have reduced the quality of the riparian corridor along the mainstem of Mud Creek and its tributary streams. The pre-settlement vegetation of the area was dominated by prairie, with areas of Aspen-Birch forest mixed in on the eastern and southern boundaries of the watershed. Post-settlement land cover has been altered through a conversion of prairie to agricultural lands, with pasture/hay land being especially prominent along certain reaches of Mud Creek.

Riparian habitat quality was evaluated at Mud Creek biological monitoring sites using quantitative and qualitative methods developed by MPCA. In all, riparian habitat measurements were collected at five sites along the mainstem of the creek. The qualitative assessment followed Minnesota Stream Habitat Assessment (MSHA) protocols, which evaluate riparian conditions under three main categories–riparian width, bank erosion, and shading. The quantitative assessments of the riparian corridor were completed using the methodologies developed by MPCA's biological monitoring program. These methods include measurements of buffer width, dominant land use, percent "disturbance", overhanging vegetation, and measurements of overhead canopy cover.

Among the sites where riparian conditions were assessed, anthropogenic alterations of the riparian corridor were most notable at Site 3. 100 percent of the land within 30-meter and 100-meter of the stream channel were impacted or "disturbed" by cattle grazing at this site. Many of the mature deciduous trees in this cattle pasture were left standing, so overhead canopy cover is still quite good in this reach. The habitat types that seem to be most affected by the riparian disturbance seem to be those within, or just adjacent to the stream channel. Both qualitative and quantitative habitat measures for in-stream cover were lower at Site 3 in comparison to other Mud Creek monitoring sites (Figure 13). The low scores for percent cover at Site 3 are likely related to the lack of cover provided by streambanks (no tall vegetation or undercut banks), a lack of large substrate (boulder, cobble), and the general lack of emergent and submergent aquatic macrophytes.



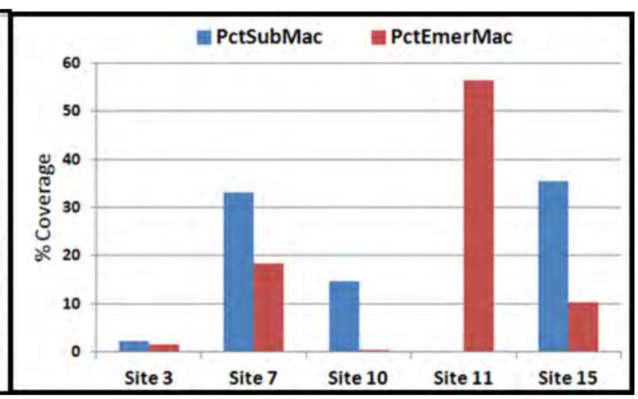


Figure 13. Habitat scores for in-stream cover (left) and percent submergent and emergent macrophytes (right) at biological monitoring stations

Emergent and submergent macrophytes are important as a form of fish cover in headwaters streams. These plants provide important structural supports in stream and river habitats, and are influential in terms of primary food production, nutrient/pollutant attenuation, and habitat for a wide-range of macro and microorganisms living in and around lotic sites. Site 3 within the impaired reach of Mud Creek had very low densities of emergent and submergent plant life. Triest (2006) found that there were significantly negative correlations between fine particle sizes and macrophyte abundance. The substrate at Site 3 is dominated by fine particles, which are likely preventing or limiting the growth of emergent and submergent aquatic plants.

Strength of evidence summary

The lack of suitable cover at Site 3 is likely limiting fish abundance and diversity within that reach and contributing to the impaired condition. The amount and quality of in-stream cover for fish and macroinvertebrates will likely improve if implementation activities are directed towards restoring riparian function and stabilizing the streambed and stream channel. This is especially the case for the reaches of Mud Creek where cattle and other livestock have unrestricted access to the stream.

Table 13. Strength of evidence scoring for Candidate Cause 2-Loss of habitat from Riparian Corridor disturbance

Types of Evidence	**07030004-566 (F-IBI / M-IBI Impairments)**
Spatial/temporal co-occurrence	+
Temporal sequence	0
Field evidence of stressor-response	++
Causal pathway	++
Evidence of exposure, biological mechanism	+
Field experiments /manipulation of exposure	NE
Laboratory analysis of site media	NE
Verified or tested predictions	+
Symptoms	+
Mechanistically plausible cause	+
Stressor-response in other lab studies	NE
Stressor-response in other field studies	+
Stressor-response in ecological models	NE
Manipulation experiments at other sites	NE
Analogous stressors	+
Consistency of evidence	**+**
Explanatory power of evidence	**++**

3.3 Candidate cause 3-low dissolved oxygen

Dissolved oxygen (DO) refers to the concentration of oxygen gas within the water column. Low or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species (Davis, 1975; Nebeker et al., 1991). DO concentrations change seasonally and daily in response to shifts in ambient air and water temperature, along with various chemical, physical, and biological processes within the water column. If dissolved oxygen concentrations become limited or fluctuate dramatically, aerobic aquatic life can experience reduced growth or fatality (Allan, 1995). Many species of fish avoid areas where dissolved oxygen concentrations are below 5 mg/L (Raleigh et al., 1986).

Sources and pathways of low dissolved oxygen

The dissolved oxygen regime of streams is driven by a combination of natural and anthropogenic factors. Natural background characteristics of a watershed, such as topography, hydrology, climate, and biological productivity can influence the dissolved oxygen regime of a waterbody. Agricultural and urban land-uses, impoundments (dams), and point-source discharges are examples of anthropogenic factors that can cause unnaturally high, low, or volatile DO concentrations. A generalized conceptual model for low dissolved oxygen as a candidate stressor is shown in Figure 14. Several of the sources in the model are not applicable in the Mud Creek Watershed (e.g. urbanization, industry, and mining). Plausible sources for low dissolved oxygen in the Mud Creek Watershed include channel alteration, agricultural land-uses, wetlands, reservoir conditions (Mud Lake), and forestry practices.

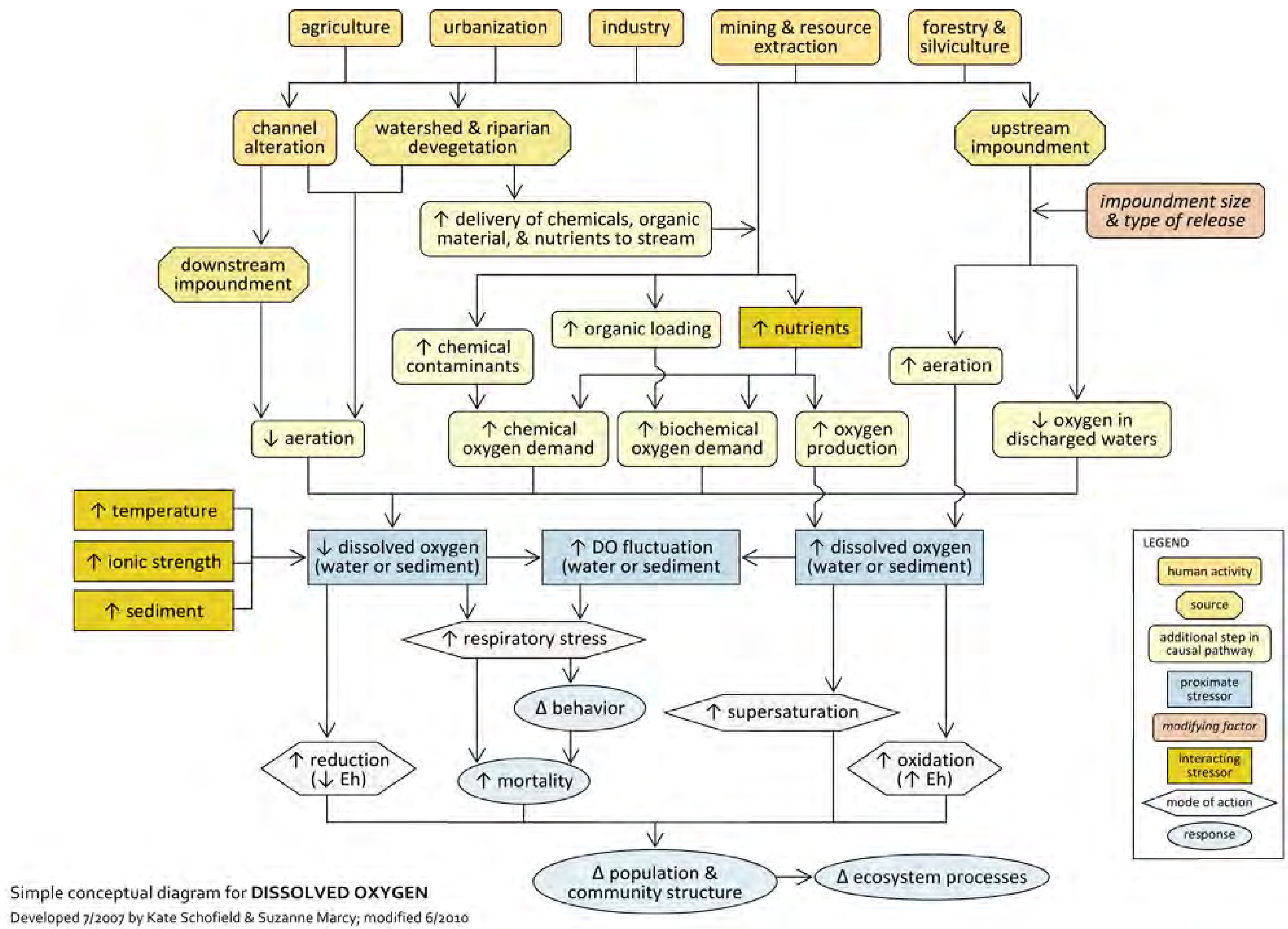


Figure 14. General conceptual model for dissolved oxygen as a candidate cause for impairment

