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# Stressor Identification Report for the Vermillion River Watershed Restoration and Protection Strategies

Prepared for:

VERMILLION RIVER WATERSHED JPO AND THE MINNESOTA POLLUTION CONTROL AGENCY

Prepared by:

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# Executive Summary

This Stressor Identification (ID) report evaluates the factors that are the likely cause or causes of biological impairment in streams in the Vermillion River watershed, in Dakota and Scott Counties, Minnesota. This analysis was prepared using the United States Environmental Protection Agency's (US EPA) and Minnesota Pollution Control Agency's (MPCA) Stressor Identification guidance and the US EPA's Causal Analysis/Diagnosis Decision Information System (CADDIS). CADDIS is a methodology for conducting a stepwise analysis of candidate causes of impairment. CADDIS characterizes the potential relationships between candidate causes and stressors, and identifies the probable stressors based on the strength of evidence from available data.

The Vermillion River watershed is located in the southeast part of the seven county Twin Cities, Minnesota Metropolitan Area. Portions of the Vermillion River and its tributaries are designated by the Minnesota DNR as trout waters. Land use within the Vermillion River watershed is primarily agricultural, but parts of the watershed are more densely populated with suburban land uses.

Fish and macroinvertebrate community information has been gathered throughout the Vermillion River watershed, which contains a mix of streams designated as both warmwater and coldwater. Two reaches of the Vermillion River main stem and two tributaries – South Creek and South Branch - do not meet State of Minnesota fish and macroinvertebrate standards for biotic integrity. One additional reach of the Vermillion River does not meet the fish biotic standard but does meet the macroinvertebrate standard.

A number of environmental factors were reviewed and ruled out because they are unlikely or there is no evidence to suspect that factor is present. Potential candidate causes of the impairments that were ruled out based on a review of available data include: pH, ionic strength (chloride), and toxic chemicals. Some potential stressors could not be ruled out but the potential affects were likely interacting and not primary: nutrients (total phosphorus), nitrate, altered flow, and fragmented habitat (connectivity).Four stressors that are potential candidate causes were examined in more detail: low dissolved oxygen; turbidity; temperature; and altered habitat.

These four stressors were evaluated according to CADDIS' structured, weight-of-evidence approach to determine which stressor or stressors were the likely candidate cause or causes of the impairments to the Vermillion River and tributaries. The evidence was assessed separately for each monitoring site and varies by site, but in general the evidence is strongest for turbidity, followed by dissolved oxygen and lack of habitat. While the temperature of the river and its tributaries is a plausible stressor and is likely contributing to the impairment, there is less direct evidence of its role. The probable causes established in this stressor identification process will be addressed in the Vermillion River Watershed Restoration and Protection Strategies plan (WRAPS).

# 1.0 Introduction

## 1.1 PURPOSE

This Stressor Identification (ID) report evaluates the factors that are the likely cause or causes of biological impairment in streams in the Vermillion River watershed, in Dakota and Scott Counties, Minnesota. This analysis was prepared using the United States Environmental Protection Agency's (US EPA) and Minnesota Pollution Control Agency's (MPCA) Stressor Identification guidance and the US EPA's Causal Analysis/Diagnosis Decision Information System (CADDIS). CADDIS is a methodology for conducting a stepwise analysis of candidate causes of impairment. CADDIS characterizes the potential relationships between candidate causes and stressors, and identifies the probable stressors based on the strength of evidence from available data.

## 1.2 PROBLEM IDENTIFICATION

This Stressor Identification report was completed to support the Vermillion River Watershed Restoration and Protection Strategies report (WRAPS). The WRAPS will address the lake and stream impairments within the watershed as well as review and assess conditions on waters that have not been listed as Impaired but where monitoring suggests pollutants or stressors are present. Table 1-1 and Figure 1-1 show the impaired stream reaches in the watershed that are being addressed in the WRAPS and TMDL.

**Table 1-1. Stream impairments addressed in the Vermillion River WRAPS.**

| Listed Reach or Water Body | AUID# | Listed Pollutant | Impaired Use | 303(d) Schedule |
|---|---|---|---|---|
| Vermillion River Main Stem | 07040001-517 | Fecal coliform | Aquatic recreation | 2008 |
| Vermillion River Main Stem | 07040001-517 | Dissolved oxygen | Aquatic life | 2010 |
| Vermillion River Main Stem | 07040001-517 | Turbidity | Aquatic life | 2008 |
| Vermillion River Main Stem | 07040001-517 | Fish, invert IBI | Aquatic life | Proposed |
| North Creek Headwaters | 07040001-542 | Fecal coliform | Aquatic recreation | 2008 |
| North Creek Hwy. 3 to VR | 07040001-545 | Dissolved oxygen | Aquatic life | 2010 |
| North Creek Hwy. 3 to VR | 07040001-545 | Fecal coliform | Aquatic recreation | 2008 |
| North Creek CR 31 to 205$^{th}$ | 07040001-670 | E. coli | Aquatic recreation | 2010 |
| North Creek 205$^{th}$ to Hwy 3 | 07040001-671 | Fecal coliform | Aquatic recreation | 2008 |
| Unnamed to Middle Creek | 07040001-546 | E. coli | Aquatic recreation | 2008 |
| Middle Creek CR 31 to Hwy 3 | 07040001-668 | Fecal coliform | Aquatic recreation | 2008 |
| Unnamed to Middle Creek | 07040001-548 | E. coli | Aquatic recreation | 2010 |
| South Cr to VR | 07040001-527 | Fecal coliform | Aquatic recreation | 2008 |
| South Cr to VR | 07040001-527 | Fish, invert IBI | Aquatic life | Proposed |
| VR Main Stem Farming to S Branch | 07040001-507 | Fish, invert IBI | Aquatic life | Proposed |
| South Branch Headwaters to T113 R19W S2, east line | 07040001-706 | Fecal coliform | Aquatic recreation | 2008 |
| South Branch T113 R19W S2, east line to T114 R18W S29, north line | 07040001-707 | Fecal coliform | Aquatic recreation | 2008 |
| South Branch T113 R19W S2, east line to T114 R18W S29, north line | 07040001-707 | Fish, invert IBI | Aquatic life | Proposed |

| Listed Reach or Water Body | AUID# | Listed Pollutant | Impaired Use | 303(d) Schedule |
|---|---|---|---|---|
| VR Main Stem S Branch to T114 R18W S20, east line | 07040001-691 | Fish IBI | Aquatic recreation | Proposed |
| VR Main Stem T114 R18W S21, west line to Hastings Dam | 07040001-692 | Fish IBI | Aquatic life | Proposed |
| Vermillion River: Headwaters to T113 R20W S8, east line | 07040001-516 | E. coli | Aquatic recreation | Proposed |

Several reaches in the Vermillion River watershed are not listed as Impaired Waters, but will be investigated in this Stressor ID for potential impaired biotic uses. These are shown in Table 1-2 and on Figure 1-2.

**Table 1-2. Unimpaired reaches addressed in the Vermillion River WRAPS.**

| Reach or Water Body | AUID # | Pollutant | Potential Impaired Use |
|---|---|---|---|
| VR Main Stem CR17 to Hwy3 | 07040001-517 | Temperature | Cold water assemblage |
| South Cr. To VR | 07040001-527 | Temperature | Cold water assemblage |
| North Cr. Hwy 3 to VR | 07040001-545 | Temperature | Cold water assemblage |
| North Cr. CR 31 to 205th | 07040001-670 | Temperature | Cold water assemblage |
| North Cr. 205th to Hwy 3 | 07040001-671 | Temperature | Cold water assemblage |
| VR Main Stem Farming to S. Branch | 07040001-507 | Temperature | Cold water assemblage |
| South Branch T113 R19W S2, east line to T114 R18W S29, north line | 07040001-707 | Temperature | Cold water assemblage |
| South Branch Headwaters to T113 R19W S2, east line | 07040001-706 | Nitrates | Aquatic life |
| South Branch T113 R19W S2, east line to T114 R18W S29, north line | 07040001-707 | Nitrates | Aquatic life |
| South Cr. To VR | 07040001-527 | Nitrates | Aquatic life |
| VR Main Stem 52 to Hastings | 07040001-692 | Nitrates | Aquatic life |

There are other impaired stream reaches in the watershed that are not part of the WRAPS, but have been or will be evaluated as part of a completed or pending TMDL (Table 1-3).

**Table 1-3. Stream reaches in the watershed with complete or pending Statewide TMDL studies.**

| Reach or Water Body | AUID # | Pollutant | Impaired Use |
|---|---|---|---|
| Lower Mississippi River | 07040001-507 | Fecal coliform | Aquatic recreation |
| Lower Mississippi River | 07040001-691 | Fecal coliform | Aquatic recreation |
| Lower Mississippi River | 07040001-692 | Fecal coliform | Aquatic recreation |
| Hastings Dam to Miss River | 07040001-504 | PCBs | Aquatic consumption |
| Hastings Dam to Miss River | 07040001-504 | Turbidity | Aquatic life |
| Vermillion Main Stem, headwaters to Mississippi River | 07040001-516, 517, 507, 504, 691, 692 | Mercury | Aquatic consumption |

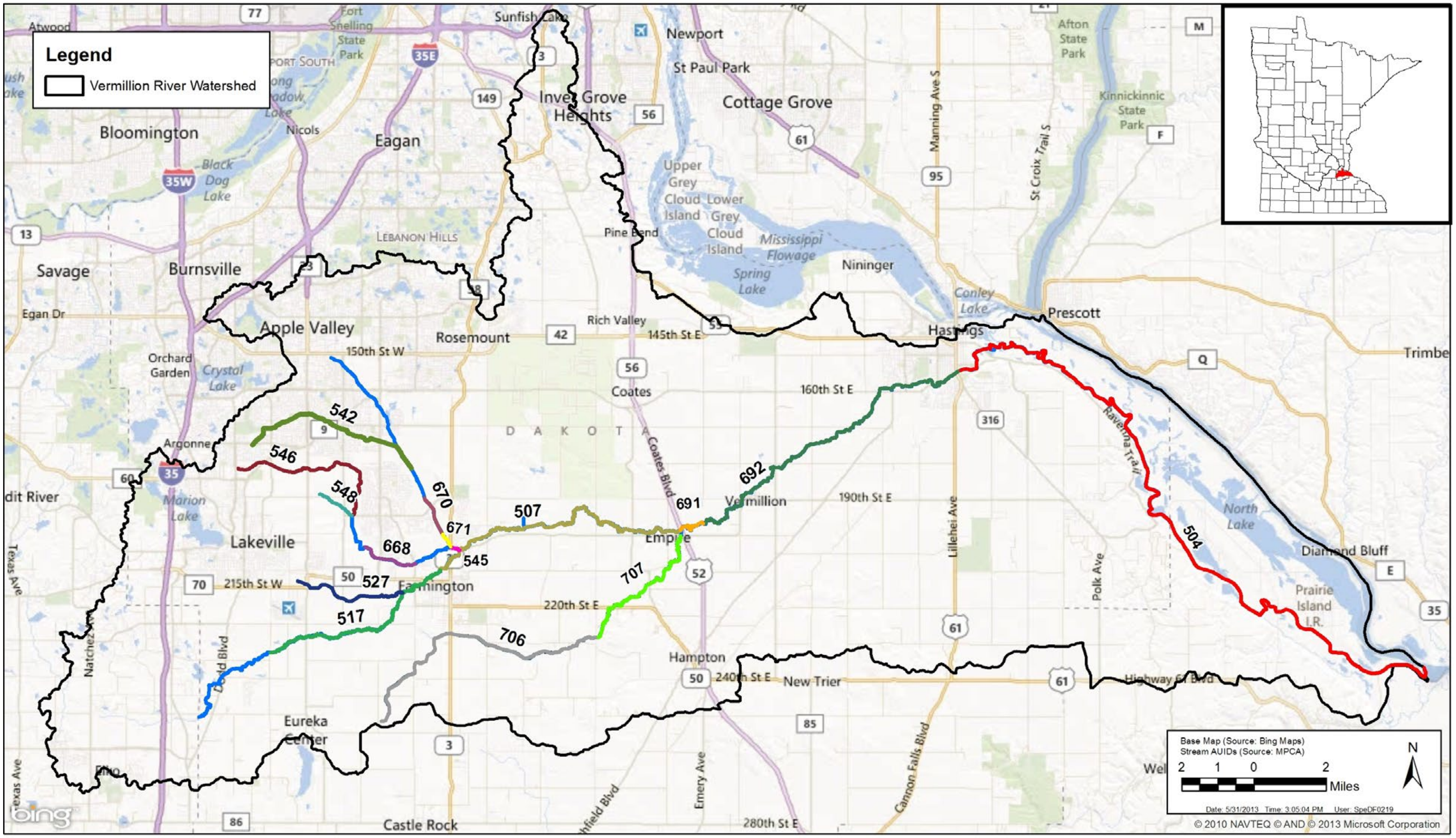



Figure 1-1. Stream reaches addressed in the Vermillion River WRAPS.

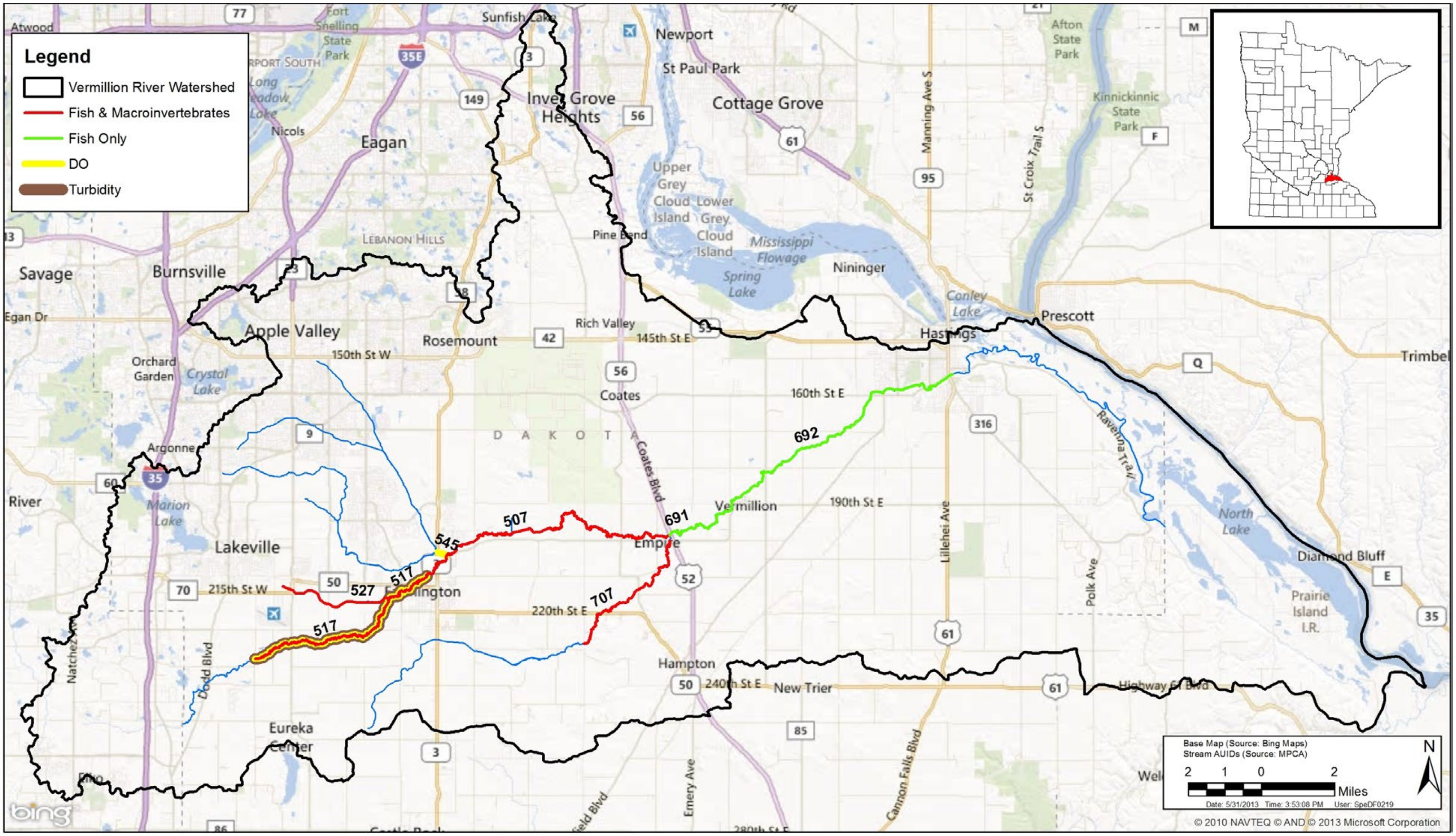



**Figure 1-2. Impaired stream reaches addressed in the Vermillion River Stressor ID.**

## 1.3 APPLICABLE STANDARDS

The Vermillion River is a prairie river with a relatively low gradient and includes stream reaches with both coldwater and warmwater use designations. The main stem of the Vermillion River from the headwaters downstream to approximately Highway 52 in Vermillion Township is designated as a Class 2A coldwater stream. Additionally portions of the major tributary streams of North Creek, Middle Creek, South Creek and South Branch are also designated as Class 2A coldwater streams. From approximately Highway 52 to the confluence of the Vermillion River with the Mississippi River, the main stem of the Vermillion River is classified as a 2B warmwater stream, along with the remaining major and minor tributary streams throughout the watershed. Some of the warmwater tributary streams discharge directly to coldwater reaches.

Minnesota Rules Chapter 7050.0222 outlines the use designations for Class 2 waters and also describes the numeric and narrative standards under each class. As defined in subpart 2, a Class 2A surface water "…shall be such as to permit the propagation and maintenance of a healthy community of cold water sport or commercial fish and associated aquatic life, and their habitats." A Class 2B warmwater designation is defined under subpart 3, of Chapter 7050.0222 as a surface water where the quality "…shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life and their habitats."

The MPCA has developed Indices of Biotic Integrity (IBIs) for stream fish communities that place all streams and rivers within Minnesota. There are nine separate IBI's that have been developed and each stream in placed into one of the nine stream classes, covering two geographic regions of the state, north and south. The application of the appropriate MPCA scoring protocol for a specific stream or reach matches the MPCA criteria being used to list stream fish communities as impaired. There are three of the nine stream classes under the state wide IBI present in the Vermillion River that include: southern headwater streams; southern streams; and southern coldwater streams. Each stream class IBI has a specific set of scoring metrics used and the type and number of metrics varies between classes. The reaches of the Vermillion River that are classified as 2A coldwater streams are scored using eight metrics for the total IBI score. Two of the metrics are tied directly to the presence and abundance of native coldwater fish species and individuals. There are nineteen species that are classifieds in the native coldwater species matrix.

Coldwater streams typically have low diversity and a limited number of total species. In general trout are the dominant coldwater species in coldwater streams of Minnesota and the upper Midwest. Although evidence documents that brook trout were observed in the Vermillion River from 1880 through at least 1930, it is not known if brook trout were ever naturally occurring in the stream and the population was never sustained in the absence of stocking programs. There are no recent records of brook trout existing within the Vermillion River. There are only four species classified within the coldwater metrics of the IBI that have been recently observed in the Vermillion River: brown trout, brook stickleback, pearl dace and longnose dace. One of these species, brown trout is an introduced fish that is not counted in the native coldwater species metrics. Based on a review of DNR fish collection records and the known range of the native coldwater species in Minnesota, it is possible that the majority of the 19 coldwater species listed under the MPCA southern coldwater streams IBI metrics never existed in the Vermillion River watershed. The limited number of native coldwater species within the watershed will make it difficult if not impossible for implementation projects to adequately improve scores for the two metrics tied to native coldwater species.

There is some potential evidence that the Vermillion River does not necessarily fit within IBI's developed for either coldwater or warmwater stream categories. The brown trout was introduced into the Vermillion River watershed through stocking programs and is currently widespread throughout the watershed and the dominant top carnivore predator species observed.  The DNR discontinued their brown trout stocking program however the brown trout population continues to thrive, is naturally reproducing and is now self-sustaining in the watershed. Brown trout have been by far the most numerous coldwater fish collected over the last four years of routine monitoring. The Vermillion River and tributaries now supports trophy class brown trout in several reaches. However, brown trout have also been found in several reaches that are classified as 2B warmwater streams in both the upper and lower portions of the watershed. The presence of brown trout throughout the watershed adds to the complexity of determining how the streams within Vermillion River watershed fit within the existing IBI categories.

Beyond the limited presence of native coldwater species and individuals, there is also an abundance of tolerant species and a low number of sensitive species influencing the impairment of the Vermillion River biotic community and these factors must be addressed. In the absence of an alternate scoring protocol, this stressor identification analysis has been prepared using the three available scoring categories for the Vermillion River, including application and analysis of the coldwater reaches using the southern coldwater stream category. Based on the results of the biological monitoring efforts and the analysis conducted within the stressor identification process, it is appropriate to explore the potential future application of a site specific standard for the fish communities of the Vermillion River, specifically for the 2A coldwater reaches.

## 1.4 WATERSHED AND STREAM DESCRIPTION

The Vermillion River watershed is located in the southeast part of the seven county Twin Cities Metropolitan Area. Encompassing 335 square miles, the headwaters are located in southeastern Scott County, with the majority of the watershed located within in Dakota County. A portion of the hydrologic boundary is located within Goodhue County.

That part of the watershed's hydrologic boundary that is located within Dakota and Scott Counties is governed by the Vermillion River Watershed Joint Powers Organization (VRWJPO). The VRWJPO is governed by a three-member Joint Powers Board.  A nine-member citizen advisory Watershed Planning Commission supports the Joint Powers Organization. Dakota and Scott Counties jointly fund the administration and activities of the organization.

The main stem of the Vermillion River begins in New Market Township in southeastern Scott County and flows generally northeast across Dakota County to its confluence with the Mississippi River to the north in Hastings and to the south near Red Wing. The River is approximately 38 miles long and drops approximately 420 feet from its source to its mouth, including 90-foot drop at the falls in Hastings.

Several streams are tributary to the Vermillion River. South Branch originates in Eureka Township and joins the main stem of the River in southwestern Vermillion Township. North Creek, Middle Creek, and South Creek drain the northwest corner of the watershed and discharge to the Vermillion River near Farmington.

The Vermillion and its tributaries are slow flowing streams that wind through both rural agricultural and developing suburban areas, through cultivated lands and pasturelands, forested areas and suburban backyards. Portions of the Vermillion River and its tributaries are designated as trout waters under Minnesota Statutes Chapter 97C.005, Special Management Waters (VRWJPO 2005).

### 1.4.1 Land Use and Land Cover

Land use within the Vermillion River watershed is primarily agricultural. Table 1-4 details 2010 land use, which is illustrated on Figure 1-4. Agricultural land uses comprise 53 percent of the total watershed area. Farmsteads, Undeveloped land, and Park, Recreation or Preserve uses constitute 26 percent of the watershed area, while Single Family Residential constitutes 13 percent. The only other land use that covers greater than 1 percent of the watershed area is industrial and utility which is localized to the area about 5 miles south of Inver Grove Heights where the Flint Hills refinery of Pine Bend is located. The north and northwest sections of the watershed are more densely populated and more impervious than the rest of the watershed.

**Table 1-4. 2010 land use in the Vermillion River watershed.**

| LAND USE | Area (acres) | Percent |
|---|---:|---:|
| Single Family Residential | 26,575 | 12.7% |
| Park, Recreation or Preserve | 13,970 | 6.7% |
| Industrial and Utility | 3,887 | 1.9% |
| Undeveloped | 39,156 | 18.6% |
| Commercial | 1,963 | 0.9% |
| Institutional | 2,925 | 1.4% |
| Water | 3,059 | 1.5% |
| Agricultural | 111,741 | 53.2% |
| Major Highways | 1,650 | 0.8% |
| Extractive | 1,862 | 0.9% |
| Multi-Family Residential | 429 | 0.2% |
| Airport | 281 | 0.1% |
| Mixed Use | 194 | 0.1% |
| Railway | 165 | 0.1% |
| Farmsteads | 2,132 | 1.0% |
| TOTAL | 209,989 | 100.0% |

Source: Metropolitan Council, derived from city comprehensive plans and aerial photo interpretation.
Note: Excludes that part of the watershed in Goodhue County, outside the seven-county Metro area.

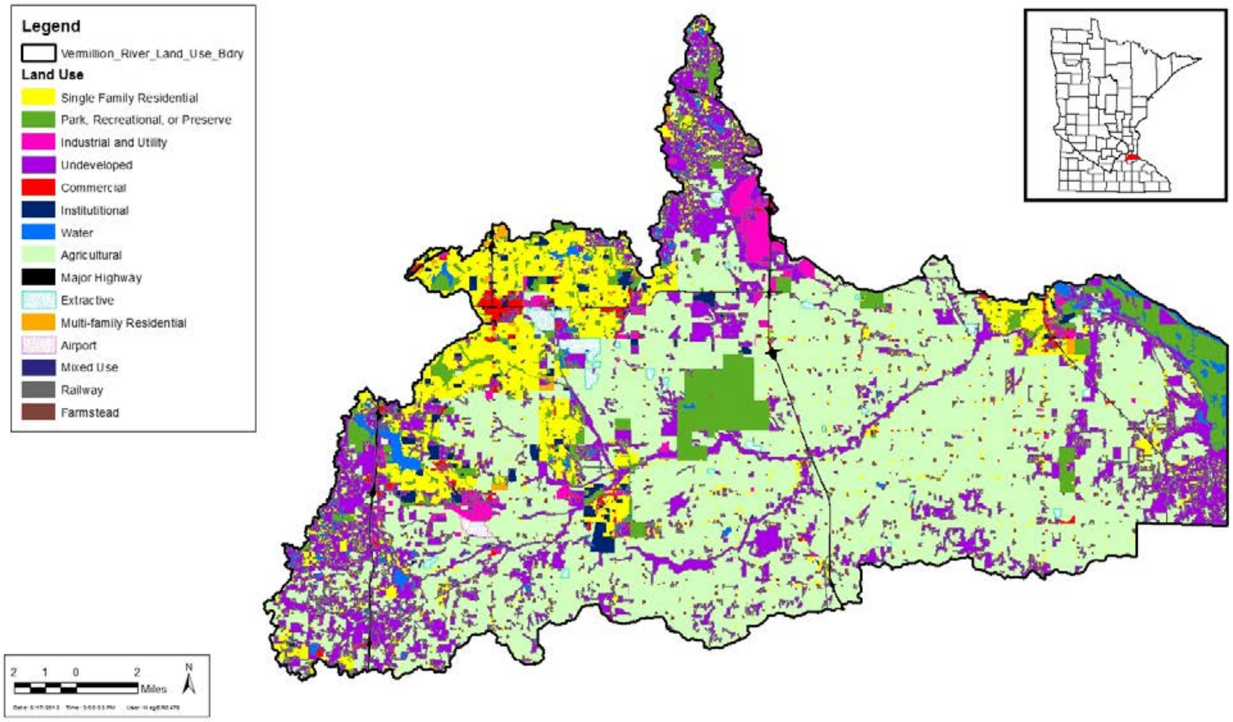



**Figure 1-3. 2010 land uses in the Vermillion River watershed.**
Note: Excludes that part of the watershed in Goodhue County, outside of the seven county Metro Area.

The National Agricultural Statistics Service (NASS) compiles land cover data by type of crop as well as more general categories of land cover. The 2011 NASS land cover data is summarized into 9 categories within the Vermillion River watershed. Table 1-5 and Figure 1-4 show land cover within the entire watershed, as well as by major tributaries and main stem of the River.

North Creek is the most highly developed subwatershed, with developed land covering 68 percent of the land. The South Creek subwatershed contains 39 percent developed land cover, compared to only 14 percent of the Vermillion River main stem subwatershed. The South Branch is 62 percent cropland, with most of that in corn-soybean rotation.

**Table 1-5. 2011 land cover in the Vermillion River watershed.**

| LAND COVER | Entire Watershed | Subwatershed | | | | |
|---|---|---|---|---|---|---|
| | | Vermillion R. | North Creek | Middle Creek | South Creek | South Branch |
| Corn | 24.4% | 27.0% | 2.9% | 18.4% | 13.9% | 35.2% |
| Soybeans | 15.9% | 16.2% | 4.2% | 26.8% | 10.2% | 25.2% |
| Other Crops | 1.3% | 1.2% | 0.6% | 2.9% | 2.9% | 1.4% |
| Pasture/Grass | 16.6% | 17.4% | 9.8% | 16.1% | 13.9% | 18.9% |
| Forest | 12.2% | 13.3% | 7.6% | 5.6% | 14.4% | 9.6% |
| Barren | 0.5% | 0.2% | 2.8% | 0.6% | 0.3% | 0.0% |
| Developed | 20.5% | 14.0% | 68.4% | 27.4% | 39.3% | 7.7% |
| Open Water | 3.6% | 4.3% | 2.1% | 0.4% | 3.6% | 0.4% |
| Wetlands | 5.1% | 6.4% | 1.7% | 1.8% | 1.5% | 1.6% |
| *Total* | *100.0%* | *100.0%* | *100.0%* | *100.0%* | *100.0%* | *100.0%* |

Source: National Agricultural Statistics Service (NASS).

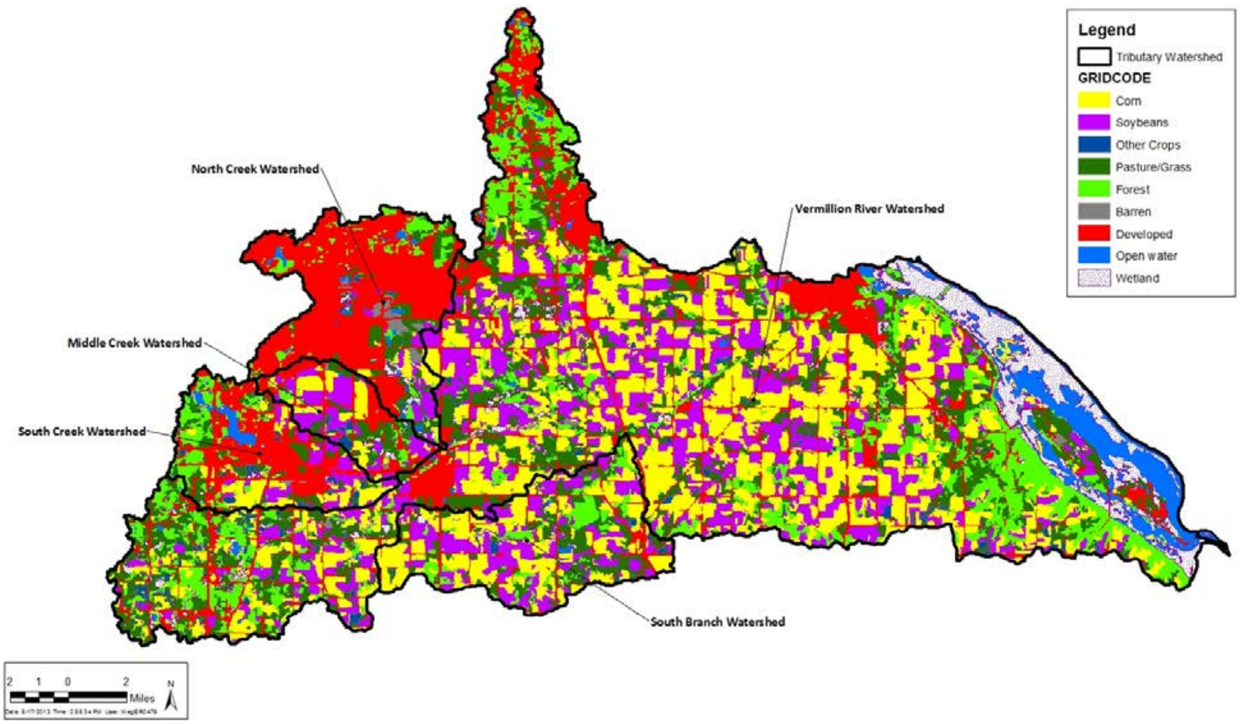



**Figure 1-4. 2011 National Agricultural Statistics service land cover in the Vermillion River watershed.**

### 1.4.2 Historic Watershed Conditions

Most of the Vermillion River watershed is located in the Great Plains – Temperate Prairies - Western Corn Belt Plains - Lower St. Croix and Vermillion Valley ecoregion. The area is characterized by dissected till plain and outwash valleys with nearly level to gently rolling glaciated till plains and hilly loess plains (Wiken et al. 2011). It is a transition zone between the more steeply rolling Driftless Area to its southeast and the North Central Hardwood Forests to its north and west. The ecoregion has a mid-latitude, humid continental climate, marked by hot summers and cold winters. Prior to European settlement, the area was mostly tallgrass prairie (Table 1-6 and Figure 1-5), covered with little bluestem, big bluestem, Indiangrass, switchgrass, numerous forbs, and with areas of bur oak and oak-hickory woodlands called oak openings or oak barrens.

**Table 1-6. Presettlement vegetation of the Vermillion River watershed.**

| VEGETATION TYPE | Area (ac) | Percent |
|---|---|---|
| Aspen-Oak Land | 6,429 | 2.8% |
| Big Woods - Hardwoods (oak, maple, basswood, hickory) | 9,589 | 4.1% |
| Lakes (open water) | 2,506 | 1.1% |
| Oak openings and barrens | 70,967 | 30.5% |
| Prairie | 125,837 | 54.0% |
| River Bottom Forest | 8,605 | 3.7% |
| Wet Prairie | 8,899 | 3.8% |
| *Total* | *232,832* | *100.0%* |

Source: Minnesota DNR.

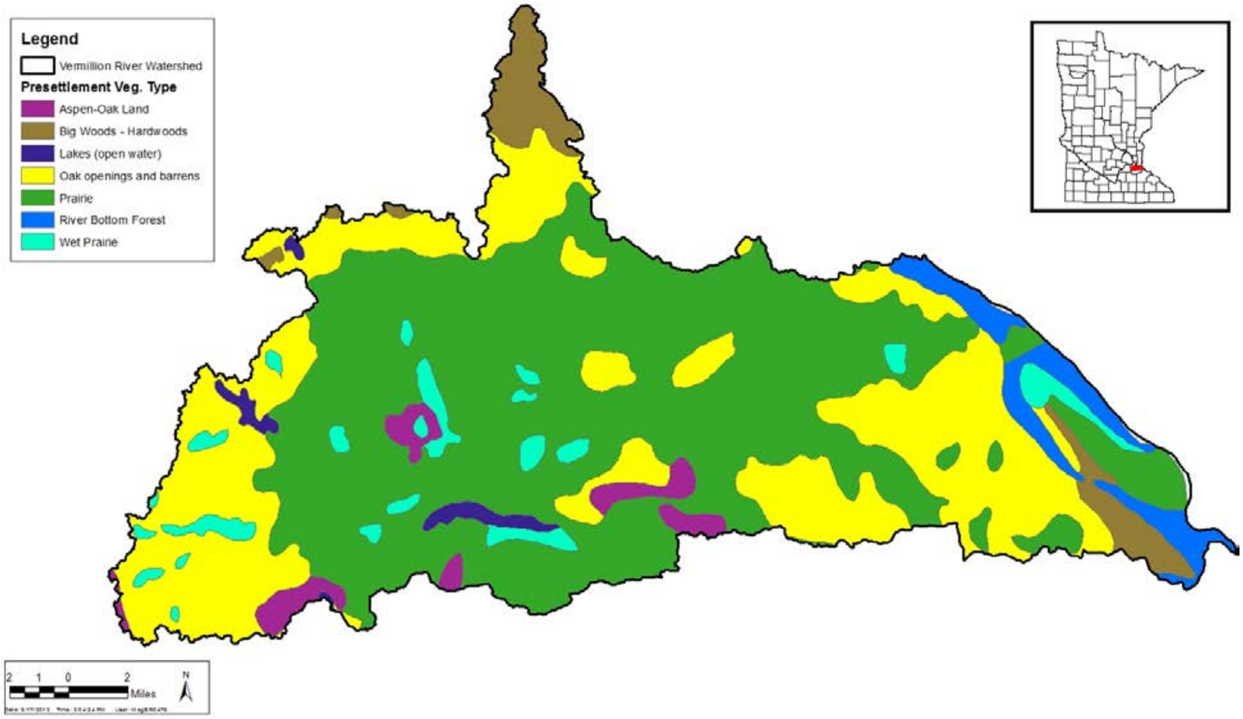



**Figure 1-5. Presettlement vegetation in the Vermillion River watershed.**

## 1.5 CURRENT STREAM CONDITIONS

The VRWJPO has completed a series of geomorphic assessments for major streams in the watershed, including the impaired reaches (Interfluve 2009, Interfluve 2010, Interfluve 2011, and Interfluve 2012). Table 1-7 provides an overview of findings.