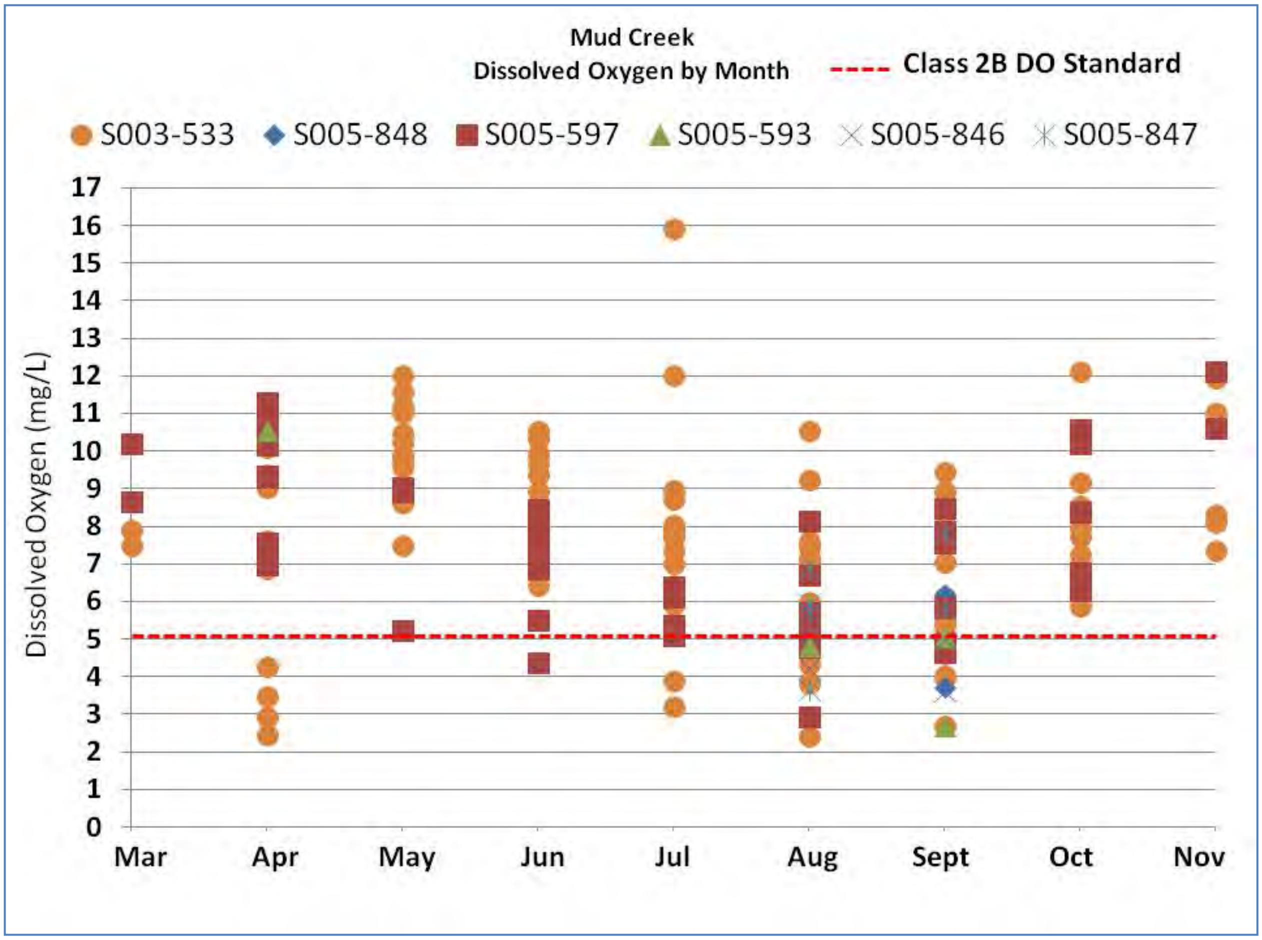
Discussion of dissolved oxygen data

1. Point 1

   Instantaneous dissolved oxygen data is available for several Mud Creek sites and can be used as an initial screening for low dissolved oxygen conditions. These measurements represent discrete point samples, which are usually collected in conjunction with surface water sample collection. Because DO concentrations can vary significantly as a result of changing flow conditions and time of sampling, instantaneous measurements need to be used with caution and are not completely representative of the DO regime at a given site.

   Instantaneous dissolved oxygen data for the Mud Creek mainstem is summarized by monitoring site and calendar month in Figure 15. DO concentrations below the 5 mg/L water quality standards were observed throughout the watershed, although there is limited data available for several sites. Two sites in the watershed have robust instantaneous DO data sets; site 7 (near the inlet to Mud Lake) and Site 15 (near the mouth of Mud Creek). About 10 percent of the DO readings at Site 7 were below 5 mg/L. Site 10 had a slightly higher rate of readings below 5 mg/L (14 percent). Although duration of time below 5 mg/L cannot be determined from instantaneous readings, these data are an indication that low DO is a plausible stressor that deserves further consideration.

   Most of the low dissolved oxygen readings occur during the months of July, August, and September. Several readings below 5 mg/L were recorded at Site 15 in April. This site is near some expansive wetland areas, and these low DO readings may be the result of these wetlands flushing during snowmelt and releasing water that is low in oxygen.



Location	# DO Readings	< 5 mg/L	% < 5 mg/L
Site 2	4	2	50 %
Site 7	49	5	10 %
Site 8	4	2	50 %
Site 11	4	2	50 %
Site 14	6	1	16 %
Site 15	98	14	14 %

Figure 15. Summary of instantaneous dissolved oxygen measurements available for Mud Creek

2. Longitudinal (synoptic)

A series of synoptic longitudinal synoptic dissolved oxygen surveys were conducted throughout the length of Mud Creek in 2009 and 2010. A synoptic monitoring approach aims to gather data across a large spatial scale and minimal temporal scale. In terms of dissolved oxygen, the objective was to sample a large number of sites from upstream to downstream under comparable ambient conditions. For the most part, the surveys took place in mid to late summer when low dissolved oxygen is most commonly observed. Dissolved oxygen readings were taken at pre-determined sites in late afternoon/evening and early morning in attempt to capture the peak and trough of the diurnal fluctuation.

Monitoring results from the longitudinal DO surveys provide further support for low DO as a stressor in Mud Creek. DO concentrations below the 5 mg/L were observed regularly in all of the reaches that were monitored. Early morning DO concentrations were slightly lower on average, but afternoon measurements were also found to be below 5 mg/L with regularity. Severely low DO concentrations (below 2 mg/L) were observed at Site 16 and site 8 in July 2010. Site 16 is located at the mouth of Mud Creek, an area of the creek that exhibits many wetland qualities, which may be responsible for the low DO concentration, observed at that location. Site 8 is at the outlet of Mud Lake, which is eutrophic and currently listed as impaired for excess nutrients. A noticeable drop in DO concentration was observed at this location during the September 2009, and July 2010 longitudinal surveys.

3. Continuous dissolved oxygen monitoring results

Continuous dissolved oxygen surveys were conducted at a selection of Mud Creek sites in 2007, 2008, and 2009. The goal of these surveys was to observe 24-hr (diurnal) fluctuations in dissolved oxygen concentration and observe daily maximum and minimum concentrations. Another benefit of diurnal DO data is the ability to quantify the duration of time that a given site violated the dissolved oxygen water quality standard of 5 mg/L, if a violation occurs.

Diurnal dissolved oxygen measurements were collected by deploying YSI 6920 multi-parameter sondes in representative locations within selected river reaches. "Representative" means that the sample locations had adequate flow (no backwater areas) and stream substrate conditions were similar to those found within the rest of the reach. The YSI Sondes were calibrated prior to deployment and set to log stream temperature, specific conductivity, pH, turbidity, and dissolved oxygen at 15-minute intervals. Sondes were deployed for an average duration of 2.8 days (max = 3.8 days; min = 1.8 days).

The majority of DO measurements collected during continuous monitoring were above the 5 mg/L dissolved oxygen standard. DO concentrations at site 15 dipped slightly below 5 mg/L for a duration of about 3 hours on September 1, 2011. All of the continuous measurements recorded during the June 2009 showed adequate DO concentrations for support of a diverse fish and macroinvertebrate assemblage.

DO flux was within a suitable range for aquatic life. The largest gap between maximum and minimum DO concentrations was 3.62 mg/L, recorded at Site 7 in August 2011. Based on this limited data, it does not appear that DO flux is stressor to aquatic life in Mud Creek.

The continuous DO data for Mud Creek provided results that are contradictory to those taken from longitudinal synoptic monitoring in that there were very few sub 5-mg/L measurements recorded. The timing of the June 2009, continuous monitoring period was probably too early in the season to observe low DO conditions in the creek. The instantaneous data from June shows only one measurement below 5 mg/L. The frequency of measurements below 5 mg/L is much higher during months of July, August, and September. DO concentrations dipped slightly below 5 mg/L for a short duration of time (three hours) during the August 2011 continuous monitoring period.

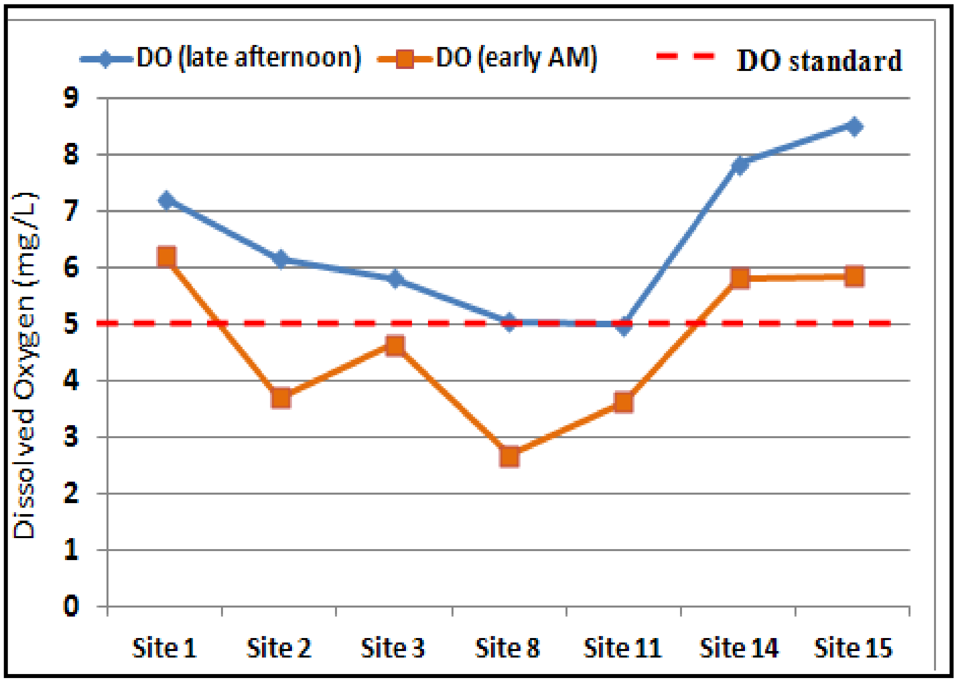


Figure 16. Longitudinal dissolved oxygen survey of Mud Creek--August 25th and 26th of 2009

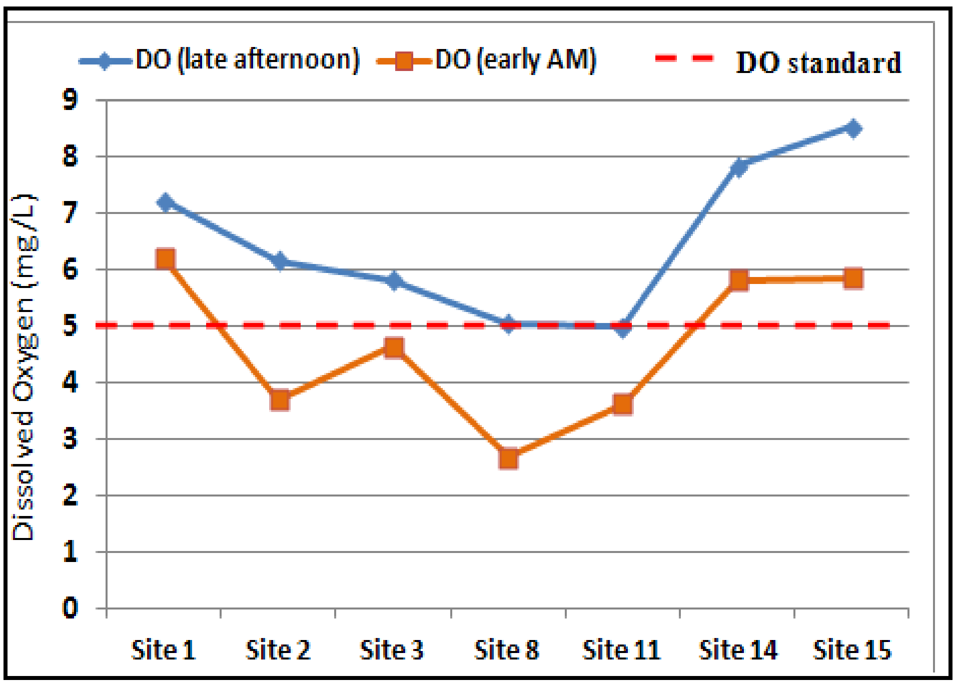


Figure 17. Longitudinal dissolved oxygen survey of Mud Creek--September 22nd, 2009

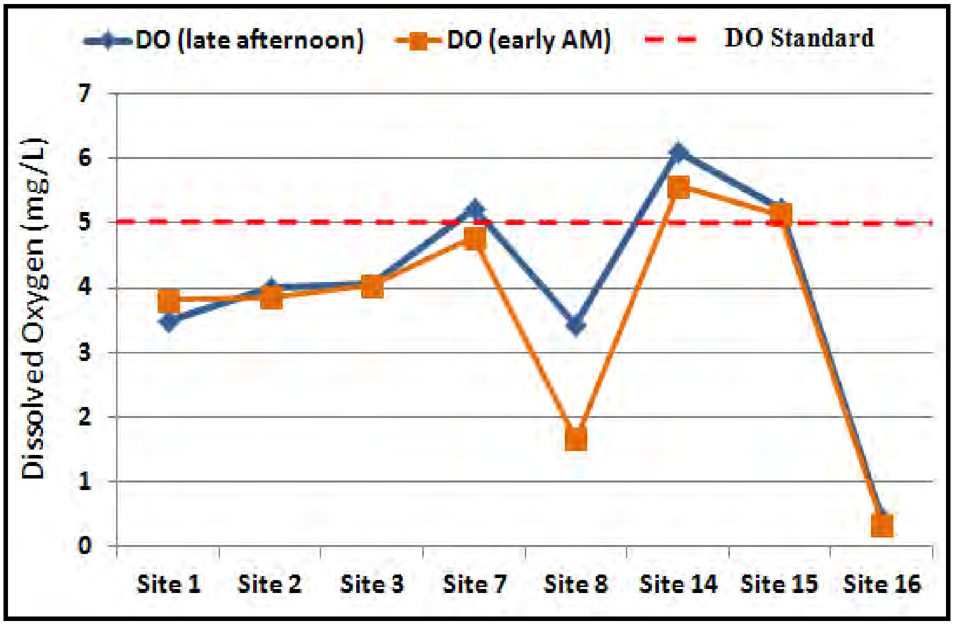


Figure 18. Longitudinal dissolved oxygen survey of Mud Creek--July 7th and 8th, 2010

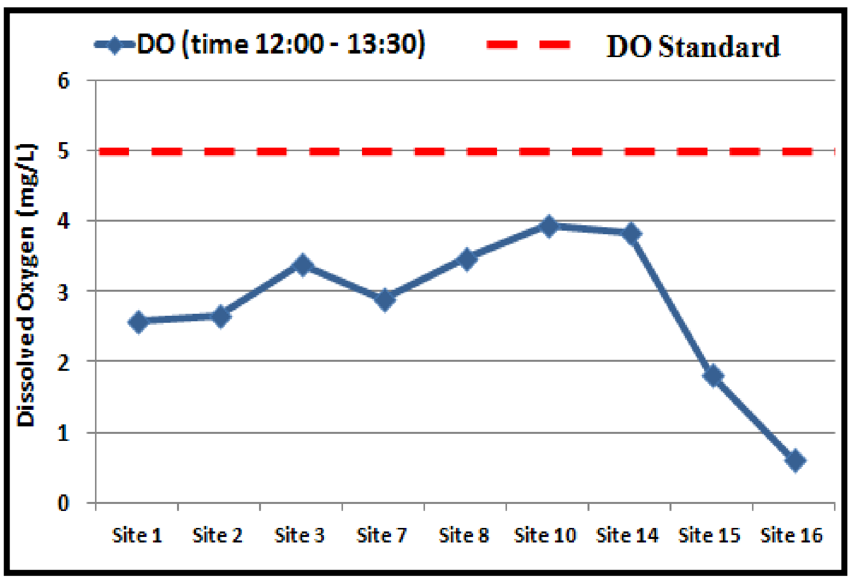
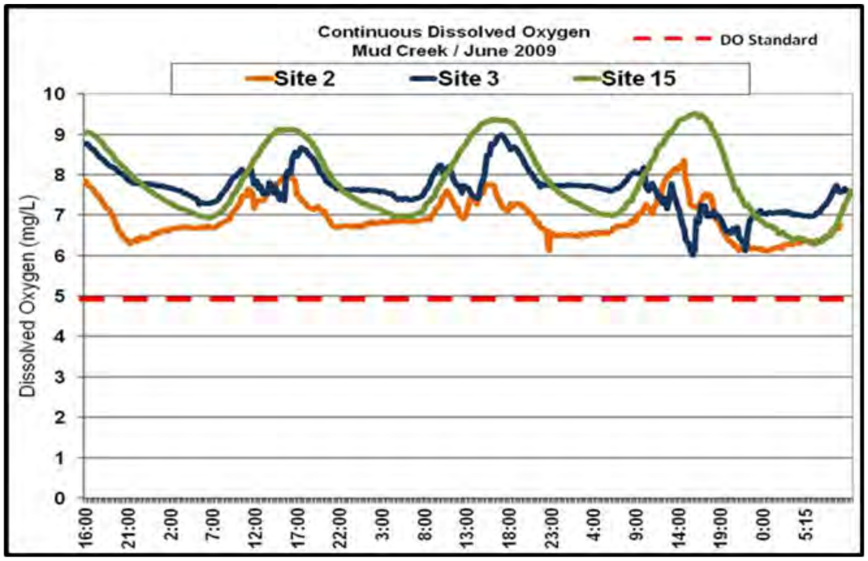
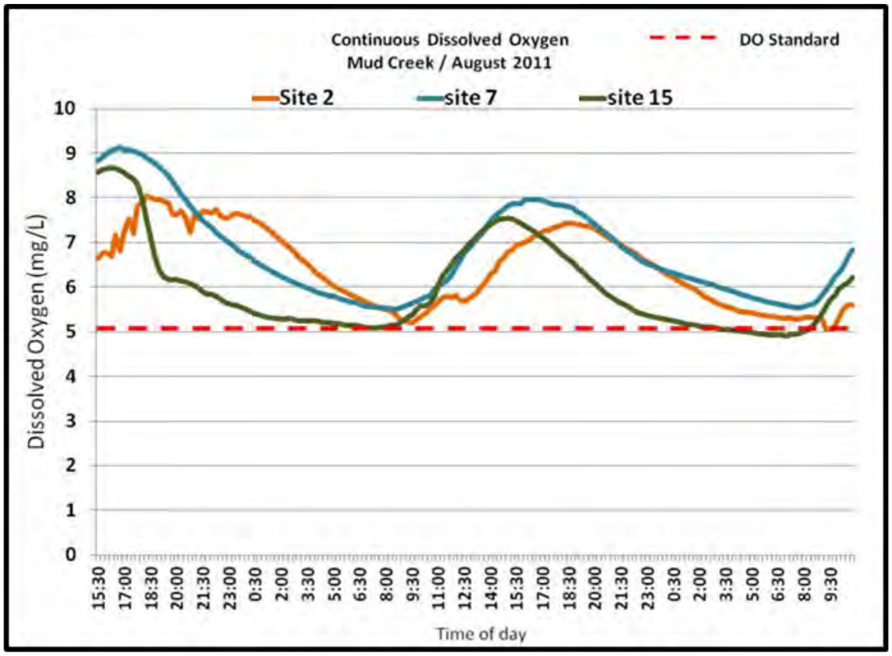


Figure 19. Longitudinal dissolved oxygen survey of Mud Creek--August 20th, 2010



Site	# Readings	Min (mg/L)	Max (mg/L)	% readings below 5 mg/L	Avg. Duration below 5 mg/L (hours)	Max Duration below 5 mg/L (hours)	Avg. 24-hr Flux (mg/L)
2	358	6.10	8.35	0	0	0	1.93
3	361	6.02	9.00	0	0	0	1.92
15	363	6.28	9.52	0	0	0	2.35

Figure 20. Continuous dissolved oxygen survey of Mud Creek--June 2009



Site	# Readings	Min (mg/L)	Max (mg/L)	% readings below 5 mg/L	Avg. Duration below 5 mg/L (hours)	Max Duration below 5 mg/L (hours)	Avg. 24-hr Flux (mg/L)
2	174	5.05	8.03	0	0	0	2.98
7	174	5.50	9.12	0	0	0	3.62
15	174	4.91	8.68	6.8%	3	3	3.60

Figure 21. Continuous dissolved oxygen survey of Mud Creek--August 2011

Causal analysis-biological response to low dissolved oxygen

Dissolved oxygen concentrations in the impaired reach of Mud Creek are routinely below the Class 2B standard. Below, several biological indicators of low dissolved oxygen were evaluated to better understand the cause and effect relationships between these conditions and aquatic life in Mud Creek. The scores for these metrics are summarized in Table 14.

1. Lack of sensitive Fish Taxa
   Sites 3 and 7 exhibited a general lack of sensitive fish taxa and low overall taxa richness of headwaters minnow species. These two sites scored a 0 / 10 and 2.5 / 10 for the fish metric that focuses on sensitive species. The fish community at Site 3 was dominated by central mudminnow (Umbra limi); a species that is known to be tolerant of low dissolved oxygen conditions (Becker, 1983). Central mudminnow was also the most abundant fish species collected at Site 7.
2. Low fish abundance
   Both Sites 3 and 7 scored very low in the fish metric NumPerMeter-Tolerant; which is a measure of fish density (# fish/meter) excluding tolerant fish species. Although this metric could be responsive to a variety of stressors, it is likely that the sustained low DO conditions observed within this reach limit fish population size, especially those species that are not considered tolerant of those conditions.

Table 14. Selection of fish and macroinvertebrate metrics that can show sensitivity to low dissolved oxygen

Metric	Metric Type	Site 3 Metric Score (out of 10)	Site 7 Metric Score (out of 10)	Low DO Response
NumPerMeter-Tolerant	fish	2.4	0.5	Yes
Sensitive	fish	2.4	0.0	Yes
TolTxPct	fish	10.0	10.0	No
POET	Invertebrate	5.7 / 4.3	8.6	No
Intolerant2ch	Invertebrate	0.0 / 0.0	5.0	Only at site 3

3. Lack of sensitive macroinvertebrate taxa
   Intolerant macroinvertebrate taxa are absent, or present in very low numbers at Site 3. Metric scores for ***Intolerant2ch***, which measures the taxa richness of were 0 / 10 or both sampling events. Site 7, further downstream on the impaired reach of Mud Creek, scored a 5/10 in this metric. Most of the data collected indicate slightly higher DO concentrations at this site, so it is possible that the effects are less severe at this location.

4. POET (Plecoptera, Odonata, Ephemeroptera, Trichoptera)
   Some macroinvertebrate taxa from these orders can be sensitive to low DO conditions (Marcy, 2010). Despite the low dissolved oxygen levels seen throughout the creek, all sites had moderate to high scores in this metric, including the two sites on the impaired reach (Site 3 and Site 7). These results can be misleading due to the fact that there are a wide variety of tolerance levels for specific taxa within the POET orders. For example, individuals from the order Plecoptera (stoneflies), which are very sensitive to low DO conditions, were not found at all throughout the entire length of Mud Creek. Tricoptera (caddisfly) and Odonata (dragonfly) taxa were present in low numbers. The moderately high POET metric scores at Site 3 were the result of good numbers or common mayfly taxa that are somewhat tolerant to disturbance.
5. TolTxPct
   Tolerant fish taxa made up 27 percent of the fish community at Site 3 and 22 percent at Site 7. Metric scores were high (10/10 at both sites), but as previously mentioned, central mudminnow was the most abundant fish species found at both of these sites.

Strength of evidence summary

Low dissolved oxygen concentrations are likely limiting the diversity of fish and macroinvertebrates within the impaired reach and throughout Mud Creek (Table 15), although the effects of this stressor may be less severe than some of the others that have been identified (e.g. deposited fine sediment). Analysis of the dissolved oxygen and biological data suggests that Mud Creek does not possess the dissolved oxygen regime to support sensitive fish and macroinvertebrate species on a year-round basis. However, neither the DO data nor the biological monitoring results suggest that Mud Creek is ***severely*** limited in dissolved oxygen.