**Table 1-7. Summary of stream conditions found by geomorphic assessment.**

| AUID(s) | Report Year | General Notes |
|---|---|---|
| 07040001-671<br>Site A7<br><br>North Creek | 2009 | · Section flows through forest and reed canarygrass and other grasses<br>· Extremely stable banks observed<br>· Reach has poor sediment transport capacity<br>· From 1999 to 2009, little or no change in riparian vegetation, bank stabilization or channel morphology was observed.<br>· Lack of channel complexity due to channelization is major geomorphic factor limiting the biota |
| 07040001-507 R<br>Sites A8 and A9<br><br>Vermillion between Clayton Ave E and Biscayne Ave W | 2009 | · Section flows through land dominated by reed canarygrass<br>· Trapezoidal ditch<br>· Row crops are grown to edge of channel top<br>· Minor erosion and sediment input<br>· From 1999 to 2009, little or no change in riparian vegetation, bank stabilization or channel morphology was observed. |

| AUID(s) | Report Year | General Notes |
|---|---|---|
| 07040001-507<br>Not a bio site<br><br>Vermillion R between Biscayne Ave and Chippendale | 2010 | · Section includes a riparian zone with a wooded buffer that is 300-700 feet wide<br>· Meandering, sand-dominated channel with a well-developed floodplain.<br>· Poor sediment transport capacity<br>· Sediment accumulation, riparian quality and lack of channel complexity are the major stressors |
| 07040001-517<br>Site A5<br><br>Vermillion R upstream of 220th St. W | 2010 | · Section flows through land made up of grasses, with some wooded and shrub understory on a bank of the downstream portion<br>· Low gradient meandering channel with low banks, and a well-developed and frequently inundated floodplain<br>· Substrate in the surveyed reach is predominantly sand, with some gravel in the riffle<br>· Major stressors are active grazing and associated sediment inputs due to erosion, and the hydrologic effects of continued agricultural use and tile drainage |
| 07040001-692<br>Site A14<br><br>Vermillion R DS of Goodwin Avenue | 2010 | · A forested buffer ranges in width from 100 – 500 feet, but the channel has cut to the outer edge of the buffer and is actively migrating into row crop agricultural fields<br>· Outer meander bends have migrated 10-15 feet over the past 20 years<br>· The channel bottom contains at least one foot of unconsolidated sand deposits in most places |
| 07040001-707<br>Site A12<br><br>South Branch DS of Darson Avenue | 2010 | · Section flows through mostly reed canarygrass and large patches of aquatic vegetation. Very few mature trees.<br>· No planform changes observed from 1991 to 2009<br>· Little change in riparian vegetation, bank stabilization or channel morphology observed in the past 10 years |
| 0704001-707<br>(~200 ft section downstream of CO RD 79) | 2011 | · Section flows adjacent to a floodplain with reed canarygrass dominating the vegetation composition with some sedges interspersed.<br>· Low gradient contributes to the thin layer of organic matter on top of the channel bed.<br>· The aquatic habitat in the reach is poor due to excessive siltation of the channel bed and possibly due to higher temperatures if groundwater is not present. |
| 0704001-507<br>Site A9<br><br>Vermillion R DS of Blaine Avenue | 2011 | · Reach has low gradient (0.062%) and poorly connected floodplain<br>· Overbank sediment deposition is prevalent<br>· Meander migration rates varied from 0 to 1 ft/year between 1991 and 2010<br>· The abundance of reed canary grass throughout the floodplain is preventing native trees from becoming established |
| 0704001-507<br>Site A8<br><br>Vermillion R DS of Biscayne Avenue | 2011 | · Throughout the reach, the channel does not appear to be well connected to the floodplain<br>· Meander migration is present at rates of approximately 1 ft/year since 1991<br>· Habitat in the reach is good; gravel and cobbles are abundant in the steeper, lower reach and sand dominates the upper reach<br>· In addition to good spawning habitat, an island in the middle of the reach provides habitat complexity for a variety of fish life stages. |

| AUID(s) | Report Year | General Notes |
|---|---|---|
| 0704001-517<br>Site A6<br><br>Vermillion R DS of CR 31 | 2011 | · Sandy/silty sediments are present throughout the reach in the channel bed, however, a gravel thalweg and gravel riffles were present during baseflow conditions<br>· Habitat in the reach is relatively good considering the potential detrimental effects of upstream agriculture and urbanization<br>· Excellent heterogeneity of bed grain sizes<br>· This is important macroinvertebrate habitat and prevents trout eggs from being smothered by sediment. |
| 0704001-692<br>Site A14<br><br>Vermillion R DS of Goodwin Avenue | 2011 | · Meander migration at rates of up to 1ft/yr are present in this section<br>· The channel bed composition reflects the excessive sediment supply as it is primarily sand with some gravels interspersed<br>· It is likely that agriculture and urbanization increased sediment supply to the reach which resulted in excessive sedimentation<br>· Even during baseflow conditions, sand remains in transport creating poor spawning habitat. Juvenile rearing habitat is also poor in this segment as there is few backwater or shallow depth areas for young to escape larger fish. |
| 0704001-507<br>Sites A7, A8, A9<br><br>Entire AUID | 2012 | · Generally sinuous channel flowing through a wide riparian corridor with agriculture fields nearby.<br>· Channel is generally in good geomorphic condition with decent aquatic habitat<br>· Due to tributary ditching and straightening and tiling of agricultural fields, the amount of water entering the Vermillion River has increased.<br>· These practices have resulted in flashy runoff events and compromised in-stream habitat diversity.<br>o Historical land use involved clearing the land for agricultural use and encroachment upon the riparian corridor and associated channelizing to maximize the cropland.<br>o Agricultural land has decreased infiltration and reduced the riparian corridor, resulting in larger quantities of rainwater reaching the river more quickly |

Source: Interfluve 2009, Interfluve 2010, Interfluve 2011, Interfluve 2012.

# 2.0 Description of the Impairment

## 2.1 AVAILABLE DATA

Fish and macroinvertebrate community information has been gathered throughout the Vermillion River watershed. Data has been collected by state agencies as well as the by the VRWJPO. The monitoring locations and their identification numbers used by various agencies are shown in Table 2-1. The following sections present and discuss the available data and the current status of the fish and macroinvertebrate communities.

**Table 2-1. Biological data collection sites.**

| MPCA Site | Stream Reach/AUID | Biological Site | Description |
|---|---|---|---|
| 09LM002 | 517 | A1 | Vermillion River at 235th St. W |
| 09LM003 | 527 | A2 | South Creek at Cedar Avenue |
| 08LM124 | 527 | A3 | South Creek at Flagstaff Avenue |
| 09LM004 | 666 | A4 | Unnamed at 215 St W (E Eureka Cr) |
| 08LM123 | 517 | A5 | Vermillion River at 220th St. W |
| 09LM005 | 517 | A6 | Vermillion River at Denmark Avenue (Hwy 31) |
| 08LM121 | 671 | A7 | North Creek West of Chippendale Ave (Hwy 3) |
| 98LM004 | 507 | A8 | Vermilion River DS of Biscayne Ave |
| 08LM114 | 896 | A9 | Vermillion River at Blaine Avenue |
| 08LM117 | 552 | A10 | South Branch at Blaine Avenue |
| 09LM007 | 707 | A12 | South Branch at Darsaw Avenue |
| 08LM116 | 707 | A13 | South Branch at CSAH-66 |
| 08LM115 | 692 | A14 | Vermillion River at CSAH-85 Bridge |
| 09LM008 | 668 | A15 | Middle Creek at Akin Rd |

### 2.1.1 Fish

There is a significant amount of fish community data that has been collected within the Vermillion River Watershed. Initial fish monitoring was conducted by the Minnesota Department of Natural Resources (DNR) as part of their trout population monitoring efforts. However, these collections focused mainly on mark and recapture sampling efforts to estimate standing brown trout populations and did not provide an overall measure of fish community health within the watershed. Additional fish community monitoring efforts were conducted by the MPCA as part of the watershed wide fish community assessment. These watershed wide assessments were conducted in 1998 and 2008. The MPCA efforts focused on fish community sampling under the Index of Biotic Integrity (IBI) protocols.

The VRWJPO has been responsible for the majority of the fish community data collected over the last four years. The VRWJPO developed a biological monitoring plan in 2008. The plan identified long term fish community monitoring goals and reaches. The VRWJPO identified 14 sites for long term fish community monitoring. Seven of the sites identified by the VRWJPO within the biological plan coincided with stream reaches already monitored by the DNR as part of their trout population surveys in the watershed. In 2009, the DNR began conducting stream fish community monitoring in the Vermillion River watershed following the MPCA IBI protocols, along with their trout populations monitoring. The VRWJPO began monitoring the remaining seven of the 14 sites identified in biological monitoring plan in 2009.

The Vermillion River watershed contains a mix of streams designated as both warmwater and coldwater, which has an influence on the stream fish community. The main stem of the Vermillion River is a coldwater stream upstream of approximately Highway 52, and a warmwater stream downstream of this. There are several tributaries to the Vermillion River that are also coldwater streams including North Creek, South Creek and South Branch, all of which drain into the main stem of the Vermillion River upstream of Highway 52. There are also warmwater tributaries scattered throughout the watershed that drain into both coldwater reaches and warmwater reaches of the Vermillion River and its tributaries.

The reaches of the Vermillion River monitored by the VRWJPO fall into three categories of stream type based on the MPCA Statewide Fish IBI. The stream categories present within the Vermillion River watershed include southern headwater streams, southern streams and southern coldwater streams. Streams in the southern headwaters category are classified as small to moderately sized reaches with moderate to high gradient and watershed area of less than 30 square miles. Streams in the southern streams category are classified as medium to large size warmwater/coolwater systems with watershed areas between 30 and 300 square miles. Streams in the southern coldwater category include all coldwater streams in the southern portion of Minnesota. The 14 monitoring reaches maintained by the VRWJPO include three reaches within the southern headwaters category, one reach in the southern stream category and ten reaches in the southern coldwater category. Fish community monitoring was conducted by the VRWJPO from 2009 through 2012 and sampling results were used to calculate IBI scores. The IBI scores from the 14 monitoring sites are presented in Table 2-2. Monitoring site locations are shown on Figure 2-1.

**Table 2-2. Fish Index of Biotic Integrity scores for sites on the Vermillion River and select tributaries.**
Note: Calculated using the new MPCA Statewide IBI scoring criteria for all fish community monitoring sites in the Vermillion River stream fish monitoring project from 2008 to 2012. NS indicates reach not surveyed that year.

| Site | Stream AUID | Stream Classification | MPCA IBI Category | 2008 | 2009 | 2010 | 2011 | 2012 | Listing Threshold |
|---|---|---|---|---|---|---|---|---|---|
| A1 Vermillion | 517 | Coldwater | Southern Coldwater | NS | 41 | 33 | 45 | 39 | <45 |
| A2 S Creek | 527 | Coldwater | Southern Coldwater | NS | 36 | 42 | 43 | 38 | <45 |
| A3 S Creek | 527 | Coldwater | Southern Coldwater | 31 | 42 | 55 | 52 | 42 | <45 |
| A4 Unnamed | 666 | Warmwater | Southern Headwaters | NS | 73 | 75 | 75 | 61 | <51 |
| A5 Vermillion | 517 | Coldwater | Southern Coldwater | 28 | 45 | 40 | 36 | 34 | <45 |
| A6 Vermillion | 517 | Coldwater | Southern Coldwater | NS | 34 | 36 | 41 | 34 | <45 |
| A7 N Creek | 545 | Coldwater | Southern Coldwater | 25 | 40 | 45 | 36 | 34 | <45 |

| Site | Stream AUID | Stream Classification | MPCA IBI Category | 2008 | 2009 | 2010 | 2011 | 2012 | Listing Threshold |
|---|---|---|---|---|---|---|---|---|---|
| A8 Vermillion | 507 | Coldwater | Southern Coldwater | 41 | 51 | 39 | 48 | 39 | <45 |
| A9 Vermillion | 507 | Coldwater | Southern Coldwater | 37 | 42 | 49 | 38 | 29 | <45 |
| A10 S Branch | 552 | Warmwater | Southern Headwaters | 68 | 80 | 74 | 80 | 80 | <51 |
| A12 S Branch | 707 | Coldwater | Southern Coldwater | NS | 40 | 38 | 41 | 49 | <45 |
| A13 S Branch | 707 | Coldwater | Southern Coldwater | 23 | 46 | 48 | 42 | 29 | <45 |
| A14 Vermillion | 692 | Warmwater | Southern Streams | 36 | 43 | 38 | 40 | 47 | <45 |
| A15 Middle Cr | 668 | Warmwater | Southern Headwaters | NS | NS | 75 | 75 | 71 | <51 |

The metrics used to score the fish community are specific to each stream category. A discussion of the metrics to calculate the IBI score for each category along with an analysis of the metric scoring results for the reaches of the Vermillion River within each stream category is provided.

| MPCA Site | Biological Site |
|---|---|
| 09LM002 | A1 |
| 09LM003 | A2 |
| 08LM124 | A3 |
| 09LM004 | A4 |
| 08LM123 | A5 |
| 09LM005 | A6 |
| 08LM121 | A7 |
| 98LM004 | A8 |
| 08LM114 | A9 |
| 08LM117 | A10 |
| 09LM007 | A12 |
| 08LM116 | A13 |
| 08LM115 | A14 |
| 09LM008 | A15 |

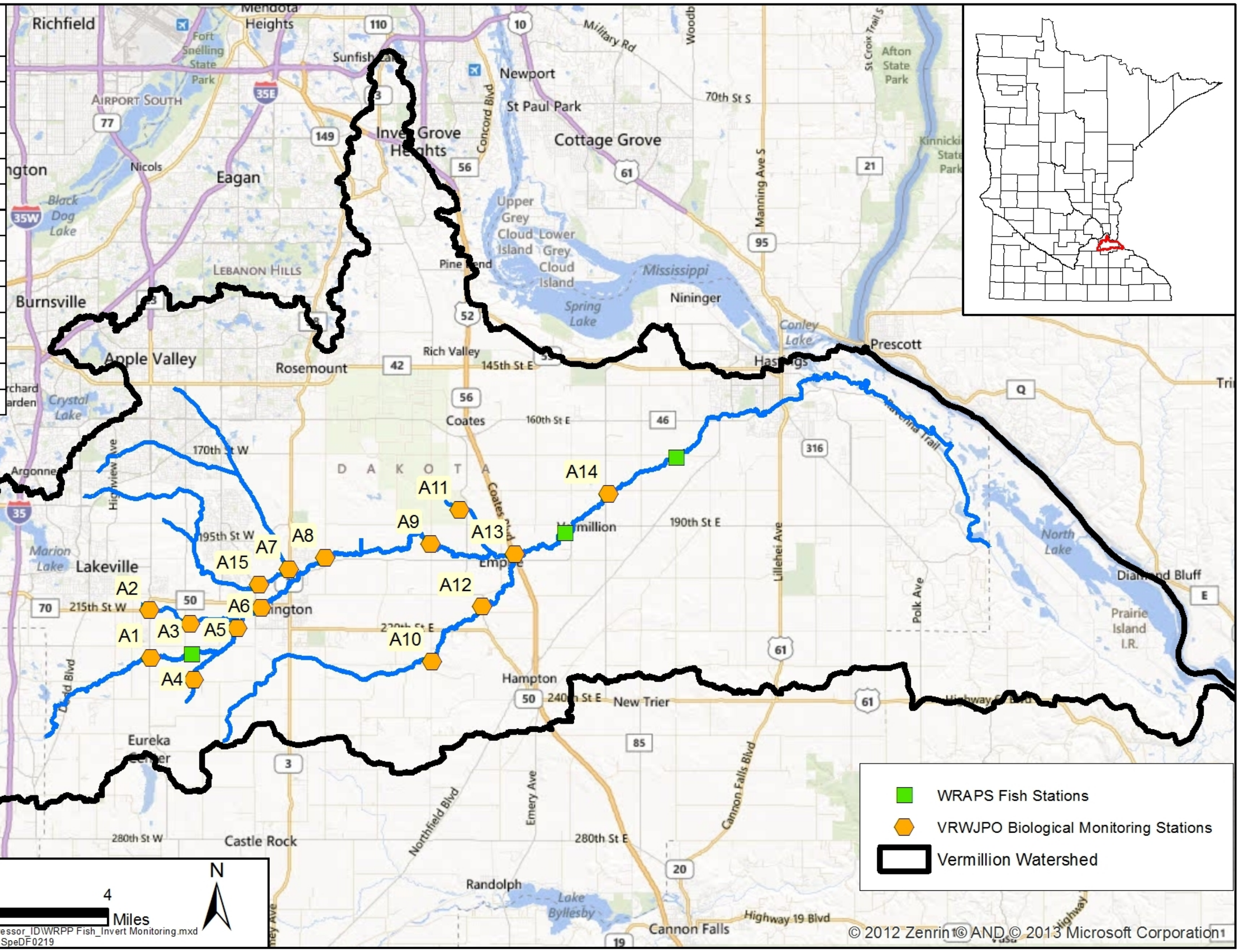



**Figure 2-1. Fish and macroinvertebrate monitoring locations in the Vermillion River watershed.**

#### 2.1.1.1 Southern Headwater Streams

There are three reaches in the Vermillion River within the Southern Headwaters category, sites A4, A10 and A15. All three of these stream sites score high under the MPCA Statewide IBI scoring criteria, with scores ranging from 61 to 81 across the four monitoring years. The threshold for listing of the fish community as impaired is 51 or below (see Table 2-2) within this stream category. All three streams have scored well above the listing threshold during all monitoring years. There are seven metrics for streams in the Southern Headwaters category listed in the MPCA IBI scoring (Sandberg, 2011):

- Relative abundance (%) of taxa that are detritivores (DetNWQTXPct);
- Relative abundance (%) of individuals with DELT anomalies;
- Relative abundance (%) of taxa that are generalist feeders (GeneralTXPct);
- Taxa richness of sensitive species;
- Relative abundance (%) of individuals that are short-lived (SLvdPct);
- Relative abundance (%) of individuals that can spawn multiple times (SSpnPct); and
- Relative abundance (%) of taxa that are very tolerant (VTolTXPct).

The total score for the IBI is 100. One of the metrics, abundance of DELT anomalies, has a score of zero unless anomalies are present, in which case negative points are given. The three sites in the southern headwater streams category received a zero for the DELT metrics for all sites for all years, with the exception of 2008 at site A10, which received a -5 score. The remaining six metrics add up to the max score of 100, which makes each metric worth a maximum of 16.7.

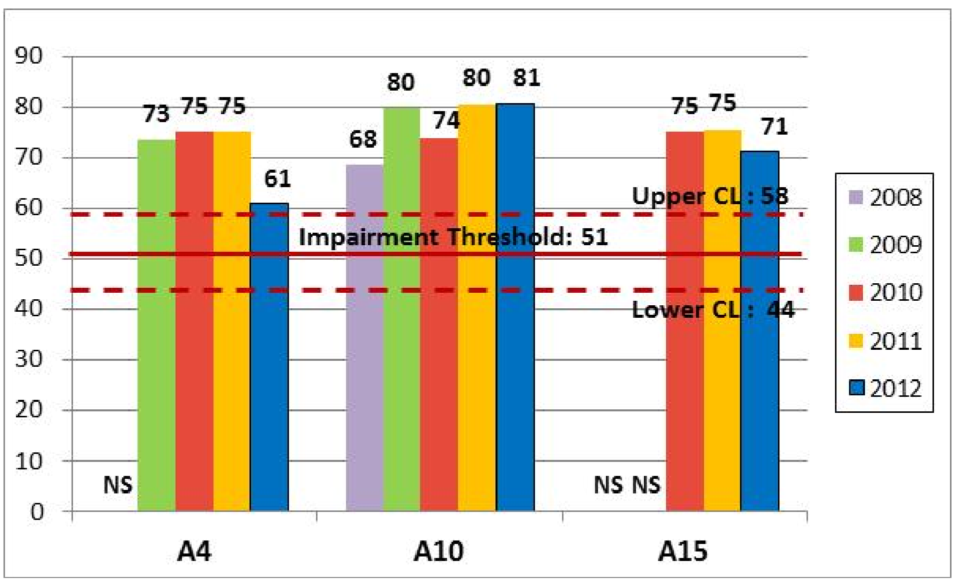



**Figure 2-2. F-IBI scores in the Southern Headwater Streams compared to impairment listing threshold.**
Note: The dashed lines are the Upper and Lower Confidence Intervals. NS indicates the reach was not sampled during that year.

The three stream reaches in the southern headwater streams category scored very well across all years of monitoring data and therefore are receiving high individual scores for many of the metrics. Specific metrics that score particularly well include: relative abundance of taxa that are generalist feeders; relative abundance of individuals that are short lived; and relative abundance of individuals that are serial spawners (multiple times per year). All three of these metrics have a “negative” relationship, indicating that as the percentage of these individuals increase in the overall total catch the metric score

goes down. Alternately, as these individuals comprise a lower number of the total catch the metric score increases. Some of the species that are classified within these metrics are present in the Vermillion River watershed, however, they are comprising a small enough percentage of the total catch at the southern headwater reaches that the metric scores are high, resulting in high total IBI scores for these sites.
A comparison of the average individual metric scores for the three southern headwater stream sites is provided as Figure 2-3. For the most part, the average metric score for the sites is well above the average score needed to be above the impairment threshold for the total IBI score. Site A15 scores below average on the sensitive species metric and the other two sites also score lower on this same metric compared to the other metrics. All three sites are scoring near or below the average threshold for the very tolerant taxa metric.

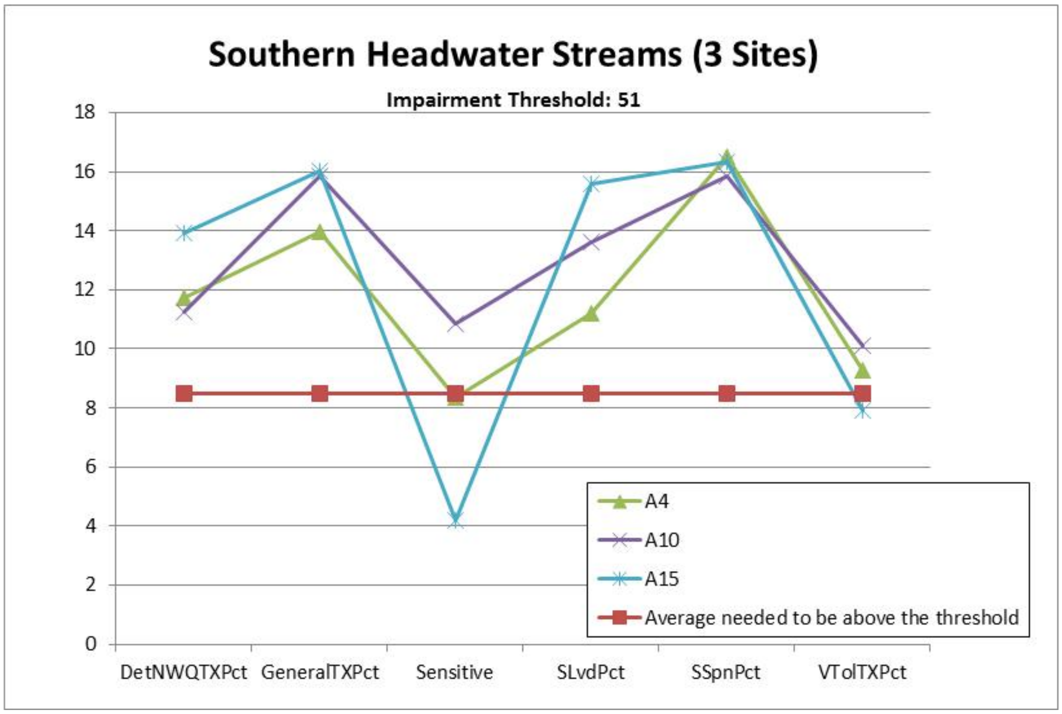



**Figure 2-3. Average (2008-2012) individual fish IBI metrics scores for southern headwater streams.**

### 2.1.1.2 Southern Streams

Site A14 is the only warmwater stream reach in the watershed within the southern streams category. This site is on the main stem of the Vermillion River and is currently located the farthest downstream in the overall watershed of the routine monitoring sites. The threshold for listing of the fish community within this stream category as impaired is 45 or below (see Table 2-2 and Figure 2-4). Site A14 scored below the impairment listing threshold from 2008 through 2011, but was above the impairment threshold in 2012 for the first time with a score of 47. There are nine metrics in the southern streams category of the MPCA IBI (Sandberg, 2011):

- Relative abundance (%) of taxa Benthic Insectivores (excludes tolerant) (BenthinsectTolTxPct);
- Relative abundance (%) of taxa that are detritivores (DetNWQTxPct);
- Relative abundance (%) of individuals with a female mature age <=2 (MA<2Pct);
- Relative abundance (%) of individuals with DELT anomalies;
- Relative abundance (%) of taxa that are sensitive; (SensitiveTxPct);
- Taxa richness of short-lived species (Stlvd):

- Relative abundance (%) of taxa that are tolerant (TolTxPct);
- Relative abundance (%) of individuals that are tolerant (TolPct); and
- Relative abundance (%) of individuals the dominant 2 species (DomTwoPct).

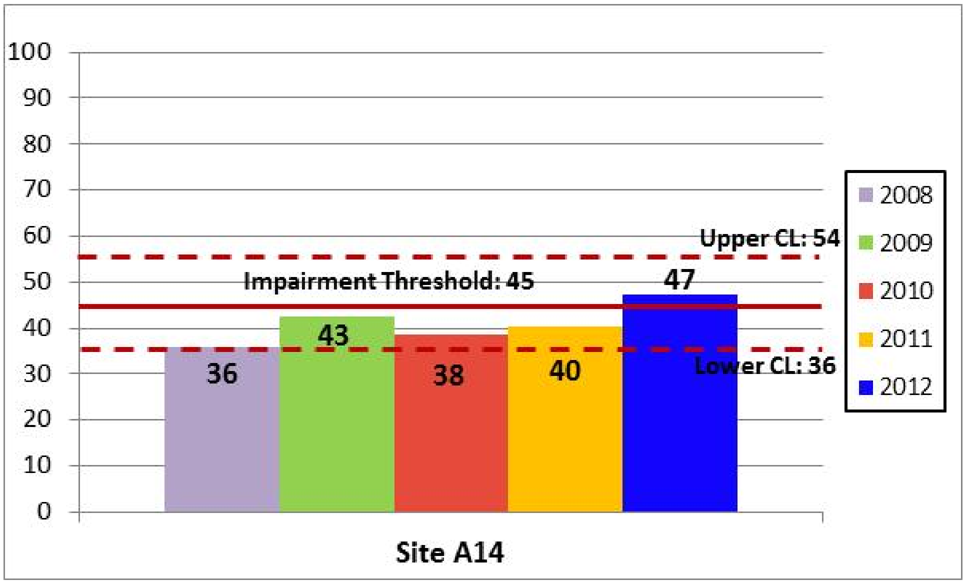



**Figure 2-4. F-IBI scores in the Southern Streams category compared to impairment listing threshold.**

The southern streams category again uses the DELT anomalies metric, which gives a zero or negative score. Site A14 in the southern streams category received a zero for the DELT metric for all five years of data. The other eight metrics add up to a total of 100, which equates to a max metric score of 12.5 per metric. Site A14 has generally scored low on many of the above metrics. The overall IBI scores at site A14 appear to be driven by moderately high scores for the relative abundance of taxa that are detritivores and also by the low to very low scores for the relative abundance of taxa that are sensitive, relative abundance of taxa that are tolerant, relative abundance of individuals that are tolerant and relative abundance of the dominant two species.

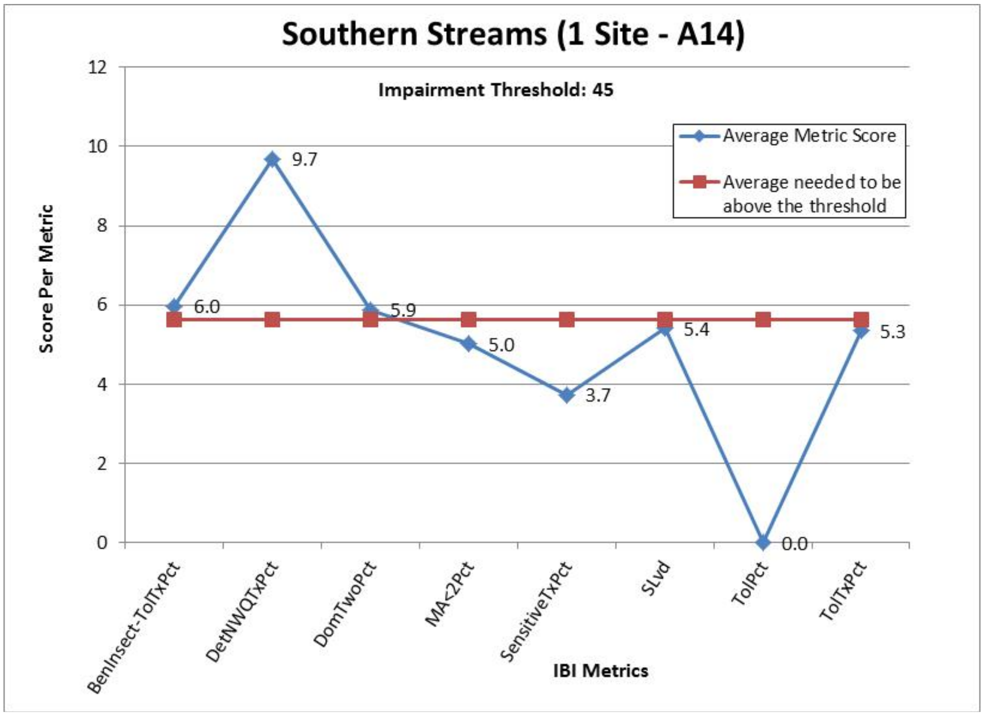



**Figure 2-5. Average (2008-2012) individual fish IBI metrics scores for southern stream sites**

A comparison of the average individual metric scores for the one southern headwater stream site is provided as Figure 2-5. In general the relatively high percentage of tolerant species (i.e., taxa) and tolerant individuals, as well as the low number of sensitive species is keeping the overall IBI score at site A14 low and generally below the impairment threshold.

As part of the WRAPS report, supplemental fish monitoring was conducted at two additional locations on the main stem of the Vermillion River within the Southern Streams category warmwater reach. The two supplemental reaches were located one each upstream and downstream of the VRWJPO long term monitoring site A14 (see Figure 2-1). These supplemental WRAPS sites were monitored by the MPCA in August 2012. The purpose of these additional monitoring sites was to further define the fish community for southern streams category of the main stem of the Vermillion River. The total number of species collected at these two sites was slightly less than the maximum number of species collected from site A14 but in general the species compilation of the total catch was similar. The IBI scores for the two sites are as follows (see Figure 2-1):

- Vermillion River near 190th Street – 12LM089 (upstream of A14): 27
- Vermillion River near 170th Street – 12LM091 (downstream of A14): 37

These IBI scores are slightly lower than the IBI scores from A14 that have ranged from 36 to 47 over the previous five years of monitoring. The individual metrics scores were not available however the species composition and the total catch were similar to what has been previously collected along this portion of the Vermillion River at A14. This includes a dominance of tolerant species and individuals present along with a limited number of sensitive species and individuals collected. These monitoring results indicate that the impairment of the fish community is fairly consistent within the warmwater reach of the main stem of the Vermillion River in the southern streams category and not likely limited to habitat conditions associated with only the A14 reach.

#### 2.1.1.3 Southern Coldwater Streams

The ten remaining stream reaches fall within the southern coldwater streams category. Among the ten monitoring sites in the southern coldwater streams category, there is low to moderate variation in the IBI scores across years (Figure 2-6). The threshold for listing of the fish community as impaired is 45 or below (see Table 2-2 within this stream class). Due to the moderate variation in the IBI scores for the streams in this class, many of the streams had scores both above and below the threshold across the monitoring years including sites A3, A8, A9, A12 and A13. Other sites such as A2 and A6 scored below the listing threshold during all monitoring years.

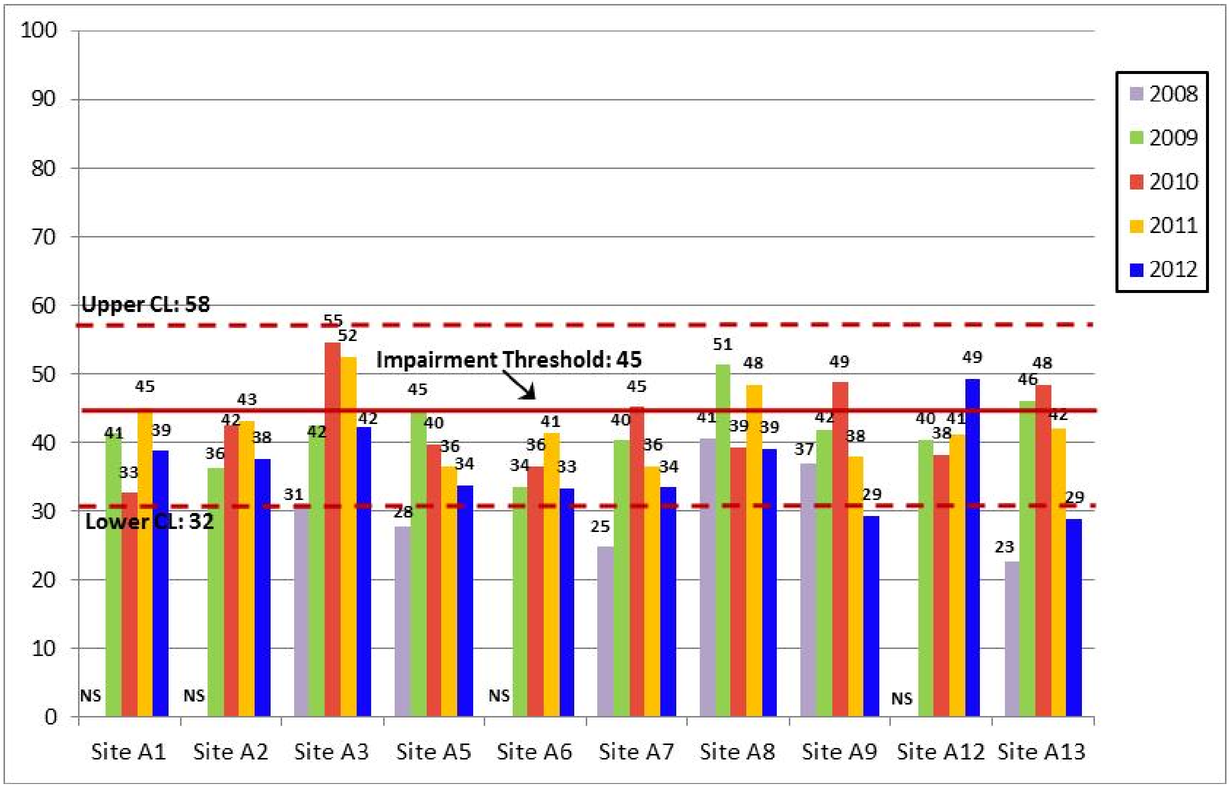



**Figure 2-6. F-IBI scores in the Southern Coldwater Streams Category compared to impairment listing threshold.** Note: The dashed lines are the Upper and Lower Confidence Intervals. NS indicates the reach was not sampled during that year.

There are eight metrics used in the southern coldwater streams IBI category (Sandberg, 2011):

- Relative abundance (%) of individuals that are sensitive in coldwater streams;
- Number of taxa that are tolerant in coldwater streams;
- Relative abundance (%) of individuals with DELT anomalies;
- Relative abundance (%) individuals that are herbivores;
- Relative abundance (%) of individuals that are native coldwater species;
- Relative abundance (%) of taxa that are native coldwater species;
- Relative abundance (%) of individuals that are pioneer species; and
- Relative abundance (%) of taxa that are detritivores.

The southern coldwater streams category again uses the DELT anomalies metric, which gives a zero or negative score. The majority of the DELT metrics scores were zero for all sites for all years. The exceptions where a score of -5 for sites A3, A7 and A13 in 2008 and scores of -10 for sites A8 and A9 in 2008. Therefore the other seven metrics add up to a total of 100, which equates to a max metric score of 14.3. All ten of the coldwater reaches are generally scoring at or below the impairment threshold, indicating that the streams are scoring poorly on several metrics while scoring well on only a few metrics. The main metrics that appear to be driving the coldwater IBI scores in the Vermillion River include good scores for the relative abundance of herbivore species and moderately good scores for the relative abundance of pioneer species, along with low to very low metric scores for the relative abundance of coldwater sensitive species, number of taxa that are tolerant in coldwater streams, relative abundance of native coldwater taxa (i.e., species) and relative abundance of native coldwater individuals.

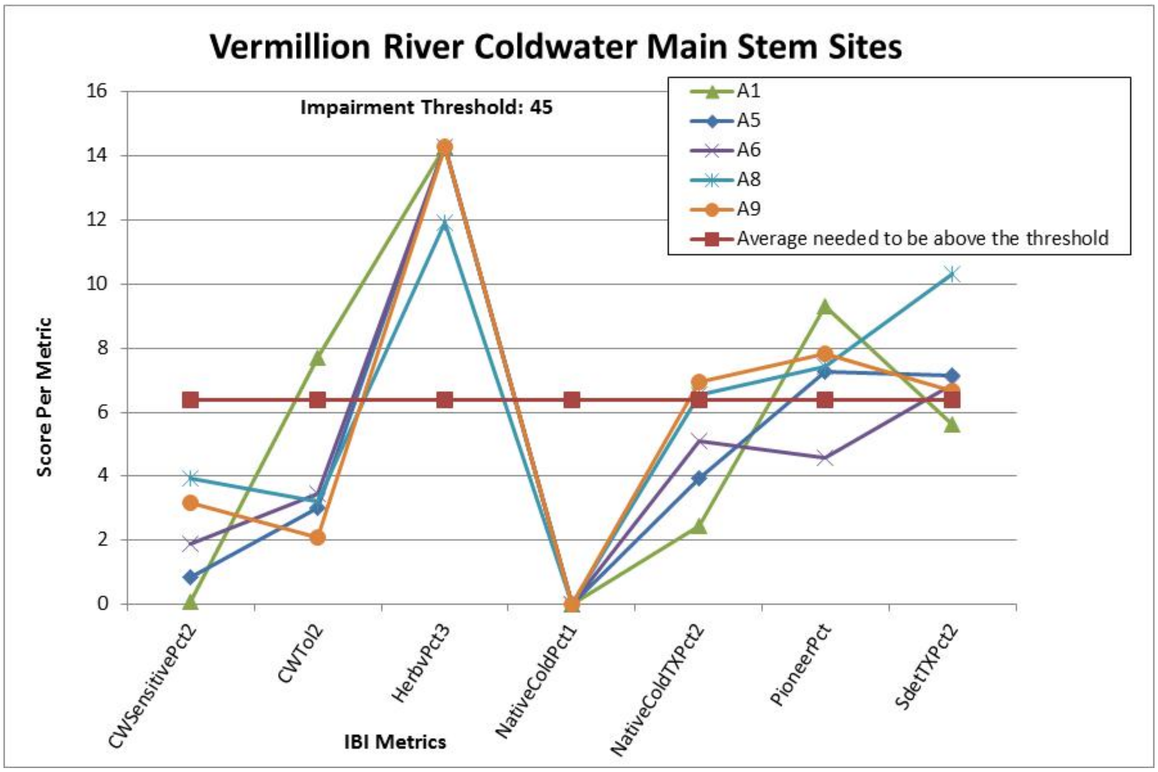



**Figure 2-7. Average (2008-2012) individual fish IBI metrics scores for southern coldwater stream sites on the main stem of the Vermillion River**

A comparison of the average individual metric scores for the southern coldwater stream sites on the main stem of the Vermillion River is provided as Figure 2-7. Examining the average metrics scores across all of the main stem sites reveals that the individual sites are scoring quite similarly on many of the metrics, indicating that the fish community is relatively similar along the Vermillion River. The metrics for the relative abundance of sensitive individuals and relative abundance of native coldwater individuals score very poorly for all sites. The metrics for the number of tolerant coldwater taxa and relative abundance of native coldwater taxa generally scored low for most sites, but there was one site scoring above the average needed to be above the threshold for each metric. All sites scored well above the average needed for the abundance of herbivore species and the sites scored moderately well for the relative abundance of pioneer species. These two metrics have a negative relationship and the coldwater sites are scoring well for both of these metrics due to the low number or complete absence of these species and individuals. It is likely that the sites will continue to always score well on these metrics in the future as the species that comprise these metrics are not prevalent in the Vermillion River watershed or even absent from the watershed.