Table 15. Strength of evidence scores for Candidate Cause 3-low dissolved oxygen

Types of Evidence	07030004-566 (F-IBI / M-IBI Impairments)
Spatial/temporal co-occurrence	+
Temporal sequence	0
Field evidence of stressor-response	+
Causal pathway	++
Evidence of exposure, biological mechanism	+
Field experiments /manipulation of exposure	NE
Laboratory analysis of site media	NE
Verified or tested predictions	+
Symptoms	+
Mechanistically plausible cause	+
Stressor-response in other lab studies	++
Stressor-response in other field studies	+
Stressor-response in ecological models	NE
Manipulation experiments at other sites	NE
Analogous stressors	+
Consistency of evidence	**+**
Explanatory power of evidence	**0**

3.4 Candidate Cause 4-loss of connectivity and altered hydrology

The connectivity of a stream refers to the flow, exchange and pathways that move organisms, energy and matter throughout the watershed system (MN DNR Watershed Assessment Tool). These interactions create complex, interdependent processes that vary over time. Stream connectivity can be described in four dimensions:

- longitudinal – linear connectivity
- lateral – floodplain connectivity
- vertical – hyporheic (below the stream bed)
- time – many scales; seasonal, multiyear, generational

The channelization of Mud Creek and many of its tributaries has disrupted the longitudinal connectivity of the watershed. Approximately one-quarter of the mainstem of the creek and nearly 100 percent of all tributaries have been channelized. While ditches can provide important drainage and flood control functions in agricultural landscapes, ecological services are often lost when previously natural channels become modified for these purposes (Allan, 1995). Schlosser (1982) compared the trophic structure, reproductive success, and growth rate in fishes from a natural and modified (ditched) stream in central Illinois. The study found that the ditched stream experienced a loss of pool habitat, increased organic substrates, and a shift in trophic structure to omnivores and herbivores in place of insectivores and piscivores. The high rate of channelization in the Mud Creek watershed is likely reducing the amount of quality habitat available to aquatic life, and is limiting the movement of aquatic organisms throughout the system.

In addition, the ditch network located in the headwaters of Mud Creek drains many wetland and bog areas and is likely reducing hydrologic storage in the watershed. The following are some of the observed hydrological impacts of ditching (material taken verbatim from MDNR Watershed Assessment Tool):

(1*) Wetland removal, ditch construction, stream rechanneling, tile drainage, and other human activities to alter landscapes for other uses have come at the costs of increased peak flows, lower base flows, and increased nutrient and sediment concentrations in streams, rivers, and lakes (Mitch and Gosselink, 2007)*

(2) Water quality usually is degraded when storage is removed, and improved when storage is added (Zedlar, 2003; Kovacic et al., 2006; Mitsch and Day, 2005).

Strength of evidence summary

Without a long-term flow gauging station it is difficult to determine the extent that ditching has altered hydrologic connectivity, but based on the amount of ditching in the headwaters reaches and tributary streams, it is very likely that streamflow patterns have been altered from their natural state (Table 16). Further evaluation of hydrological alteration is recommended using available flow data and hydrologic models.

Table 16. Strength of evidence scores for Candidate Causes 4 and 5--loss of connectivity and hydrology

Types of Evidence	**Loss of Connectivity**	**Altered Hydrology**
Spatial/temporal co-occurrence	0	+
Temporal sequence	NE	NE
Field evidence of stressor-response	0	0
Causal pathway	0	0
Evidence of exposure, biological mechanism	0	0
Field experiments /manipulation of exposure	NE	NE
Laboratory analysis of site media	NE	NE
Verified or tested predictions	NE	NE
Symptoms	0	0
Mechanistically plausible cause	+	+
Stressor-response in other lab studies	0	NE
Stressor-response in other field studies	+	+
Stressor-response in ecological models	+	+
Manipulation experiments at other sites	NE	NE
Analogous stressors	+	+
Consistency of evidence	**0**	**0**
Explanatory power of evidence	**0**	**0**

Section IV. Stressor ID Summary/Recommendations

4.1 Summary

A summary of strength of evidence (SOE) scores for the five candidate causes for impairment are listed in Table 17. Deposited and bedded sediments (DBS) emerged as the candidate cause with strongest and most consistent supporting evidence, followed by low dissolved oxygen and loss of riparian function. Several of the candidate causes listed in this table are inter-related through various watershed processes, so even the candidate causes with lower SOE scores may need to be addressed in efforts to restore biological integrity to the watershed.

4.2 Recommendations

Based on the SOE results, it is recommended that a total maximum daily load (TMDL) and implementation plan be developed for clean sediment and low dissolved oxygen. Although the existing biological impairment is limited to the upper 1/2 of the Mud Creek Watershed, a watershed wide evaluation of sediment and dissolved oxygen is recommended to further understand these stressors, along with the sources and pathways involved.

SOE results also suggest that the loss of riparian function in some reaches of Mud Creek is also contributing to the biological impairments. Although some of the effects of this stressor are unrelated to increased sedimentation (e.g. lack of fish cover, decreased canopy cover), it is likely that many of the impacts of riparian degradation will be addressed in the sediment TMDL. Erosion of streambanks and sparsely vegetated or non-vegetated riparian areas appear to be a major source of the sediment entering Mud Creek. A separate TMDL for loss of riparian function is not recommended, but an emphasis on riparian condition must be included in the sediment TMDL and implementation plans.

Loss of connectivity remains a probable candidate cause for impairment in the Mud Creek watershed. However, given the limited data available to evaluate these potential stressors through the SOE process, the magnitude and extent of impacts to watershed connectivity are difficult to determine. The ditching of the headwaters (upper 1/3 of the entire creek) and a significant amount of the tributaries reduce the amount of quality habitat available for fish and macroinvertebrates and likely limit their movement throughout the watershed.

Additional flow data or a hydrological model is needed to evaluate altered hydrology as a potential cause of biological impairment. Long-term hydrological datasets are not available to compare the hydrograph of Mud Creek pre and post-watershed and stream-channel alterations. A TMDL for flow alteration is not recommended at this time, but if initial restoration efforts are unsuccessful, altered hydrology should be further evaluated as a candidate cause for impairment.

Table 17. Final strength of evidence scoring for all candidate causes

	Candidate Causes for Impairment				
Types of Evidence	Deposited and Bedded Sediments	Low Dissolved Oxygen	Loss of Riparian Function	Loss of Connectivity	Altered Hydrology
Spatial/temporal co-occurrence	+	+	+	0	+
Temporal sequence	0	0	0	0	NE
Field evidence of stressor-response	+	+	++	0	0
Causal pathway	++	++	++	0	0
Evidence of exposure, biological mechanism	+	+	+	0	0
Field experiments /manipulation of exposure	NE	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE	NE
Verified or tested predictions	+	+	+	0	0
Symptoms	+	+	+	0	0
Mechanistically plausible cause	+	+	+	+	0
Stressor-response in other lab studies	NE	++	NE	NE	NE
Stressor-response in other field studies	++	+	+	+	+
Stressor-response in ecological models	+	+	NE	NE	+
Manipulation experiments at other sites	NE	NE	NE	NE	NE
Analogous stressors	++	+	+	+	+
Consistency of evidence	+	+	+	0	0
Explanatory power of evidence	0	0	++	0	0

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Appendices

Appendix A Stressor ID Reconnaissance (SIDR) Screening-Physical Impacts

	Stressor ID Recon (SIDR) – Physical **Land Uses (SOURCES)**	STREAMFLOW / STREAM POWER				LANDCOVER ALTERATION		RIPARIAN	CHANNEL STABILITY					CONNECTIVITY	
		Streamflow changes (magnitude/ timing/ duration)	Surface/ sub-surface slope hydrology	Clear water discharge	Stream power change	Surface disturbance (% bare ground/ compaction)	Loss of stream buffers	Riparian vegetation change (composition / density)	Direct channel impacts that destabilize channel	Altered dimension, pattern and profile	Excess sediment deposition/ supply (agradation)	Streambed scour / channel incision (degradation)	Large woody debris in channel	Floodplain encroachment channel confinement	Loss of connectivity (fish passage, nutrient cycling, etc.)
A	Urban development	D / L	D / L	D / L	D / L	D / L	D / L	D / L	D / L	D & I / L	I / L	I / L	I / L	D & I / L	D & I / L
B	Logging	D / L	D / L	NR	I / L	D / L	D / L	D / L	D / L	I / L	D & I / L	I / L	D & I / L	NR	I / L
C	Agricultural	D / L	D / L	NR	D / L	D / M	D / H	D / H	D / H	D & I / H	D & I / H	D & I / M	I / H	D / M	D & I / M
D	Channelization	D / H	D / M	NR	D / H	NR	D / X	D / X	D / H	D / H	D & I / H	D / H	I / H	D / H	I / H
E	Flood control, dredging, levees	X	X	X	X	X	X	X	X	X	X	X	X	X	X
F	Reservoir storage, hydropower	X	X	X	X	X	X	X	X	X	X	X	X	X	X
G	Diversions, depletions (-) Imported (+)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
H	Grazing	I / L	D / L	NR	I / L	D / M	D / H	D / H	D / H	D & I / H	D / H	D & I / M	I / H	X	I / L

I	Road Crossings/ Culverts	D / L	D / L	D / L	D / L	D / L	D / L	D / L	D / L	D & I / L	D & I / L	I / L	X	D / L	D / L
J	Mining	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Comments on land-use/land cover categories from chart

A	**Urban development**	Urban and developed areas are scarce within the watershed, with the cities of Quamba (population: 123) and Henriette (population: 61) being the only incorporated communities.
B	**Logging**	Current logging activity is limited
C	**Agricultural**	Pasture / Hay operations common throughout the watershed. Some of these operations are reducing the quality of riparian habitat. Row cropping more common in southern half of watershed.
D	**Channelization**	Significant channelization of headwaters and tributaries.
E	**Flood control, dredging, levees**	No flood control structures in watershed. Beaver dams are common throughout the creek, which likely alter hydrology/gemorphology to some extent.
F	**Reservoir storage, hydropower**	No hydropower activity in this watershed
G	**Diversions, depletions (-) Imported (+)**	None
H	**Grazing**	Cattle operations are common in the watershed. Most of these operations are pasture / hay.
I	**Road Crossings/ Culverts**	The majority of the watershed is rural, so road density is not high. All culverts/bridges were evaluated on the mainstem of Mud Creek and were sufficient for fish passage.
J	**Mining**	A few small gravel pits are located within the watershed. These are small operations and they are not located within the riparian corridor of Mud Creek or tributaries.

Appendix B Stressor ID Reconnaissance (SIDR) screening-water quality

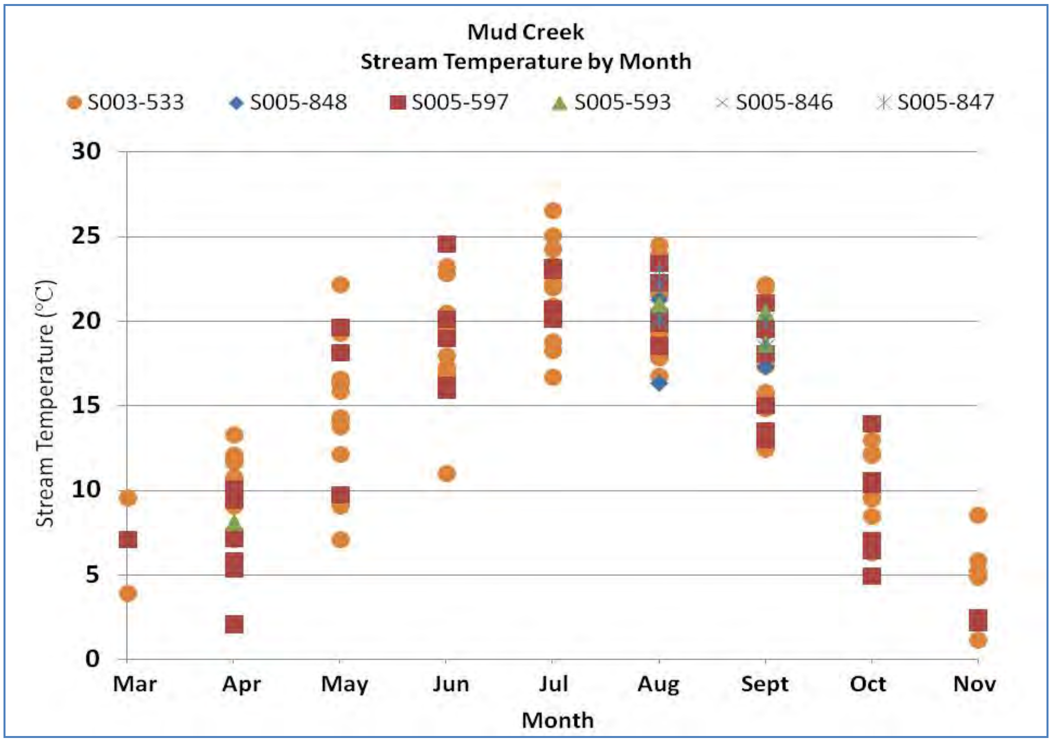
Stressor ID Recon (SIDR) – Water Quality