A comparison of the average individual metric scores for the southern coldwater stream sites from the tributaries to the Vermillion River is provided as Figure 2-8. The trends from average individual metrics from the coldwater tributary sites are similar to the trends from the Vermillion River coldwater sites. The metrics for the relative abundance of native coldwater individuals score very poorly for all sites. The relative abundance of native coldwater taxa also scored low for all the tributary sites. The metrics for the number of tolerant coldwater taxa and relative abundance of sensitive individuals scored slightly higher on the tributary sites compared to the main stem but still below the average needed to be above the impairment threshold. The coldwater tributary sites all scored well on abundance of herbivore species and the sites scored above the average needed on the relative abundance of pioneer species.

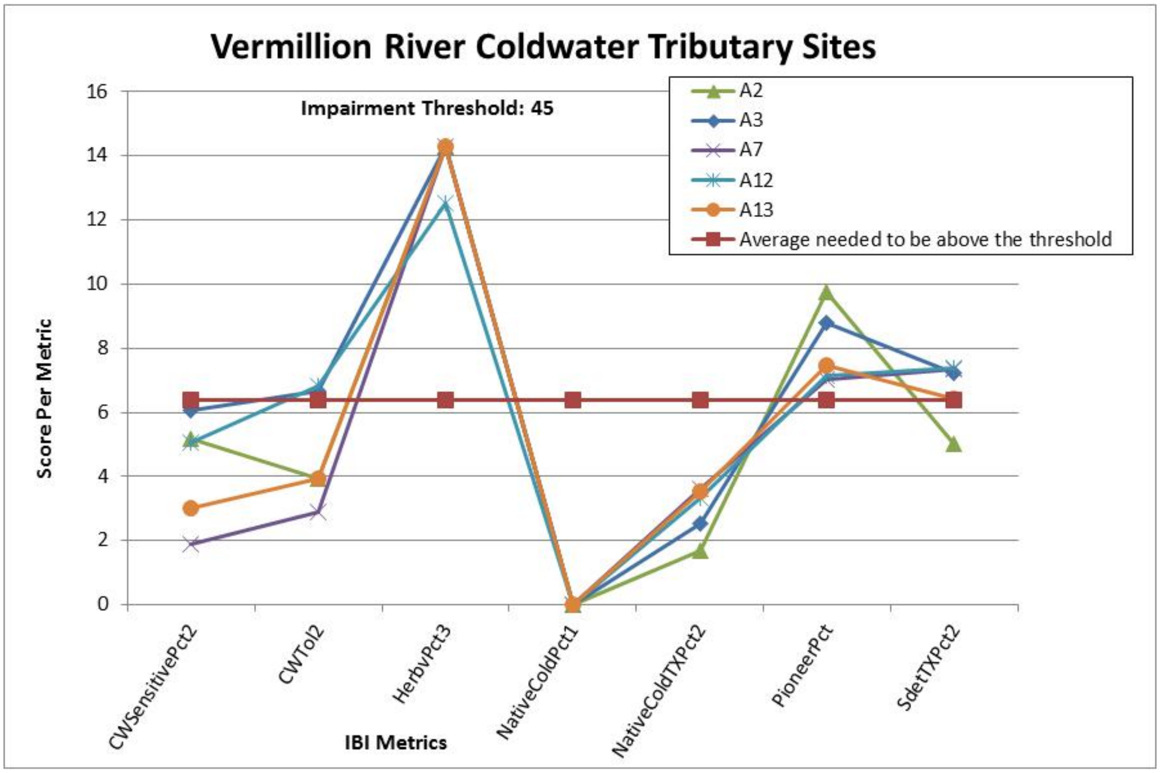



**Figure 2-8. Average (2008-2012) individual fish IBI metrics scores for southern coldwater stream sites for the tributaries of the Vermillion River**

As part of the WRAPS study, supplemental fish monitoring was conducted at one additional location on the main stem of the Vermillion River within the Southern Coldwater Streams category. The additional monitoring reach was on the main stem of the Vermillion downstream of the VRWJPO long term monitoring site A1 approximately (see Figure 2-1). The monitoring was conducted by the MPCA in August 2012. The purpose of this additional monitoring site was to further define the fish community near site A1 as water levels and habitat conditions have often lead to sampling difficulties and a very low total catch at this site.

The total number of species collected at the WRAPS site was greater than what has been typically found at the long term site A1. The IBI scores for the one WRAPS supplemental site is as follows (see Figure 2-1):

- Vermillion River Downstream of Cedar Ave (downstream of A1): 38

This IBI score is within the range of IBI scores from A1 that have ranged from 33 to 45 over the previous four years of monitoring. The individual metric scores were not available for this reach. The total catch was much higher at this supplemental reach in terms of both species and total individuals collected compared to the long term site at A1. One species listed within the native coldwater metrics was found at this site, brook stickleback. Even though the total IBI score was not different than the IBI scores from A1, the increase in total catch and the habitat conditions suggest that this alternate site is likely a better location for long term monitoring on this portion of the Vermillion River.

The most abundant coldwater species in the Vermillion River watershed is the brown trout, which is an introduced species. As a result it is not counted in the native coldwater taxa or individuals metrics. There are three native coldwater species that have been collected during the recent data collections from 2008 through 2012 including the brook stickleback, pearl dace and longnose dace. These species are currently very limited within the watershed in terms of distribution and total individuals. For example in 2012, brook stickleback were collected from only five sites with only ten individuals collected and pearl dace were collected at only two sites with five total individuals. Longnose dace were not collected in 2012 and there has only been on recent collection record of the longnose dace in the Vermillion River, which was one individual collected in 2009 from Site A14, which is within the warmwater section of the watershed. By contrast, the brown trout were collected at ten of the 14 sites and there were 209 individuals collected.

There is one record of a brook trout collected by the MN DNR in 2004. This record may be associated with a stocking effort that was conducted by the DNR in an attempt to establish brook trout in the Vermillion River or possibly by a local sportsman's club that has been known to release trout into the river near Farmington. There are reports that the Vermillion River did support brook trout prior to 1950 (Nerbonne and Chapman, 2007) however the information is anecdotal as to whether the species was naturally occurring or only present due to stocking efforts. It was suggested that municipal wastewater discharge to the river was the likely cause of extirpation of species from the watershed. Review of articles and information gathered by the historical society indicate that stocking efforts were the reason for brook trout being present in the Vermillion River, with stocking programs beginning in the late 1800's and continuing various years into the 1930's. The historical records allude that the brook trout populations were never sustainable.

Beyond the collection records for pearl dace, brook stickleback and longnose dace, there is little to no information to determine if the other species used to calculate the native coldwater metrics have ever occurred within the watershed. Based on known species range distributions, it is possible that these other native coldwater species did not historically occur in the Vermillion River watershed. Species such as redside dace are found in watersheds to the south, such as the Cannon River but have never been collected in the Vermillion River and likely never occurred there. Other species such as finescale dace are found in the northern part of Minnesota and species such as fantail darters and mottled sculpin are not found in low gradient streams such as the Vermillion River. The very low number of native coldwater species that have either historically occurred or currently exist in the watershed is limiting the portion of the IBI scores associated with these two metrics. The two native coldwater species metrics account for almost 30 percent of the total IBI score and all reaches are scoring zero out of 14 almost every year for the native coldwater individuals metric and zero to five most years for the native coldwater taxa metric.

The coldwater stream reaches are also receiving relatively low scores for the taxa richness of tolerant species in coldwater streams and relative abundance of individuals that are sensitive in coldwater streams. A fairly large number of tolerant species and individuals have been collected from all sites in the watershed, including tolerant warmwater species found in coldwater reaches driving down the scores for this metric. Additionally, there have been very few species rated as sensitive found in the watershed. There have been three coldwater species rated as sensitive collected in the Vermillion River watershed between 2008 and 2012 including the pearl dace, longnose dace and brown trout. Brown trout is the only one of the three species which has been widespread in the collections in terms of both total individuals collected and total number of sites observed.

### 2.1.2 Macroinvertebrates

The majority of the stream monitoring sites considered in this Stressor ID fall into the Southern Coldwater classification. Two sites are classified as Southern Forest Glide-Pool Streams, and one as Southern Riffle-Run Streams.

#### 2.1.2.1 Southern Coldwater Streams

The individual metrics that make up this classification are primarily related to sensitivity to temperature, disturbance and to pollution, and to a community composition that are supportive of cold water fish taxa and that are typically found in clear, cool or cold water streams. Table 2-3 shows the individual metrics and their expected response to disturbance.

**Table 2-3. Metrics that make up the Southern Coldwater Stream IBI.**

| Metric Name | Category | Response | Metric Description |
|---|---|---|---|
| Coldwater Biotic Index | Habitat | Increase | Coldwater Biotic Index score based on coldwater tolerance values derived from Minnesota taxa/temperature data. |
| ChiroDip | Composition | Increase | Ratio of Chironomidae abundance to total Dipteran abundance. |
| Percent (%) Collector – Filterers | Trophic | Decrease | Relative abundance (%) of collector-filterer individuals in a subsample |
| Hilsenhoff Biotic Index, MN TVs | Tolerance | Increase | A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart |
| Intolerant Taxa Richness, 2 ch | Tolerance | Decrease | Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, using MN TVs |
| Percent (%) Trichoptera Taxa | Composition | Decrease | Relative percentage of taxa belonging to Trichoptera |
| Percent (%) Very Tolerant, 2 | Tolerance | Increase | Relative abundance (%) of macroinvertebrate individuals in subsample with tolerance values equal to or greater than 8, using MN TVs. |

The M-IBI scores for the eight monitoring sites that are classified as Southern Coldwater streams are detailed in Table 2-4 and shown in Figure 2-9. Some sites were monitored in 2004 and 2008, but most of the data is from the VRWJPO's fish and macroinvertebrate monitoring program.

Many of the monitoring sites scored at or just below the southern coldwater streams listing threshold, within the lower confidence limit. Sites A2 and A3 on South Creek; A5 on the upper reach of the main stem of the Vermillion just upstream of Farmington and A12 on the South Branch near Highway 52 most years scored below the lower confidence limit.

Table 2-4. Macroinvertebrate Index of Biotic Integrity scores for Southern Coldwater sites.

| Site | Stream AUID | 2004 | 2008 | 2009 | 2010 | 2011 | 2012 | Average | Listing Threshold |
|---|---|---|---|---|---|---|---|---|---|
| A1 Vermillion | 517 | -- | -- | 59 | 43 | 43 | 39 | 46 | 46 |
| A2 S Creek | 527 | -- | -- | 0.3 | 15 | 19 | 6 | 10 | 46 |
| A3 S Creek | 527 | -- | 36 | 16 | 42 | 15 | 21 | 36 | 46 |
| A5 Vermillion | 517 | 19 | 14 | 16 | 42 | 36 | 12 | 23 | 46 |
| A6 Vermillion | 517 | -- | 50 | 50 | 45 | 44 | 13 | 38 | 46 |
| A7 N Creek | 545 | -- | 16 | 29 | 51 | 44 | 39 | 36 | 46 |
| A8 Vermillion | 507 | -- | 43 | -- | -- | -- | -- | 43 | 46 |
| A9 Vermillion | 507 | -- | 24 | -- | -- | -- | -- | 24 | 46 |
| A12 S Branch | 707 | 55 | 12 | 12 | 26 | 30 | 37 | 32 | 46 |
| A13 S Branch | 707 | -- | 22 | 43 | 45 | 38 | 42 | 38 | 46 |

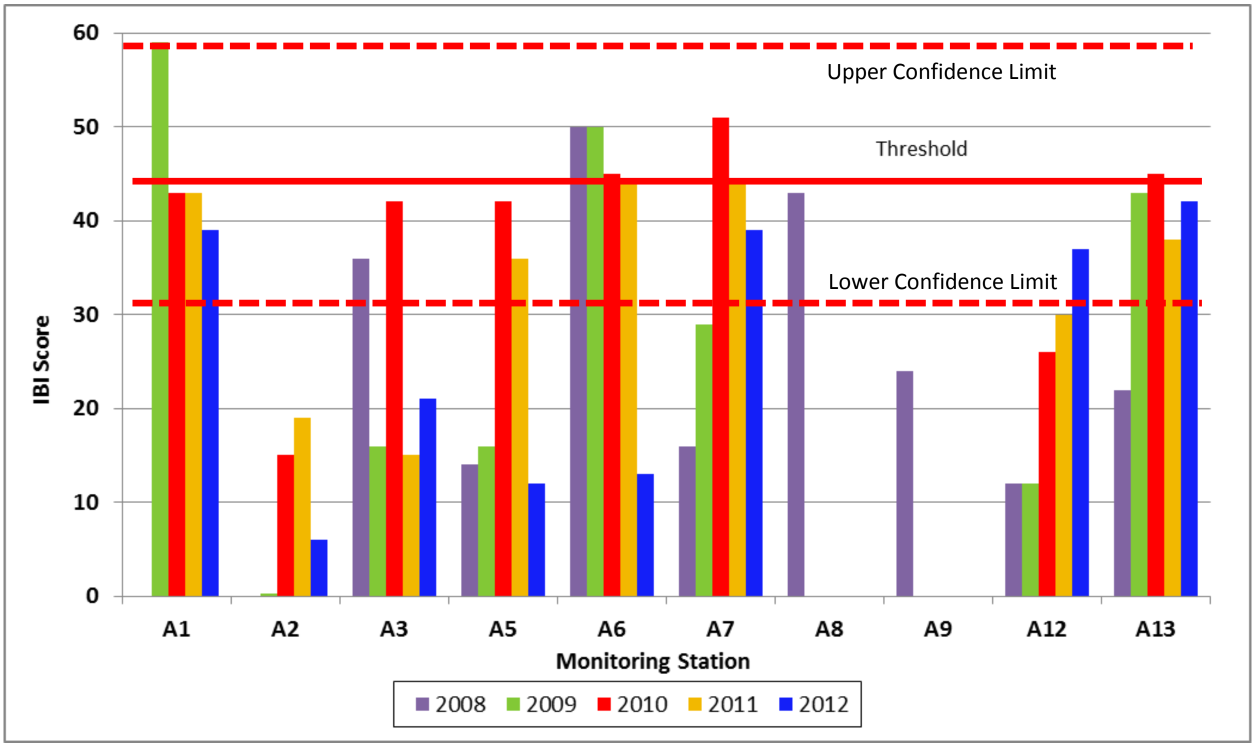



Figure 2-9. M-IBI scores in the Southern Coldwater Streams Category compared to impairment listing threshold

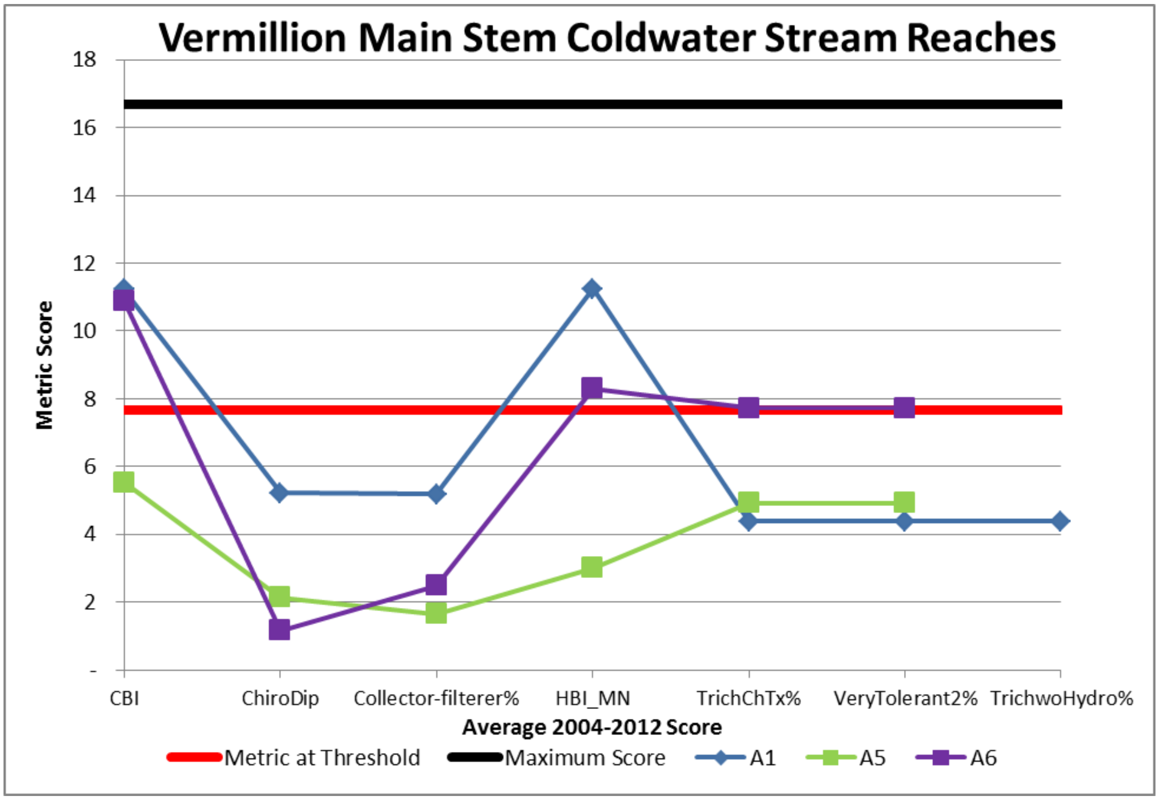



**Figure 2-10. Individual metrics for coldwater stream sites on the Vermillion River.**

*Vermillion River Sites.* Figure 2-10 above shows the individual metrics for three sites on the Vermillion River main stem.