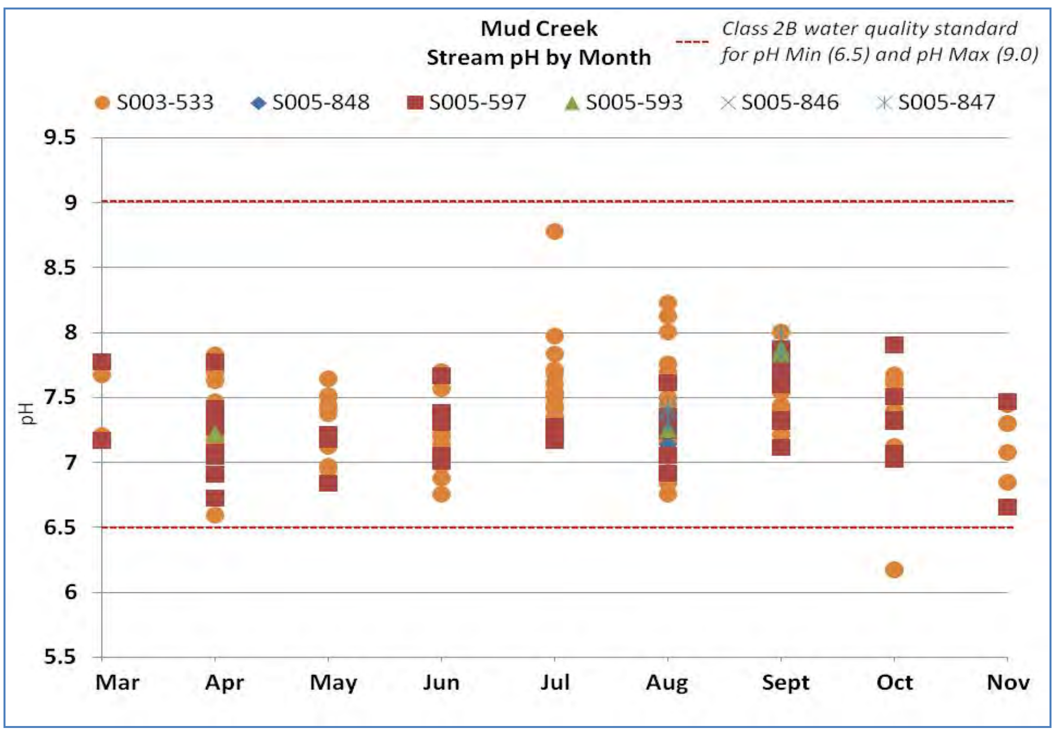
Land Uses (SOURCES)	Potential Water Quality Stressors: Increased TSS / Turbidity	Increased Nutrient Loading	Low Dissolved Oxygen	Δ Stream Temperature	high / low pH	Chloride Toxicity	Toxicity (Metals)	Toxicity (Nitrate, Ammonia)	Pesticides
Urban development	X	D & I / M	D & I / L	X	X	X	O / X	X	O / X
Point Source Discharge	X	X	X	X	X	X	X	X	O / X
Logging	X	I / L	I / L	X	X	X	X	X	O / X
Agricultural field runoff	X	D & I / M	D & I / M	X	X	X	X	X	O / X
Channelization	X	I / L	I / L	X	X	X	X	X	X
Flood control, clearing, dredging, levees	X	X	X	X	X	X	X	X	X
Reservoir storage, hydropower	X	X	X	X	X	X	X	X	X
Grazing	X	D & I / M	I / M	X	X	X	X	X	O / X
Roads (runoff from gravel or paved roads, road de-icing)	X	D & I / L	I / L	X	X	X	O / X	X	X
Mining	X	X	X	X	X	X	O / X	X	X
Wetlands	X	D / M	D & I / M	X	X	X	O / X	X	X
	Available data do not violate state WQ standards with any regularity. It does not appear that sediment or volatile solids are present in the water column at high enough concentration to cause stress to aquatic life.	Total P concentrations are well above draft river nutrient criteria. Highest concentrations of TP occur during mid-summer months and top out around 0.2 mg/L. Concentrations also elevated in March/April.	DO levels fall below 2B WQ standard of 5.0 mg/L throughout the length of Mud Creek. Low DO is particularly common during August and September. Low DO occurs more frequently upstream of Mud Lake.	Average mid-summer stream temperature is between 20-25 C (68-77 F). This temperature range is adequate for supporting warm and coolwater fish species.	pH ranges from around 6.6 to 8.3 - within state WQ guidelines for supporting warm and coolwater fish / macroinvertebrates.	Chloride levels are well below the state WQ std of 230 mg/L.	No data exists for heavy metals. This stressor is very unlikely given the lack of point sources and urban/ industrial land-uses in the watershed.	Concentrations were all under 0.8 mg/L, with the vast majority of the results below 0.2 mg/L. The maximum Ammonia-N recorded in Mud Creek was 0.14 g/L NO2+NO3 / Ammonia-N do not appear to be problematic in this stream.	No data available for Mud Creek watershed. Existing monitoring data from the greater Snake River watershed does not suggest pesticide toxicity is a candidate cause for impairment.

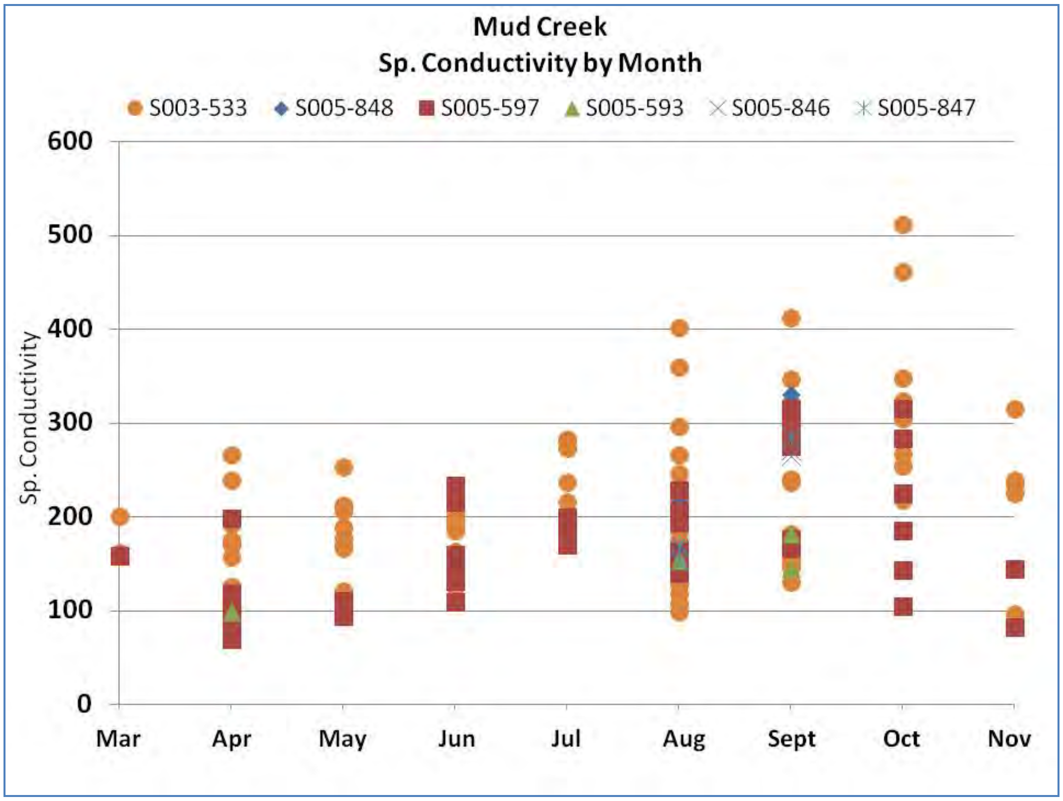
Stressor Pathway	
D	Direct
I	Indirect

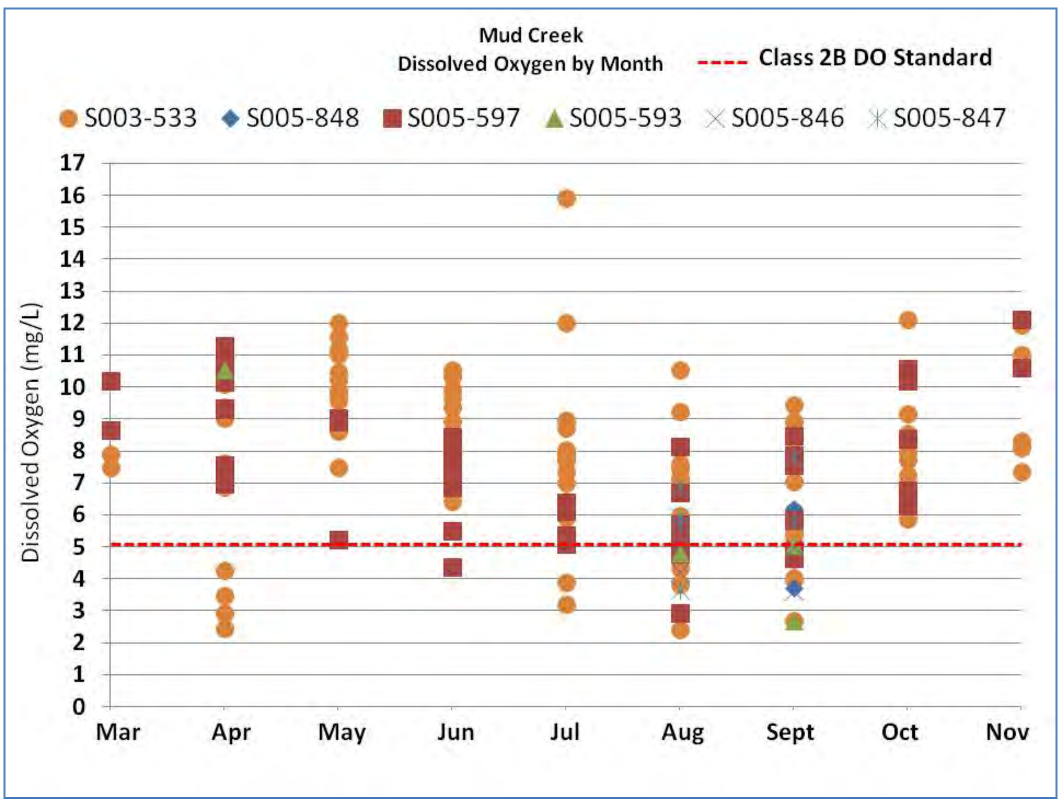
Potential for Impact	
L	Low potential for impact
M	Moderate potential for impact
H	High potential for impact
X	Stressor / Source not present
O	Data not available or lacking

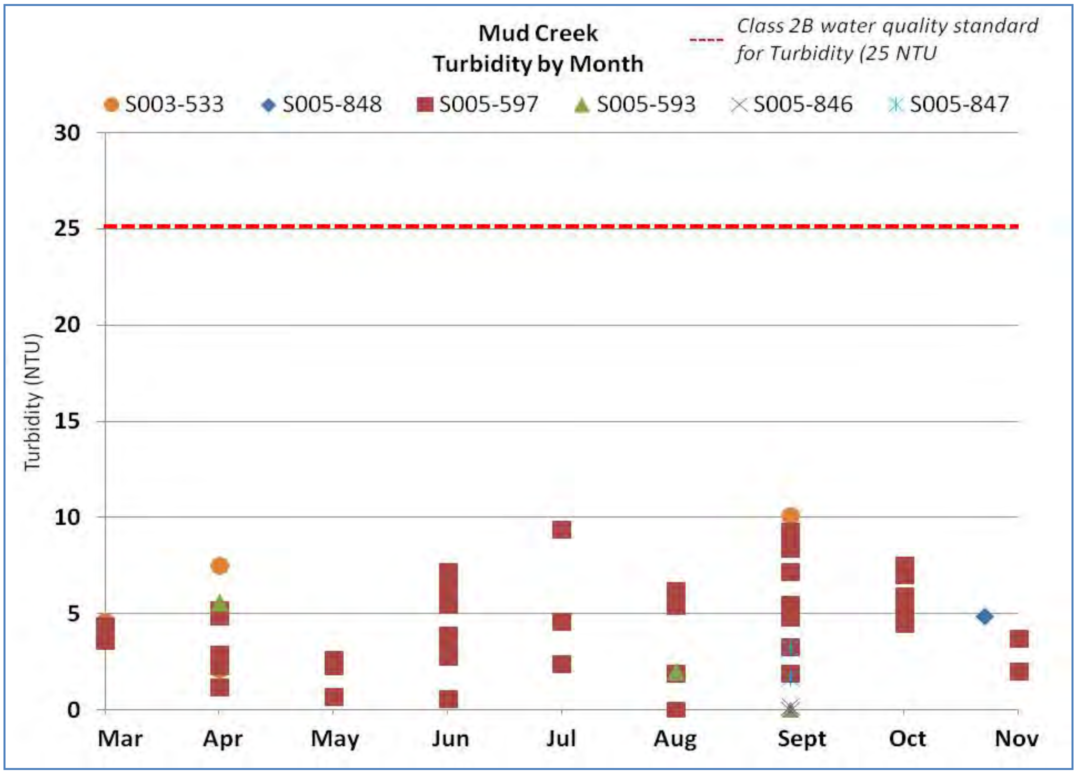
Appendix C Summary of Mud Creek water quality data

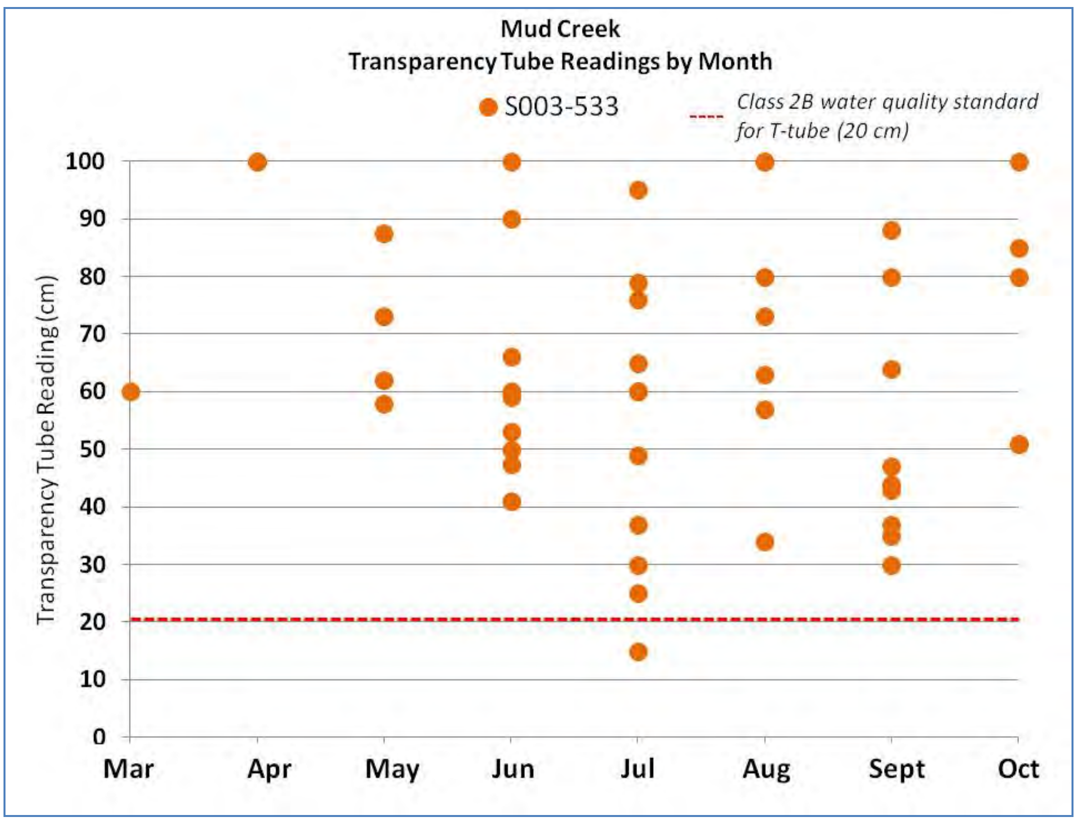

Mud Creek
Stream Temperature by Month
S003-533
S005-848
S005-597
S005-593
S005-846
S005-847
30
25
20
15
10
5
0
Stream Temperature (°C)
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Month

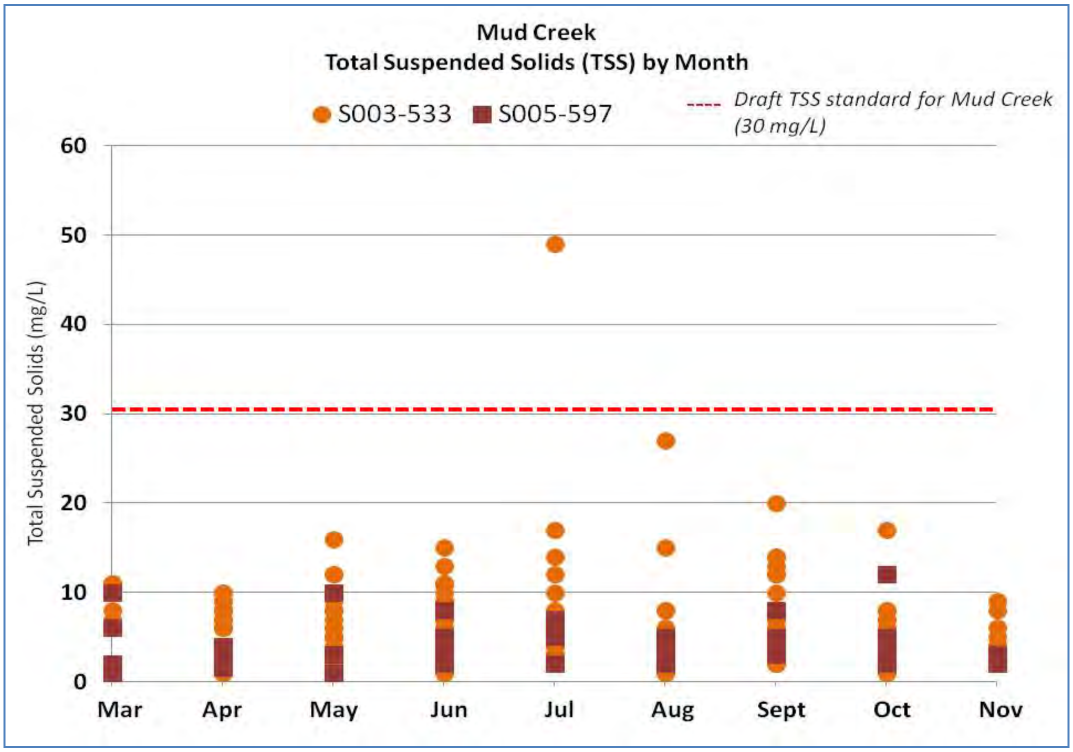

Mud Creek
Stream pH by Month
Class 2B water quality standard for pH Min (6.5) and pH Max (9.0)
S003-533
S005-848
S005-597
S005-593
S005-846
S005-847
9.5
9
8.5
8
7.5
7
6.5
6
5.5
pH
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov


Mud Creek
Sp. Conductivity by Month
S003-533
S005-848
S005-597
S005-593
S005-846
S005-847
Sp. Conductivity
600
500
400
300
200
100
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov

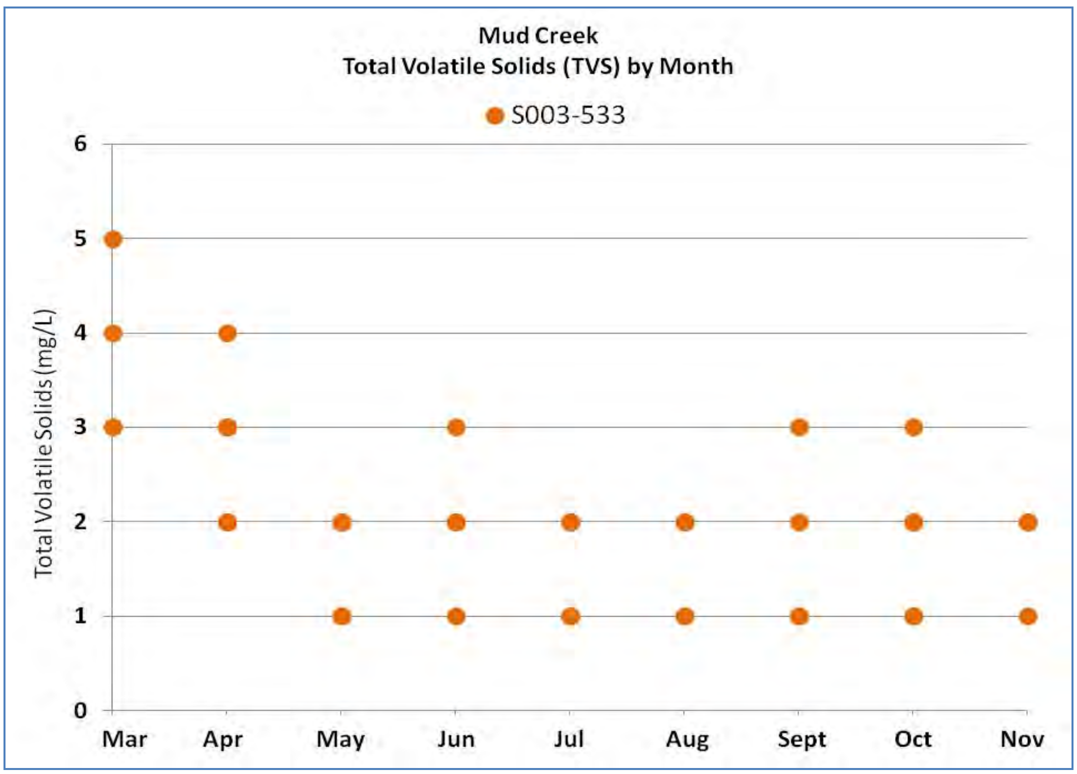

Mud Creek
Dissolved Oxygen by Month
Class 2B DO Standard
S003-533
S005-848
S005-597
S005-593
S005-846
S005-847
Dissolved Oxygen (mg/L)
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov


Mud Creek
Turbidity by Month
Class 2B water quality standard for Turbidity (25 NTU
S003-533
S005-848
S005-597
S005-593
S005-846
S005-847
Turbidity (NTU)
30
25
20
15
10
5
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov

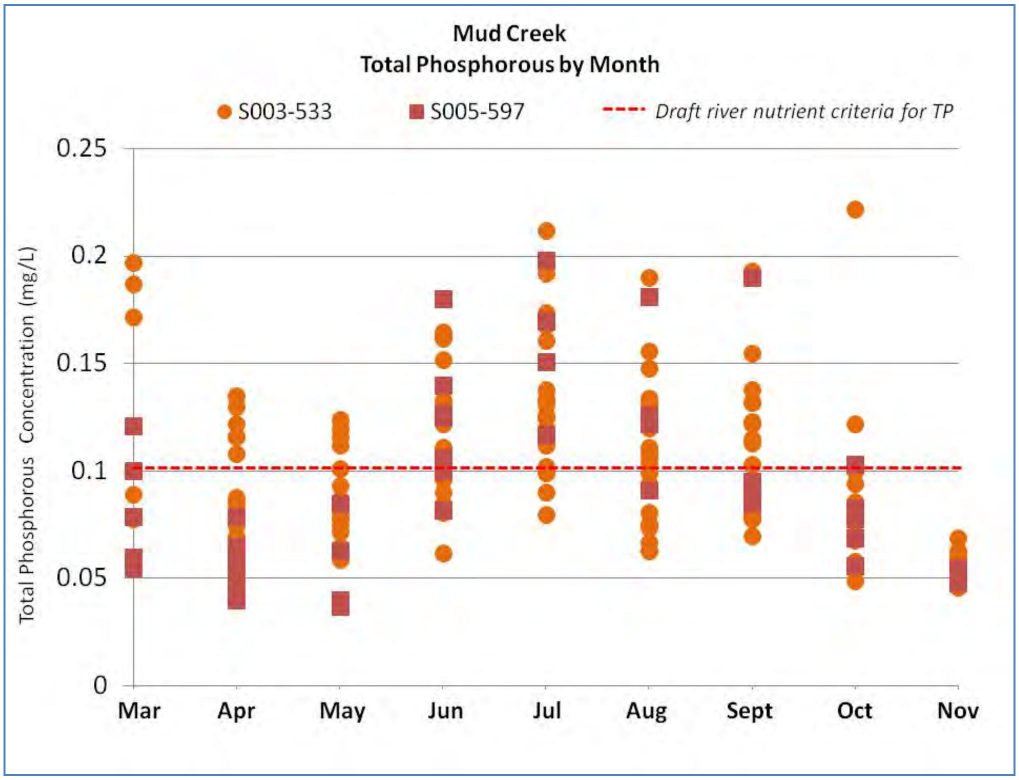

Mud Creek
Transparency Tube Readings by Month
S003-533
Class 2B water quality standard for T-tube (20 cm)
Transparency Tube Reading (cm)
100
90
80
70
60
50
40
30
20
10
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct

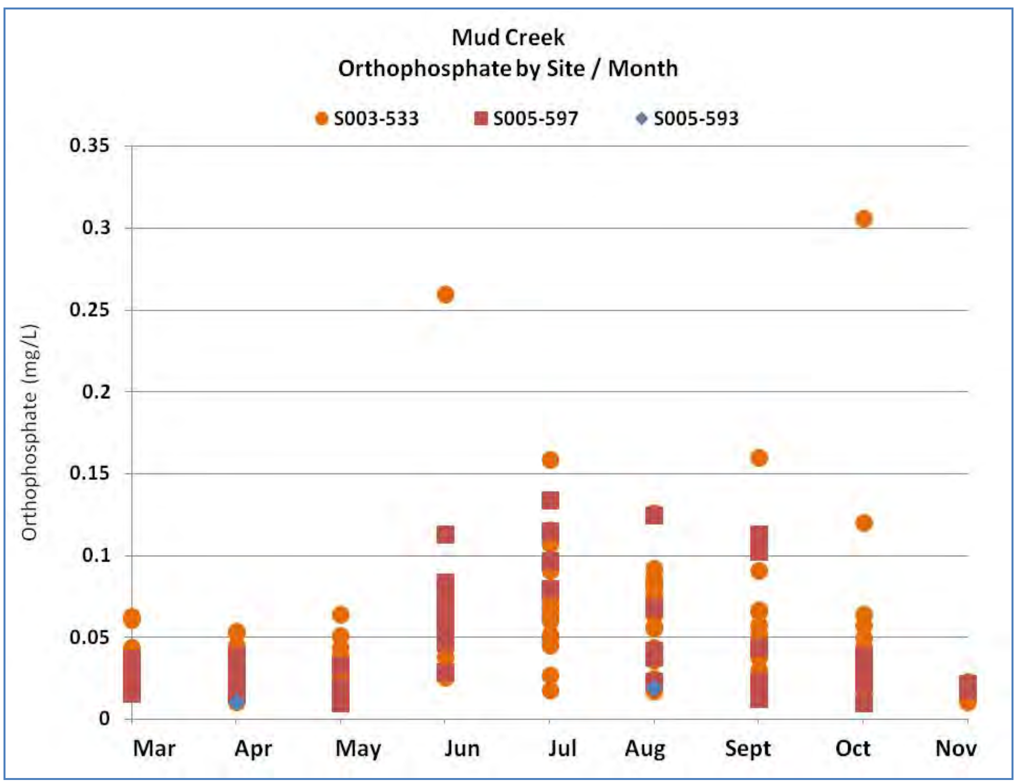


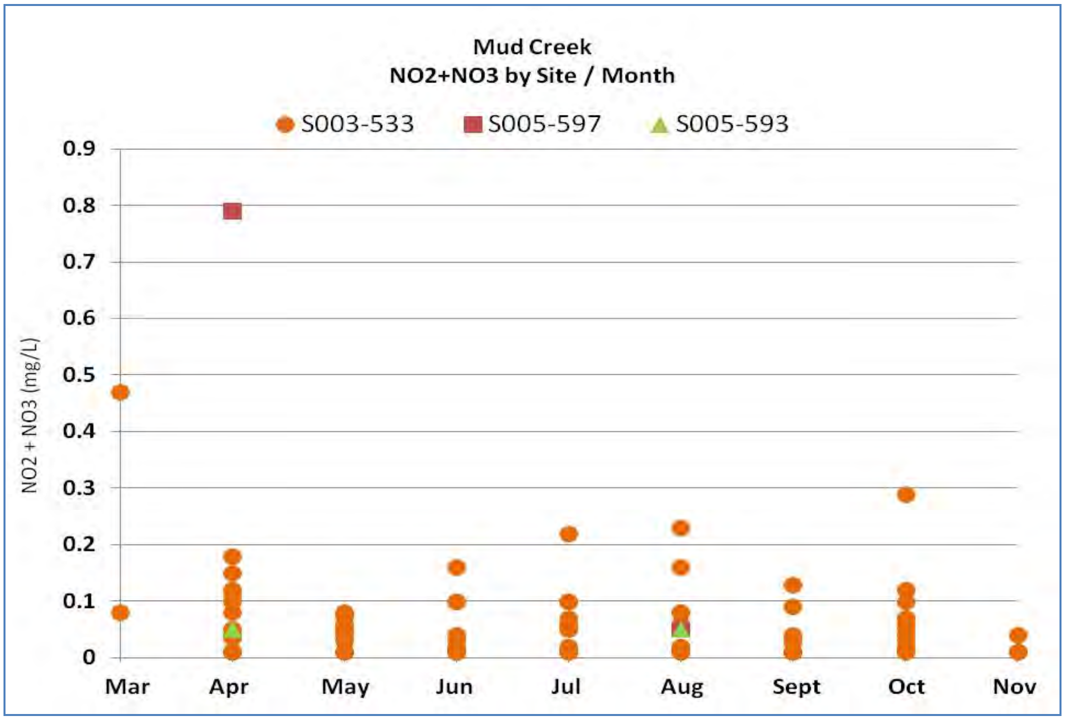
Mud Creek
Total Suspended Solids (TSS) by Month
S003-533
S005-597
Draft TSS standard for Mud Creek (30 mg/L)
Total Suspended Solids (mg/L)
60
50
40
30
20
10
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov

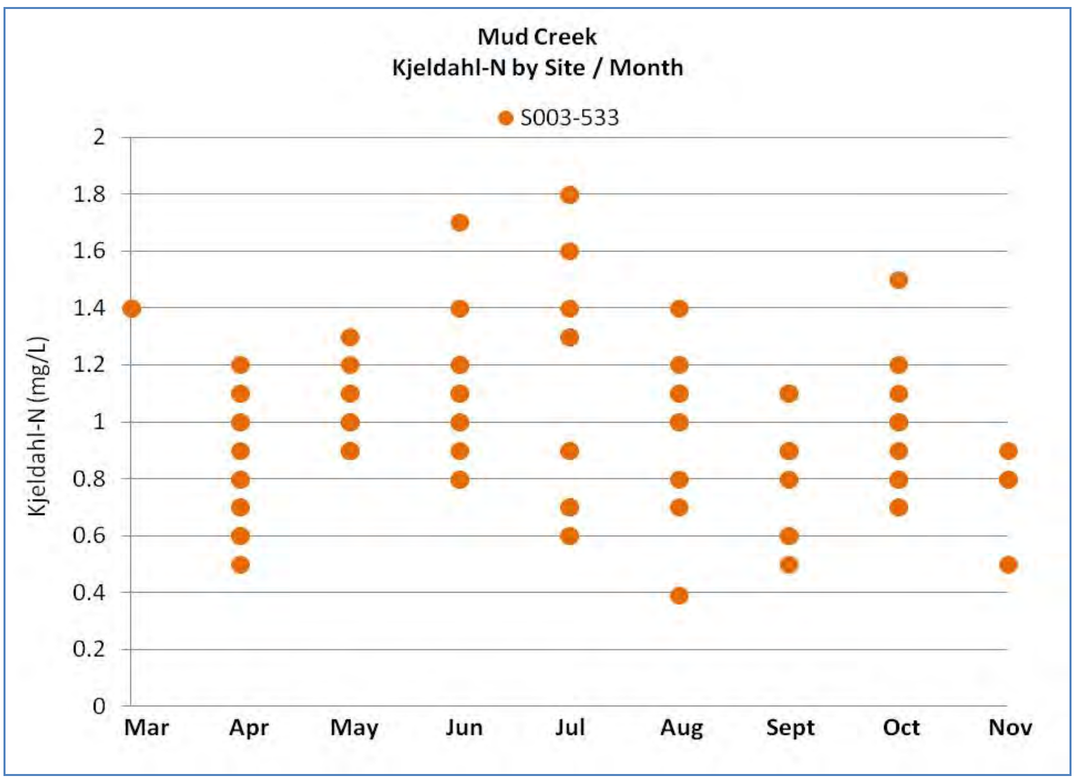


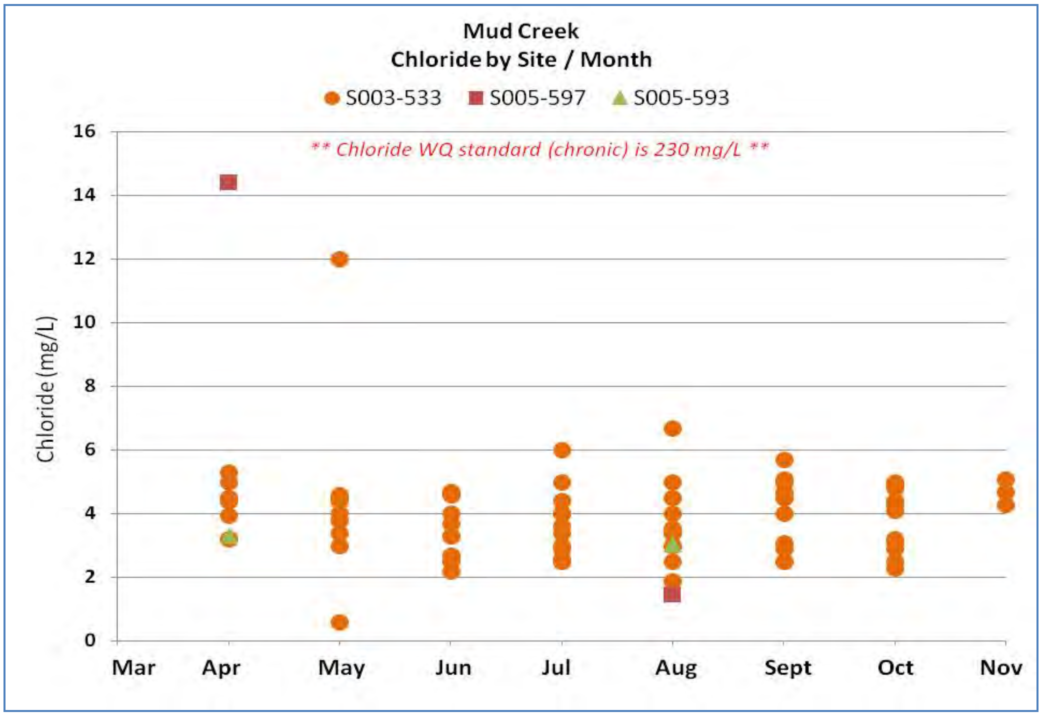
Mud Creek
Total Volatile Solids (TVS) by Month
S003-533
Total Volatile Solids (mg/L)
6
5
4
3
2
1
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov

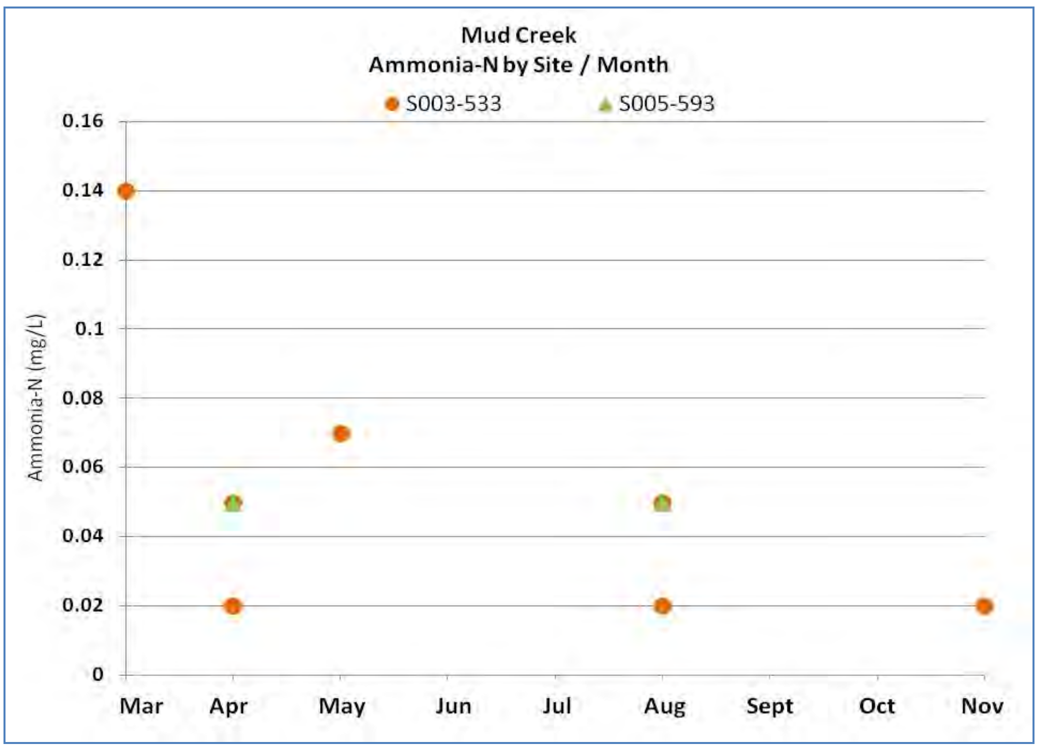

Mud Creek
Total Phosphorous by Month
S003-533
S005-597
Draft river nutrient criteria for TP
Total Phosphorous Concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov

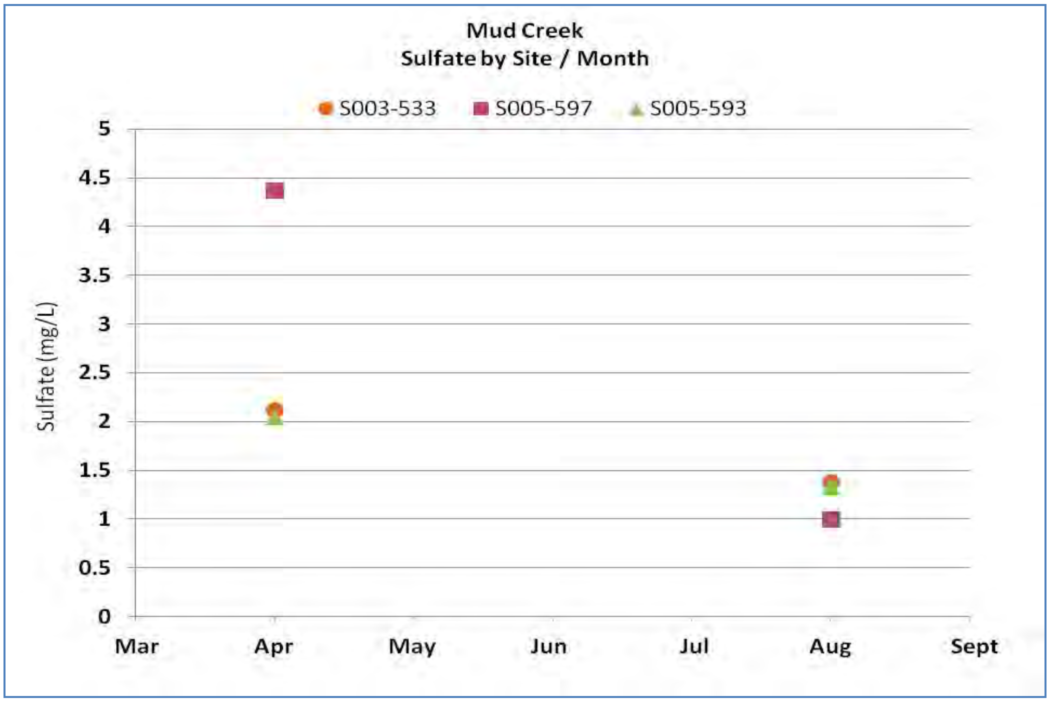

Mud Creek
Orthophosphate by Site / Month
S003-533
S005-597
S005-593
Orthophosphate (mg/L)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov

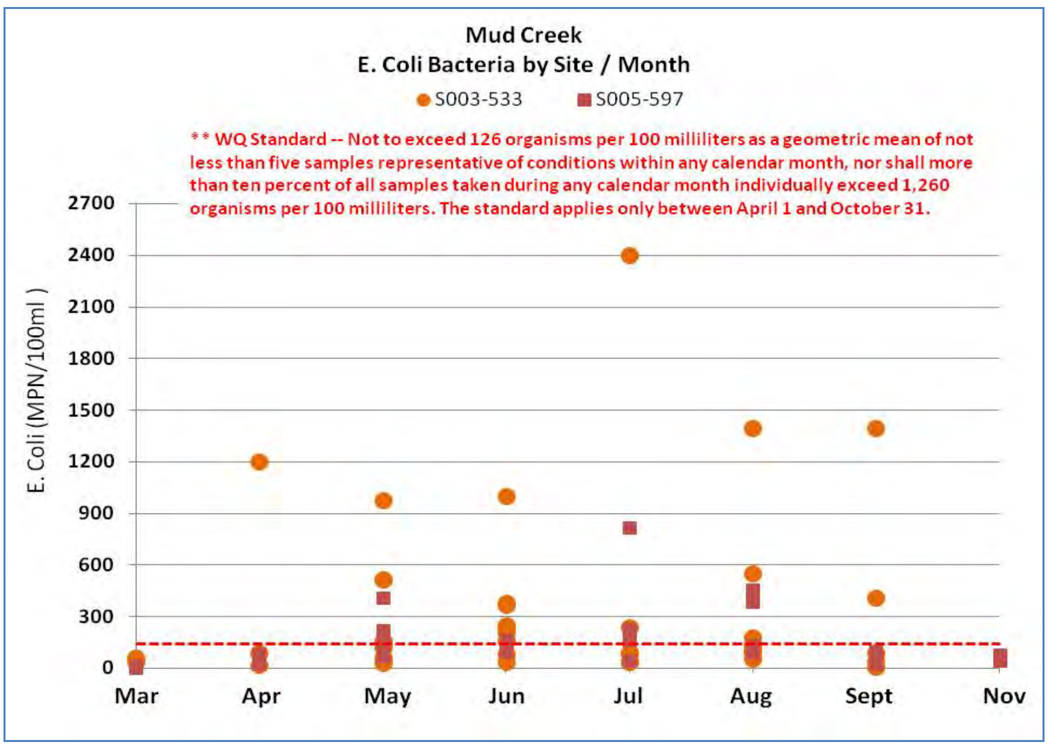

Mud Creek
NO2+NO3 by Site / Month
S003-533
S005-597
S005-593
NO2 + NO3 (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov


Mud Creek
Kjeldahl-N by Site / Month
S003-533
Kjeldahl-N (mg/L)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov


Mud Creek
Chloride by Site / Month
S003-533
S005-597
S005-593
** Chloride WQ standard (chronic) is 230 mg/L **
Chloride (mg/L)
16
14
12
10
8
6
4
2
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov


Mud Creek
Ammonia-N by Site / Month
S003-533
S005-593
Ammonia-N (mg/L)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov


Mud Creek
Sulfate by Site / Month
S003-533
S005-597
S005-593
Sulfate (mg/L)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Mar
Apr
May
Jun
Jul
Aug
Sept


Mud Creek
E. Coli Bacteria by Site / Month
S003-533
S005-597
** WQ Standard -- Not to exceed 126 organisms per 100 milliliters as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than ten percent of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies only between April 1 and October 31.
E. Coli (MPN/100ml)
2700
2400
2100
1800
1500
1200
900
600
300
0
Mar
Apr
May
Jun
Jul
Aug
Sept
Nov

Appendix D Descriptions of biological metrics used in the report

Fish metrics

Metric Name	Metric Description	Metric Class
DarterSculp	Taxa richness of darter and sculpin species	Richness
Hdw-Tol	Taxa richness of headwater species (excludes tolerant species)	Habitat
InsectCypPct	Relative abundance (%) of individuals that are insectivorous Cyprinidae species	Trophic
Insect-TolTXPct	Relative abundance (%) of taxa that are insectivorous (excludes tolerants)	Trophic
Minnows-TolPct	Relative abundance (%) of individuals that are Cyprinidae species (excludes tolerant species)	Composition
NumPerMeter-Tolerant	Number of individuals per meter of stream sampled (excludes individuals of tolerant species)	Composition
PioneerTXPct	Relative abundance (%) of taxa that are pioneers	Life History
Sensitive	Taxa richness of sensitive species	Tolerance
SLithop	Taxa richness of simple lithophilic spawning species	Reproductive
TolTXPct	Relative abundance (%) of taxa that are tolerant species	Tolerance

Macroinvertebrate metrics

Metric Name	Metric Description	MetricClass
ClingerCh	Taxa richness of clingers	Habit
Collector-filtererPct	Relative abundance (%) of collector-filterer individuals in subsample	Trophic
DomFiveCHPct	Relative abundance (%) of dominant five taxa in subsample (chironomid genera treated individually)	Composition
HBI_MN	A measure of pollution based on tolerance values assigned to each individual taxon developed by Chirhart	Tolerance
Intolerant2ch	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, using MN TVs	Tolerance
POET	Taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (baetid taxa treated as one taxon)	Richness
PredatorCh	Taxa richness of predators	Trophic
TaxaCountAllChir	Total taxa richness of macroinvertebrates	Richness
TrichopteraChTxPct	Relative percentage of taxa belonging to Trichoptera	Composition
TrichwoHydroPct	Relative abundance (%) of non-hydropsychid Trichoptera individuals in subsample	Composition