Reach 517 experiences TSS exceedances across flow regimes, and is impaired for both turbidity and low dissolved oxygen. Data recorded at Site A1 very often was less than the 7 mg/L daily minimum, while Sites A5 and A6 periodically but less frequently were below that minimum. Moderately tolerant Ephemeroptera taxa, which are typically sensitive to low oxygen levels, were relatively abundant in the samples taken there, as well as the occasional very sensitive Plecopteran individual.

Each site scored low on the metrics “Ratio of Chironomidae abundance to total Dipteran abundance,” and “Relative abundance (%) of collector-filterer individuals” and all but one were low on “Relative percentage of taxa belonging to Trichoptera.” These scores are characteristic of a stream high in turbidity. Streamflow high in suspended sediment can reduce collector-filterer feeding efficiency, and Tricoptera in particular prefer clear, flowing, well-oxygenated water.

*Tributary Sites.* Figure 2-11 shows the individual metrics for coldwater stream tributaries North Creek and South Creek in the upper watershed and South Branch, which flows into the Vermillion River downstream. The macroinvertebrate communities at sites A2 and A3 on South Creek (reach 527) are dominated by pollution- and low dissolved oxygen-tolerant chironomids and oligochaets, taxa that are common in highly disturbed aquatic environments. This stream has been straightened and ditched, with TSS concentrations that frequently exceed the water quality standard and dissolved oxygen that frequently falls below the 7 mg/L minimum standard. These sites scored poorly in pollution tolerance, community composition, and coldwater taxa. South Creek conveys runoff from the city of Lakeville, which likely receives pulses of nutrient and sediment enriched, raised-temperature runoff from impervious surface.

Similar to sites A2 and A3, sites A12 and A13 on South Branch (reach 707) exhibit low diversity and are dominated by tolerant organisms.  Reach 707 is a low gradient stream with excessive siltation and mucky pools providing little habitat diversity. However, monitoring data suggests that this reach experiences fewer DO and TSS exceedances and this is reflected in moderately greater diversity in collector-filterer and cold water taxa.

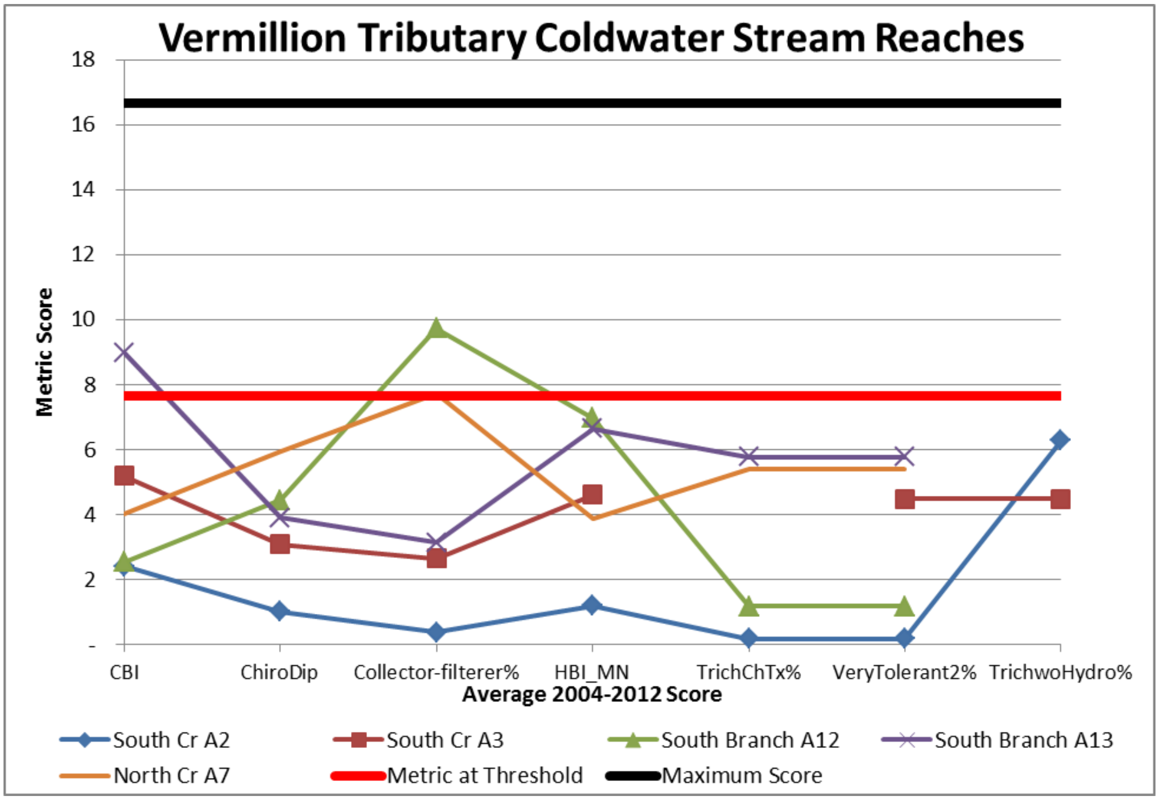


**Figure 2-11. Individual metrics for tributary coldwater stream sites.**

### 2.1.2.2 Southern Forest Glide-Pool Streams

Glide-pool streams are typically low-gradient streams with a slow current. The individual metrics that make up this classification are related to community composition and sensitivity to pollution and disturbance. In particular, the metric rating the taxa richness, or total number of different kinds of predators is an indication of trophic complexity and community stability. Table 2-5 shows the individual metrics and their expected response to disturbance.

**Table 2-5. Metrics that make up the Southern Forest Glide-Pool Stream IBI.**

| Metric Name | Category | Response | Metric Description |
|---|---|---|---|
| ClingerCh | Habitat | Decrease | Taxa richness of clinger taxa |
| Collector-filtererPct | Trophic | Decrease | Relative abundance (%) of collector-filterer individuals in a subsample |
| DomFiveChPct | Composition | Increase | Relative abundance (%) of dominant five taxa in subsample (chironomid genera treated individually) |
| HBI_MN | Tolerance | Increase | A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart |

| Metric Name | Category | Response | Metric Description |
|---|---|---|---|
| Intolerant2Ch | Tolerance | Decrease | Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, using MN TVs |
| POET | Richness | Decrease | Taxa richness of Plecoptera, Odonata, Ephemeroptera, & Trichoptera (baetid taxa treated as one taxon) |
| PredatorCh | Trophic | Decrease | Taxa richness of predators |
| TaxaCountAllChir | Richness | Decrease | Total taxa richness of macroinvertebrates |
| TrichopteraChTxPct | Composition | Decrease | Relative percentage of taxa belonging to Trichoptera |
| TrichwoHydroPct | Composition | Decrease | Relative abundance (%) of non-hydropsychid Trichoptera individuals in subsample |

The M-IBI scores for the two monitoring sites that are classified as Southern Forested Streams are detailed in Table 2-6 and shown in Figure 2-12. Both sites appear to lack taxa and trophic richness, as shown by the low scores for the Predator Abundance and Total Taxa Richness metrics, and community complexity, but some moderately pollution-tolerant taxa are present.

**Table 2-6. Macroinvertebrate Index of Biotic Integrity scores for Southern Forest Glide-Pool Streams sites.**

| Site | Stream AUID | 2004 | 2008 | 2009 | 2010 | 2011 | 2012 | Average | Listing Threshold |
|---|---|---|---|---|---|---|---|---|---|
| A10 S Branch | 517 | -- | 48 | 31 | 30 | 34 | 33 | 35 | 47 |
| A14 Vermillion | 692 | -- | 50 | 61 | 29 | 34 | 32 | 41 | 47 |

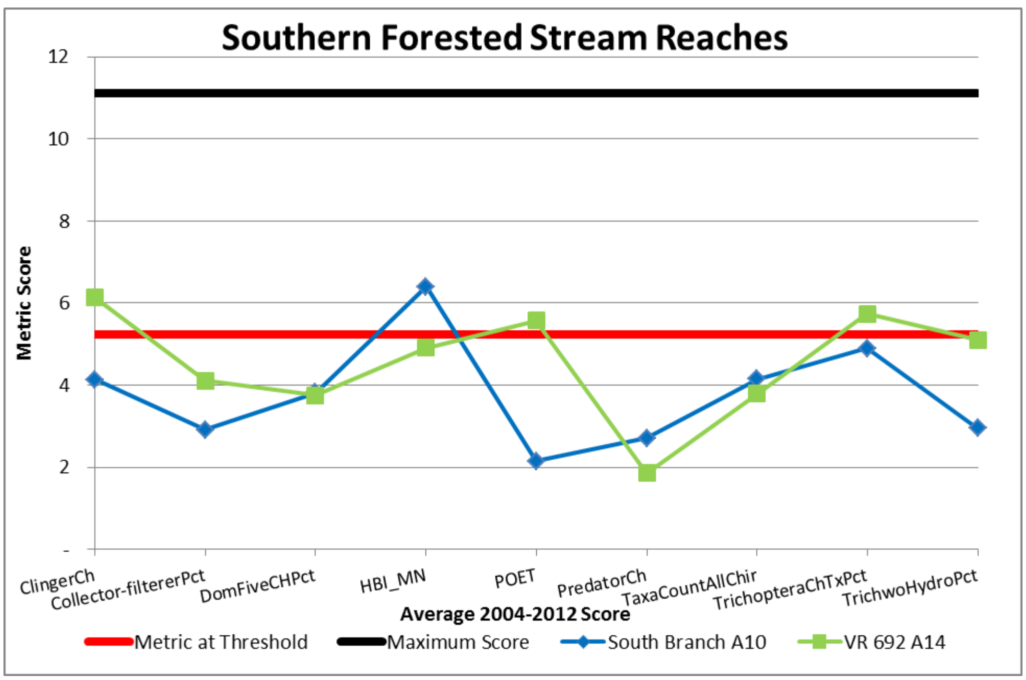



**Figure 2-12. Individual metrics for Southern Forested Stream sites.**

### 2.1.2.3 Southern Forest Riffle-Run Streams

Riffle-Run streams are typically moderate to high-gradient streams with a faster current and areas of turbulent water. The individual metrics that make up this classification are related to community composition, including taxa that are adapted for flowing water and are habitat generalists, and metrics related to sensitivity to pollution and disturbance (Table 2-7).

The M-IBI scores for the one monitoring site classified as Southern Forest Riffle-Run - A4 on an unnamed tributary to the Vermillion River in Eureka Township - are detailed in Table 2-8 and shown in Figure 2-13.

**Table 2-7. Individual metrics of the Southern Riffle-Run Stream IBI.**

| Metric Name | Category | Response | Metric Description |
|---|---|---|---|
| ClimberCh | Habitat | Decrease | Taxa richness of climbers |
| ClingerChTxPct | Habitat | Decrease | Relative percentage of taxa adapted to cling to substrate in swift flowing water |
| DomFiveChPct | Composition | Increase | Relative abundance (%) of dominant five taxa in subsample (chironomid genera treated individually) |
| HBI_MN | Tolerance | Increase | A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart |
| InsectTxPct | Composition | Decrease | Relative percentage of insect taxa |
| Odonata | Richness | Decrease | Taxa richness of Odonata |
| Plecopotera | Richness | Decrease | Taxa richness of Plecoptera |
| PredatorCh | Trophic | Decrease | Taxa richness of predators |
| Tolerant2ChTxPct | Tolerance | Increase | Relative percentage of taxa with tolerance values equal to or greater than 6, using MN TVs |
| Trichoptera | Richness | Decrease | Taxa richness of Trichoptera |

This is site that runs through areas of wetland and woodland. The individual metrics related to pollution and disturbance tolerance score relatively better than those relating to predator abundance and taxa richness of climbers. This may be related to a lack of specific types of quality habitat. The Minnesota Stream Habitat Assessment (MSHA) completed at this site found good riparian width and gravel-cobble pools and riffles, but moderate embeddedness and sparse in-stream cover. There appears to have been some filling and scouring of pools and changing embeddedness over the four years of MSHA data.

**Table 2-8. Macroinvertebrate Index of Biotic Integrity scores for Southern Riffle Run Streams sites.**

| Site | Stream AUID | 2004 | 2008 | 2009 | 2010 | 2011 | 2012 | Average | Listing Threshold |
|---|---|---|---|---|---|---|---|---|---|
| A4 Unnamed | 666 | -- | -- | 40 | 31 | 22 | 28 | 30 | 36 |

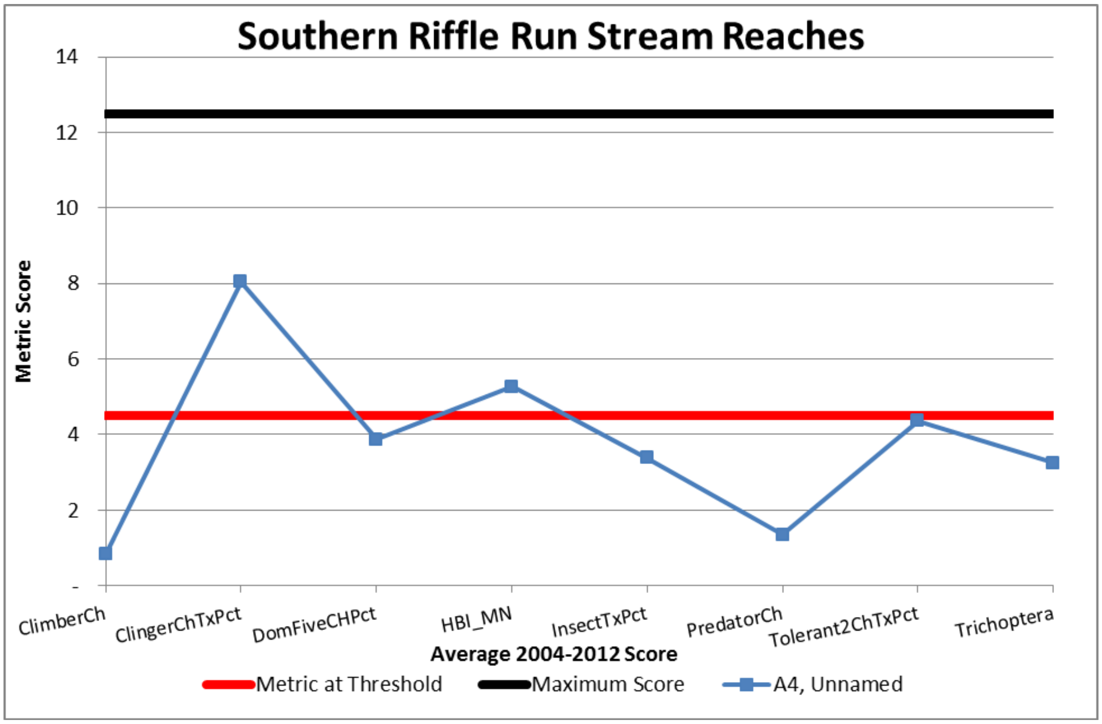
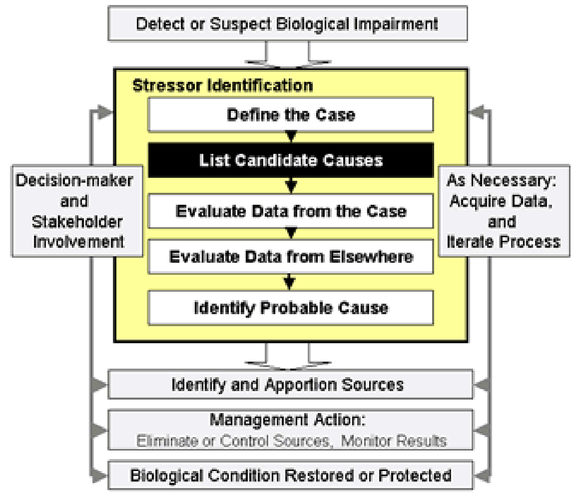



**Figure 2-13. Individual metrics for Southern Riffle-Run stream sites.**

# 3.0 Candidate Causes

## 3.1 CANDIDATE CAUSES




The CADDIS Stressor Identification analysis is a stepwise procedure that begins by defining the case, as set forth in sections 1 and 2 of this report, and then identifying potential, or candidate causes of the defined impairment.

The initial step is to identify all the potential causes and then to eliminate those that are not supported by evidence or are unlikely to be significant factors in the impairment. The remaining candidate causes are then evaluated in more detail.

The CADDIS documentation includes a lengthy list of potential candidate causes to serve as a starting point for this step. These potential candidate causes include:

- Dissolved oxygen (DO) regime alteration
- Hydrologic regime alteration (includes flow or depth conditions; timing, duration, frequency, etc.)
- Nutrient regime alteration
- Organic-matter regime alteration
- pH regime alteration
- Salinity regime alteration
- Bed sediment load changes, including siltation
- Suspended solids and/or turbidity alteration
- Water temperature regime alteration
- Habitat destruction
- Habitat fragmentation (e.g., barriers to movement, exclusion from habitat)
- Physical crushing and trampling
- Toxic substances
- Herbicides and fungicides
- Halogens and halides (e.g., chloride, trihalomethanes)
- Fish-killing agents (e.g., rotenone)
- Insecticides
- Lampricides
- Metals
- Molluscicides
- Organic solvents (e.g., benzene, phenol)
- Other hydrocarbons (e.g., dioxins, PCBs)
- Endocrine disrupting chemicals
- Mixed, cumulative effect

- Interspecies competition
- Complications due to small populations (e.g., inbreeding, stochastic fluctuation, etc.)
- 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)

## 3.2 CANDIDATE CAUSES RULED OUT

### 3.2.1 Environmental Factors

A number of environmental factors were reviewed and ruled out because they are unlikely or there is no evidence to suspect that factor is present. These include:

- Physical crushing and trampling
- Fish-killing agents (e.g., rotenone)
- Interspecies competition
- Complications due to small populations (e.g., inbreeding, stochastic fluctuation, etc.)
- 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)

Water quality monitoring data was evaluated to determine if any of the chemical or physical conditions in the streams are a plausible stressor.

**Table 3-1. Water quality data collection sites.**

| MPCA Site | Stream Reach | Biological Site | Description |
|---|---|---|---|
| S004-338 | 517 | A1 | Vermillion River at 235th St. W |
| S004-313<br>S005-444 | 527 | A3 | South Creek Vermillion River at Flagstaff Avenue |
| S003-325 | 517 | A5 | Vermillion River at 220th St. W |
| S003-326 | 517 | A6 | Vermillion River at Denmark Avenue (Hwy 31) |
| S003-323 | 545 | -- | North Creek Vermillion River at Chippendale Ave (Hwy 3) road crossing |
| S003-324 | 671 | A7 | North Creek Vermillion River, West of Chippendale Ave (Hwy 3) |
| S000-896 | 896 | A9 | Vermillion River at Blaine Avenue |
| S002-421 | 707 | A13 | South Branch Vermillion River at CSAH-66 |
| S001-398 | 692 | A14 | Vermillion River at CSAH-85 Bridge |

**Table 3-2. 2001-2012 summer average water quality data by monitoring location.**

| Parameter | Typical Ecoregion Values | Collection Site (Biological Site) ID | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S003-338 (A1) | S005-444 (A3) | S004-313 (A3) | S003-325 (A5) | S003-326 (A6) | S003-323 (--) | S003-324 (A7) | S000-896 (A9) | S001-398 (A14) | S002-421 (A13) |
| Temperature (Celsius) | *3.5-20* | 15.8 | 15.5 | 16.3 | 17.3 | 16.2 | 16.5 | 16.6 | 18.5 | 18.3 | 16.2 |
| DO (mg/L) | -- | 6.9 | 6.8 | 6.5 | 7.8 | 7.3 | 6.7 | 6.8 | 8.5 | 8.3 | 7.8 |
| pH | *8.0-8.2* | 7.6 | 7.6 | 7.5 | 7.9 | 7.9 | 7.7 | 7.7 | 8.1 | 8.0 | 7.9 |
| Total Phosphorus (µg/L) | *160-330* | 84 | 48 | 45 | 139 | 112 | 120 | 116 | 427 | 301 | 84 |
| TKN (µg/L) | *1,300-2,700* | 770 | 488 | 418 | 756 | 665 | 693 | 726 | 423 | 869 | 574 |
| NH3 (µg/L) | -- | 20 | 28 | 27 | 34 | 33 | 47 | 49 | 91 | 41 | 39 |
| Nitrate (µg/L) | --- | 270 | 1,411 | 1,499 | 1,856 | 1,932 | 774 | 797 | 1,710 | 4,842 | 5,627 |
| 5-day BOD (mg/L) | *2.0 – 5.5* | 1.0 | 2.2 | -- | 1.9 | 1.8 | 2.7 | 2.3 | 1.5 | 2.3 | 1.3 |
| Chlorophyll a (µg/L) | -- | 1.8 | 4.5 | -- | 5.1 | 4 | -- | 10.7 | 7.4 | 6.9 | 4.1 |

Source: EQuIS, McCollor and Heiskary(1993).

### 3.2.2 pH

Figure 3-1 shows available pH data. Measured pH is on the lower end of the ecoregion range, but is still well above the pH value of 5.0 or less that is typically associated with acidification impacts to the biota (Allan 1995). The applicable pH standard for most Class 2 waters in Minnesota is a minimum of 6.5 and a maximum of 8.5 (MPCA 2010). pH was eliminated as a candidate stressor because the pH range observed in the impaired reaches falls within the range necessary to support aquatic life.

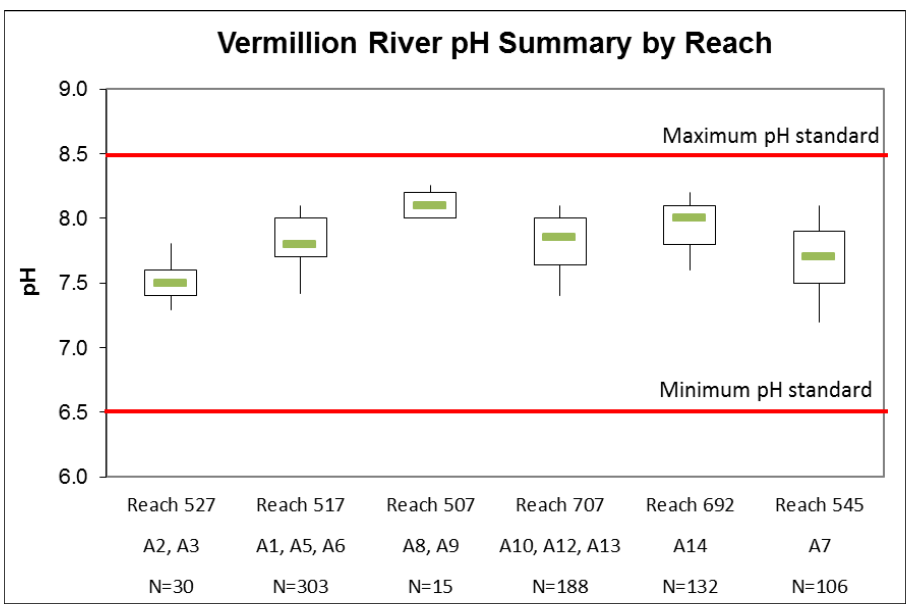



**Figure 3-1. 2001-2012 pH data for the Vermillion River and its tributaries.**

Note. The upper and lower edge of each box represents the 75th and 25th percentile of the data range for each site. Error bars above and below each box represent the 95th and 5th percentile of the dataset. The green dash is the median concentration of all data collected

### 3.2.3 Ionic Strength

Elevated in-stream concentrations of chloride from road salt used to control ice has been a stressor to aquatic life in other streams in the Twin Cities Metro Area. Figure 3-2 shows chloride concentration data for the impaired biota reaches in the Vermillion River watershed. Ionic strength, specifically chloride, was eliminated as a stressor because the observed data is well below the Class 2 waters chronic standard, and there are no observations that exceed the acute standard.

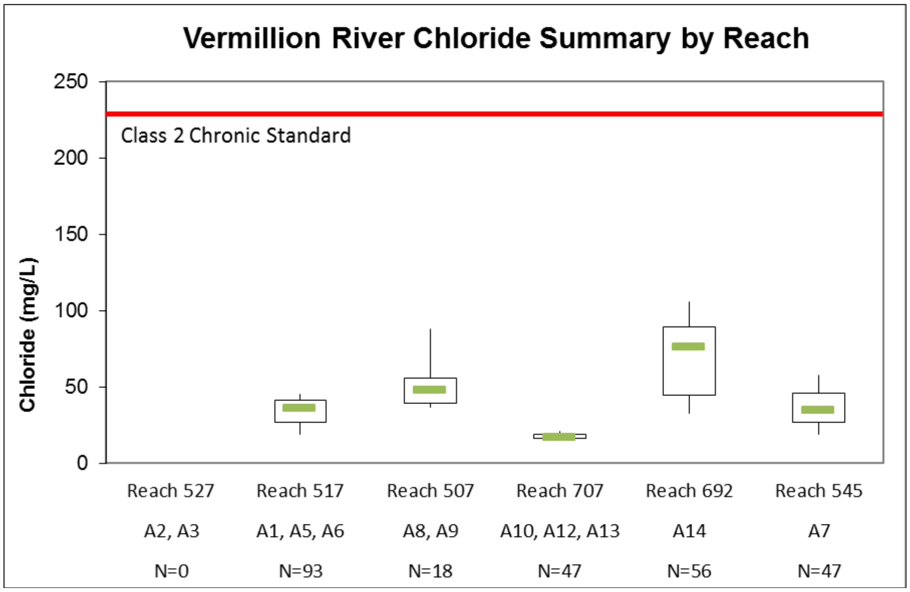



**Figure 3-2. 2001-2012 chloride data for the Vermillion River and tributaries.**
Note. The upper and lower edge of each box represents the 75$^{th}$ and 25$^{th}$ percentile of the data range for each site. Error bars above and below each box represent the 95$^{th}$ and 5$^{th}$ percentile of the dataset. The green dash is the median concentration of all data collected

### 3.2.4 Toxics

Water quality monitoring results for pesticides and organic pollutants was obtained from the MPCA EQuiS database for the Vermillion River. The primary source of pesticide and other pollutants data is the Minnesota Department of Agriculture Water Monitoring Program. Results for pesticide monitoring were available from 2002 through 2011. There is data available for more than 30 different pesticides, with a range of nine to 30 sample results for each parameter. The monitoring results were compared to the EPA Office of Pesticides Program aquatic life benchmarks for both fish and aquatic macroinvertebrates. The aquatic life benchmarks include both acute and chronic exposure levels for fish and invertebrates for several hundred different pesticides

The vast majority of the results for all monitored pesticides were non-detections with very few instances of a detection for a specific pollutant. For the samples with an observed detection all results were below both the chronic and acute exposure levels for both fish and aquatic macroinvertebrates. Of the more than 30 pesticides with monitoring results in the Vermillion River watershed there were eight pesticides where either the chronic or acute standard or both is lower than the precision of the laboratory analysis. For example, there were 30 sample results for diazinon and all 30 samples were reported as non-detections as <0.12 ug/L. However, the chronic standard for exposure to this pesticide for aquatic macroinvertebrates is 0.11 ug/L. Therefore the precision of the analysis was not sufficient to rule with

100 percent certainty that the pesticide is not present within the watershed at levels that would be stressful or detrimental to aquatic macroinvertebrates. In all cases, there were no positively detected results for these pollutants that were above the aquatic benchmark and it is only the lack of sufficient precision that adds uncertainty. However, because nearly all of the samples for all pesticides were non-detections it is unlikely that pesticides are a significant stressor leading to impairment of the fish or macroinvertebrate communities.

## 3.3 POTENTIAL INTERACTING PHYSICAL AND CHEMICAL STRESSORS

Several chemical or physical factors may not be primary stressors but may interact with other stressors, intensifying or modifying their impacts on the biota. Often there is not enough data to quantify or otherwise explain what kind of impact those interactions might have in weighing evidence supporting or refuting various stressors.

### 3.3.1 Total Phosphorus

Nutrients in streams impact the biota through eutrophication, or the increased growth of plants and algae. Excessive nutrient levels may cause accelerated growth of periphyton, phytoplankton and macrophytes. At lower levels, breakdown of this accelerated plant growth may increase consumption of dissolved oxygen from the water column, while elevated levels may result in excessive phytoplankton growth that reduces light penetration and decreases available habitat and shelter for fish and macroinvertebrates.

Figure 3-3shows total phosphorus concentrations in the biotic impaired reaches. Reaches 507 and 692 show elevated concentrations with the median at or near the South River Region proposed standard of 150 µg/L. The median in Reach 507, which is the main stem of the Vermillion from Farmington to Highway 52, is above the proposed standard, and the 75$^{th}$ percentile value is greater than 500 µg/L. However, the nutrient response variable chl-a is not elevated (Figure 3-4) and the daily DO flux for Reach 507 is less than the maximum allowed under the proposed nutrient standard (Figure 3-5). Elevated TP concentrations are probably the result of watershed washoff during storm events, and do not appear to be causing excessive, long-lasting algae blooms or stagnant pools which may reduce clarity and deplete dissolved oxygen. However, excess nutrients may be an interacting factor that is leading to an overabundance of tolerant species and lack of intolerant species.

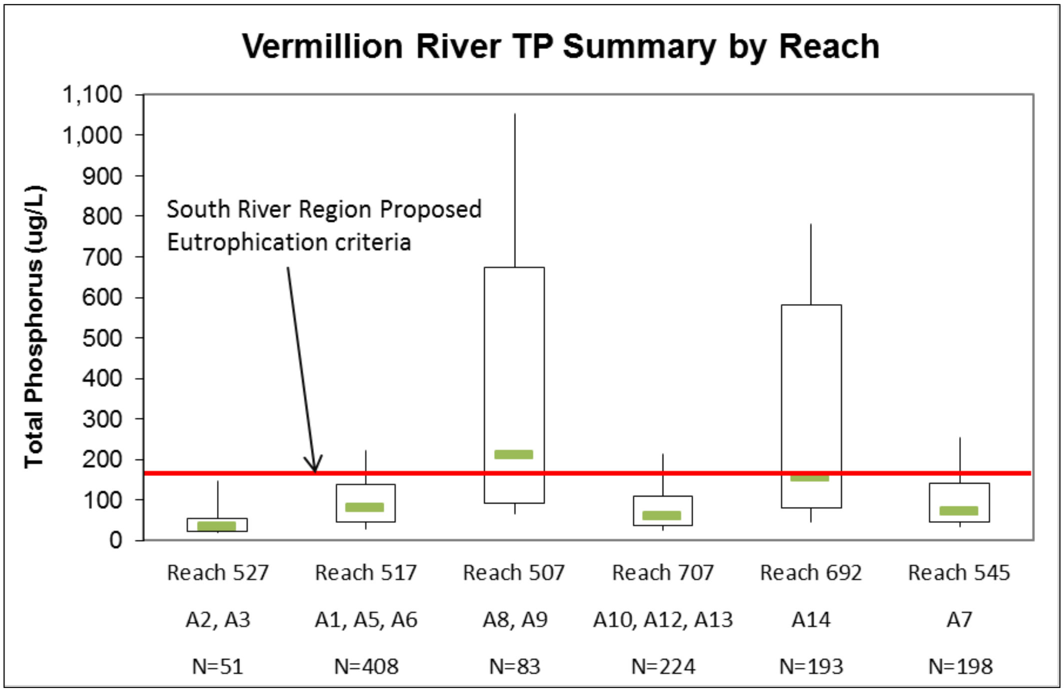



**Figure 3-3. 2001-2012 total phosphorus concentration in the Vermillion River and tributaries.**
Note. The upper and lower edge of each box represents the 75th and 25th percentile of the data range for each site. Error bars above and below each box represent the 95th and 5th percentile of the dataset. The green dash is the median concentration of all data collected.

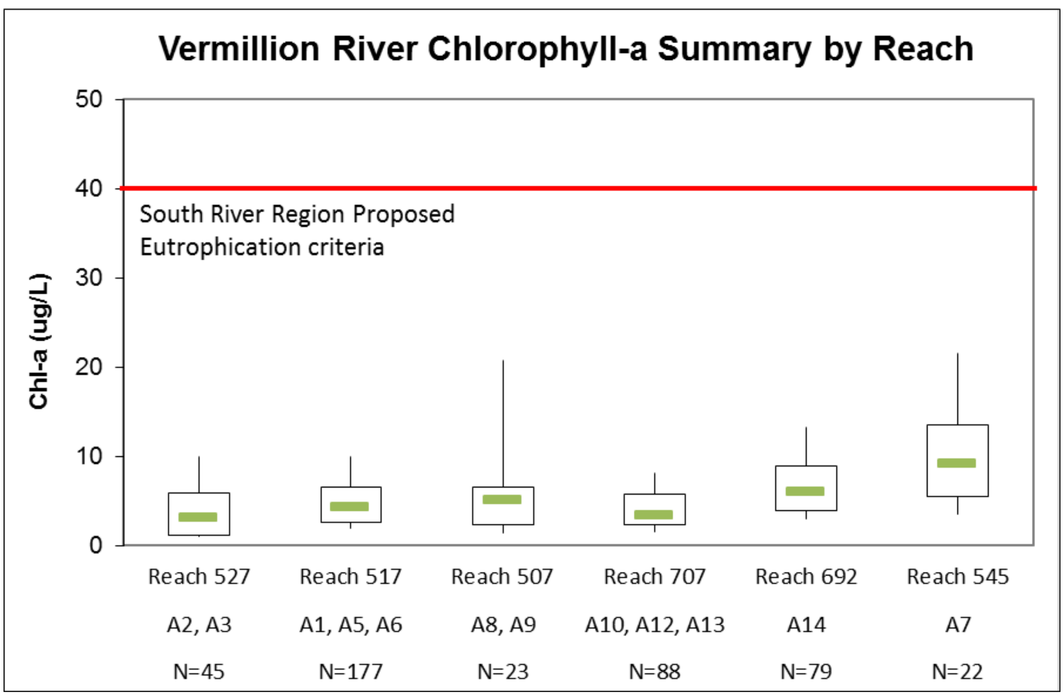



**Figure 3-4. 2001-2012 chlorophyll-a concentrations in the Vermillion River and tributaries.**
Note. The upper and lower edge of each box represents the 75th and 25th percentile of the data range for each site. Error bars above and below each box represent the 95th and 5th percentile of the dataset. The green dash is the median concentration of all data collected.

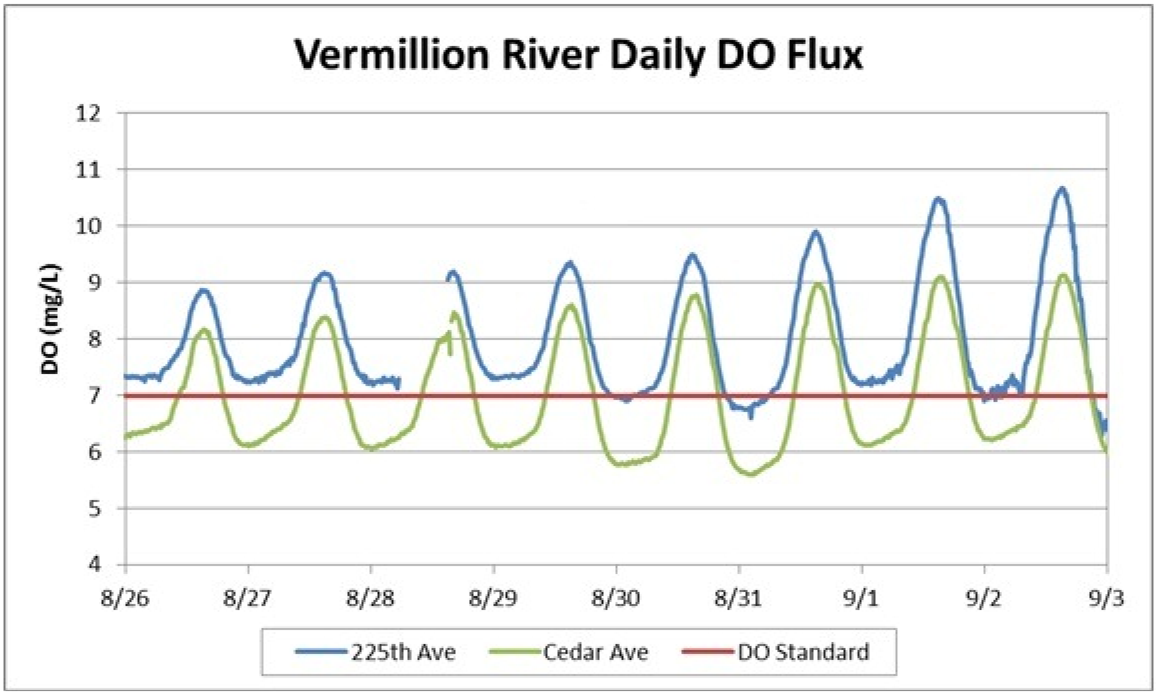


**Figure 3-5. Daily DO flux on Reach 507, August-September 2012.**

### 3.3.2 Nitrate

Nitrate-nitrogen can be toxic to certain aquatic life. Figure 3-6 shows 2001-2012 nitrate data for the biotic impaired reaches. Reach 692, which is the main stem of the Vermillion River from Highway 52 to Hastings, and Reach 707 (South Branch) shows some elevated concentrations.

A technical review prepared in support of the proposed state standard for nitrates (MPCA 2010) included a literature review and a summary of nitrate toxicity data for various aquatic organisms. Some macroinvertebrate taxa such as Ephemeroptera are more sensitive to elevated nitrate concentrations, but the concentrations in Reach 707 are well below the LC50 literature values. Nitrate was eliminated as a stressor for Reaches 527, 517, and 507 because the observed data is well below the literature values where such effects are likely to occur.  The fish community in Reach 692 is impaired, but the macroinvertebrate community is not. Nitrate may be an interacting factor on Reach 707 that is leading to an overabundance of tolerant species and lack of intolerant species.

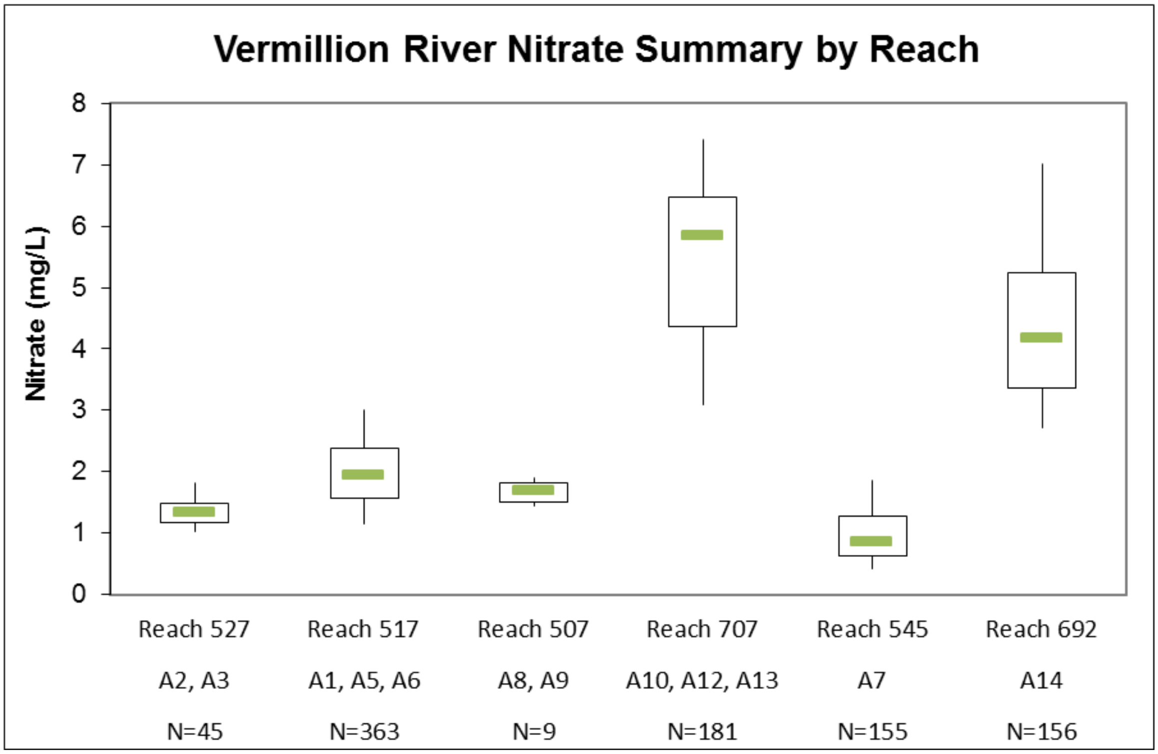



**Figure 3-6. 2001-2012 nitrate data for the Vermillion River and its tributaries.**
Note. The upper and lower edge of each box represents the 75$^{th}$ and 25$^{th}$ percentile of the data range for each site. Error bars above and below each box represent the 95$^{th}$ and 5$^{th}$ percentile of the dataset. The green dash is the median concentration of all data collected.

### 3.3.3 Hydrologic Alteration

Streams naturally experience variable flows both between seasons within a year and between years. Many stream processes are dependent on higher flows in the spring from runoff or precipitation and lower flows in the summer. However, altered flow regimes have been documented to be a stressor to biological communities. Loss of flow, low flows, or prolonged duration of low flow conditions can reduce overall habitat availability by decreasing water volume and wetted channel area. Prolonged duration of low flows tends to favor macroinvertebrate and fish species that prefer standing-water habitats, when low flows force aquatic biota to refuge in deep pools.

High-flow events can physically remove species from the channel to a downstream location. High flows also mobilize pebbles, sediment, woody debris, and plant material that can dislodge organisms. Frequent high-flow events can decrease species richness by eliminating or reducing populations that have not developed coping mechanisms, such as an ability to cling to substrate or burrow into sediments. Macroinvertebrate assemblages may shift to include more species with relatively short life cycles while fish communities would shift to favor species that prefer high current.

The main stem of the Vermillion River is a perennial stream for most of its length. There are several major tributaries that have perennial flows including North Creek, Middle Creek, South Creek and the South Branch of the Vermillion River. There are numerous smaller tributaries throughout the watershed that are a mix of perennial and intermittent streams. Some of the tributaries are ditches that have been constructed to facilitate drainage for agricultural production. The constructed ditches as well as tile lines in the agricultural portions of the watershed have altered the flow regime of the Vermillion River and its tributaries by delivering runoff and storm flow events to the stream channels more quickly, creating spikes in the hydrograph. Within the urban areas of the watershed the construction of impervious surfaces and storm water infrastructure including ponds and storm sewers can also alter runoff storage and flow patterns. Changes in the flow patterns from land use practices can have an influence on the biological community.

Within the Vermillion River watershed there are multiple monitoring stations that have seasonal or continuous flow records beginning in the early 2000s. The VRWJPO routinely tracks flow at nine stations across the watershed. The Dakota County SWCD and Scott County SWCD provide an analysis of flow data collected each year as part of the annual monitoring reports prepared for the VRWJPO. A comparison of the flow data to precipitation events within the annual reports reveals that the Vermillion River is prone to significant increases in flow as a result of major runoff or precipitation events. In addition to the flow stations maintained by the VRWJPO, there is one station maintained by the USGS within the watershed.

Flow duration curves were constructed for three monitoring stations with available flow data. Two stations are located in upstream portions of the watershed (VR2.5 and NC 0.36) while the USGS Gauge Station is located more centrally within the overall watershed (Figure 3-7). The USGS station has the longest overall dataset, with a continuous period of record for more than 80 years. Both of the upstream station's flow records are seasonal, and as a result data gaps for these stations were filled using regression relationships between the USGS gauge station and each respective upstream station to complete datasets required for analysis of the flow records.

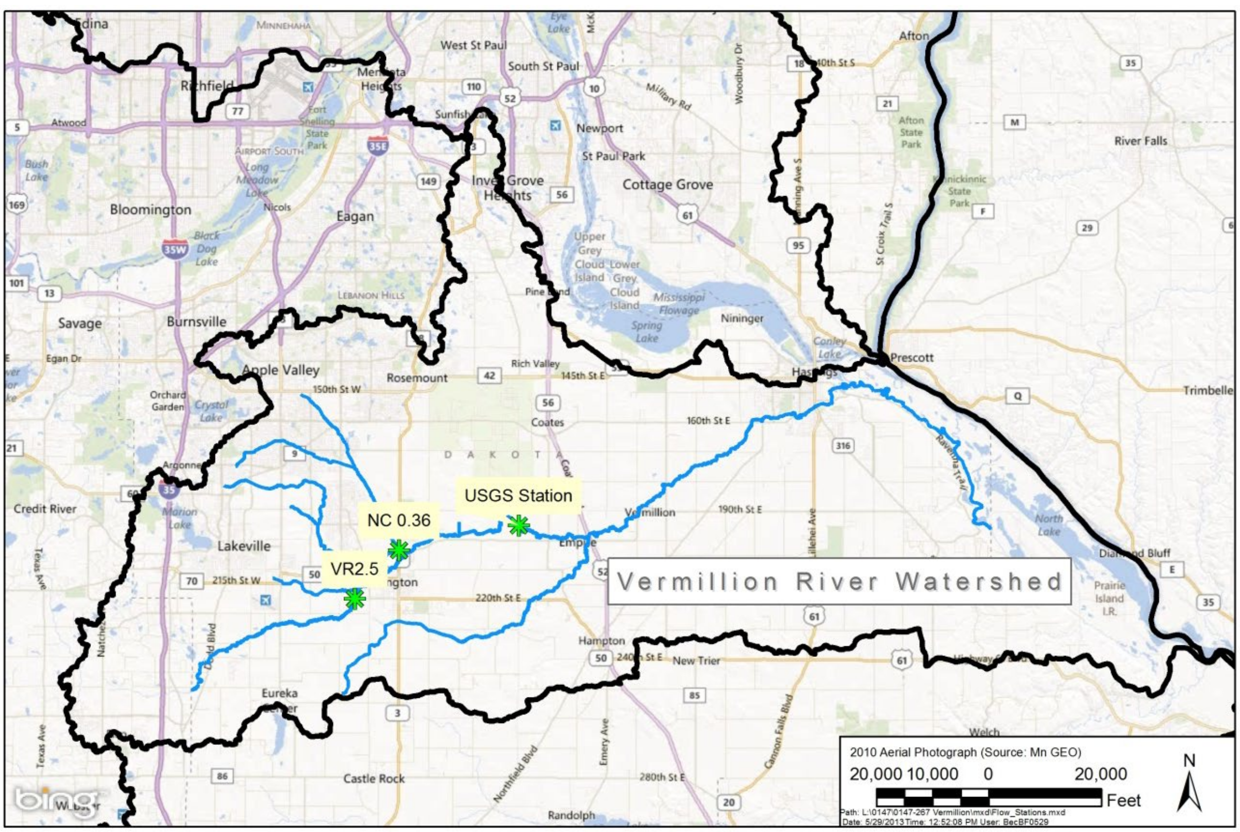



**Figure 3-7. Vermillion River watershed monitoring locations for flow record analysis.**

All monitoring stations have relatively steep slopes in the highest flow portions of the duration curves, suggesting that the Vermillion River responds quickly to storm events and returns to baseflow relatively quickly. The flashy nature of the streams may be particularly important in the upstream portions of the river, which have relatively low baseflows, but spike very quickly. Highly dynamic flows caused by storm events may negatively impact the biota by causing DO and turbidity fluctuations.

*Reach 507 Station A9:* The USGS gauge station at Empire has relatively steady base flow with a very small portion of flow considered low flow (Figure 3-8). The 20$^{th}$ and 80$^{th}$ percentile flows range from 25 to 80 cubic feet per second (cfs) alluding to a stable flow regime with a fairly significant normal flow range. Extreme runoff driven flow events can be quite high in this portion of the watershed, with flows ranging from 100 to over 500 cfs. The extreme high flows have the potential to be a stressor to stream biotic communities by physically displacing organisms from local habitat and flushing them to alternate areas of the watershed, which can be stressful to some species. Additionally, the extreme high flow events also produce scouring of pools which is a natural stream process. However due to the high amount of fine sediments within the channel of streams in the watershed results, the movement of fine sediments during high flow events results in deposition in pool areas, which can significantly reduce pool depth or volume. The filling of pools has been observed during the fish monitoring program where fairly deep pools were observed in a reach one year and then were found to be significantly shallower the following monitoring year.

The lower watershed of the Vermillion River, from the USGS monitoring station downstream, infrequently experiences extreme low flow events. The flow duration curve for the USGS station shows the lowest flow records to be greater than 10 cfs. During fish and macroinvertebrate monitoring in the lower half of the watershed, including stations A8, A9, A13 and A14, the channel was always observed to have a full wetted perimeter even during late summer periods when monitoring was conducted. This indicates that sufficient base flows exist during all times of the year. Overall, the lower half of the Vermillion River has relatively stable base flows with some periods of extreme high flows and very limited instances of extreme high flows. The hydrological flow regime is potentially a contributing stressor at times to the aquatic community but is unlikely the main stressor driving the impairment of the biological community in this portion of the watershed.

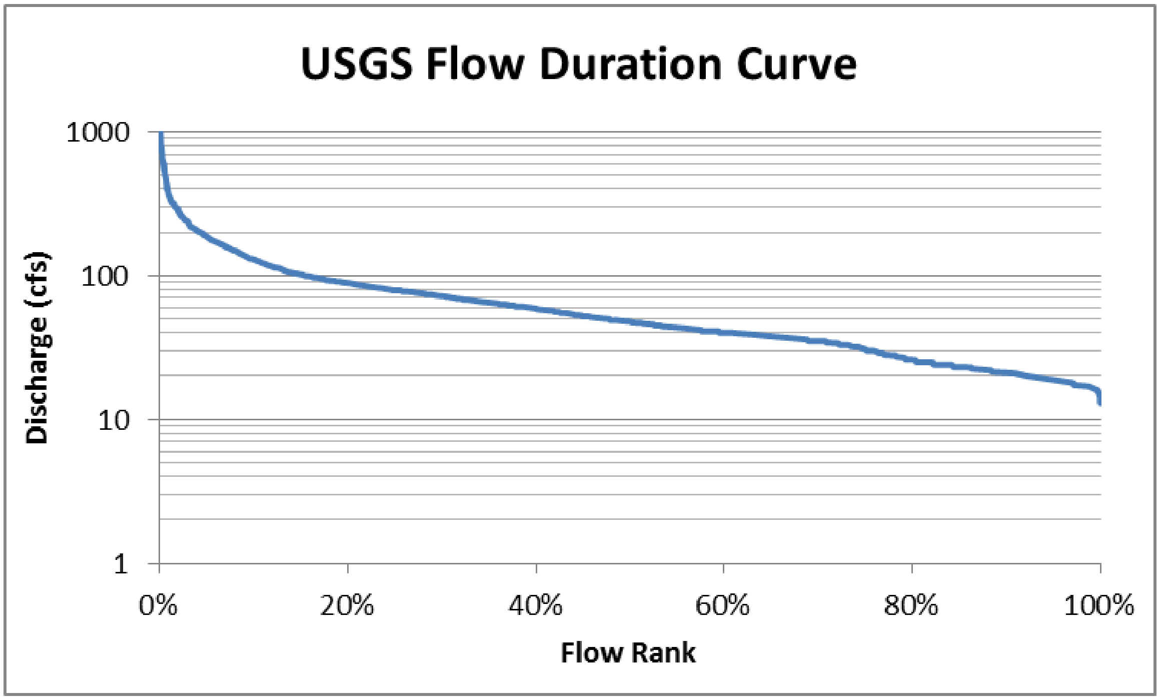


**Figure 3-8. Flow duration curve for the USGS flow monitoring site at Empire on the Vermillion River.**

*Reach 517 Stations A1 and A5:* A VRWJPO monitoring station with significant flow records is located within Reach 517, in the upper portion of the watershed, within the reach that is listed as impaired for both dissolved oxygen, turbidity, and fish and macroinvertebrate IBI. This station is located in the middle of the reach near 225th Street (VR 2.5). VR2.5 is located above the confluence of the Vermillion River with South Creek, which does provide a significant increase in flow to the lower portion of Reach 517. This monitoring station in the upper watershed has a higher occurrence of low flows and steeper slopes between the low flow and high flow conditions when compared to the downstream USGS gauge station (Figure 3-9). The 20th and 80th percentile flows range from 4 to 20 cubic feet per second (cfs), a much lower overall base flow regime within this reach. However, even with the relatively low base flow condition, Reach 517 has not been observed to be intermittent during biological monitoring at sites A1 or A5 from 2009 through 2012. The high flows at this location rarely exceed 100 cfs. It is possible that the low base flow condition contributes to the limited amount of available habitat at certain times within reach 517, which could be a contributing stressor within this reach. However, analysis of the DO at low flow conditions as part of the WRAPS study showed that the low flow condition is not the critical condition as related to DO.

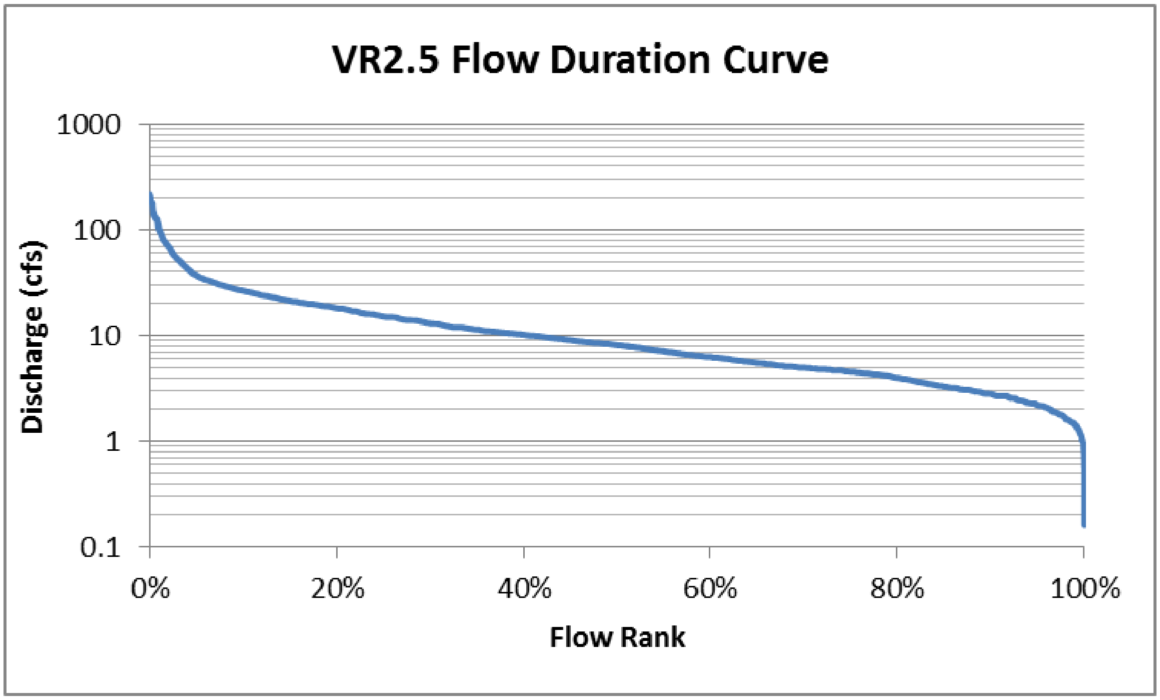



**Figure 3-9. Flow duration curve for the flow monitoring site on the Vermillion River near Farmington.**

The DO analysis also examined high flow events in relation to DO violations and determined that while violations occurred under all flow regimes, the majority of violations were recorded under high-flow conditions. Representing DO measurements on flow duration plots show the very-high and high flow categories have a significantly higher incidence of DO violations compared to the low flow conditions. This indicates that while the significant stressor in this case is likely DO, the flow regime of the reach is a contributing stressor under certain conditions as the high flows are leading to the DO violations.

*Reach 545:* The third monitoring station where a flow analysis was conducted was in reach 545 on North Creek. The station is located near Chippendale Avenue below the confluence of North Creek with Middle Creek and within the reach that is impaired for DO (NC 0.36). The flow monitoring location is located approximately 0.36 miles upstream of the confluence of North Creek with the main stem of the Vermillion River in Farmington. This monitoring station on North Creek has a similar shaped flow duration curve (Figure 3-10) compared to the flow record on Reach 517 Vermillion River (Figure 3-9), with a higher occurrence of low flows and steeper slopes between the low flow and high flow conditions when compared to the USGS gauge station.

The flow regime at this location on North Creek is also similar to the base flow conditions of Reach 517, with the 20$^{th}$ and 80$^{th}$ percentile flows range from 6 to 25 cubic feet per second (cfs). Reach 545 on North Creek has a relatively large contributing watershed with flows from both the Middle Creek and North Creek watersheds. High flows at this location are also similar to Reach 517, with maximum flows rarely exceeding 100 cfs. Annual biological monitoring in this area is conducted on North Creek, at the downstream end of Reach 671, immediate upstream of reach 545. Biological monitoring is conducted in late August through early September and during all recent monitoring years there has always been adequate flow and full wetted perimeter in this portion of North Creek. There have been no observed intermittent conditions on this reach.

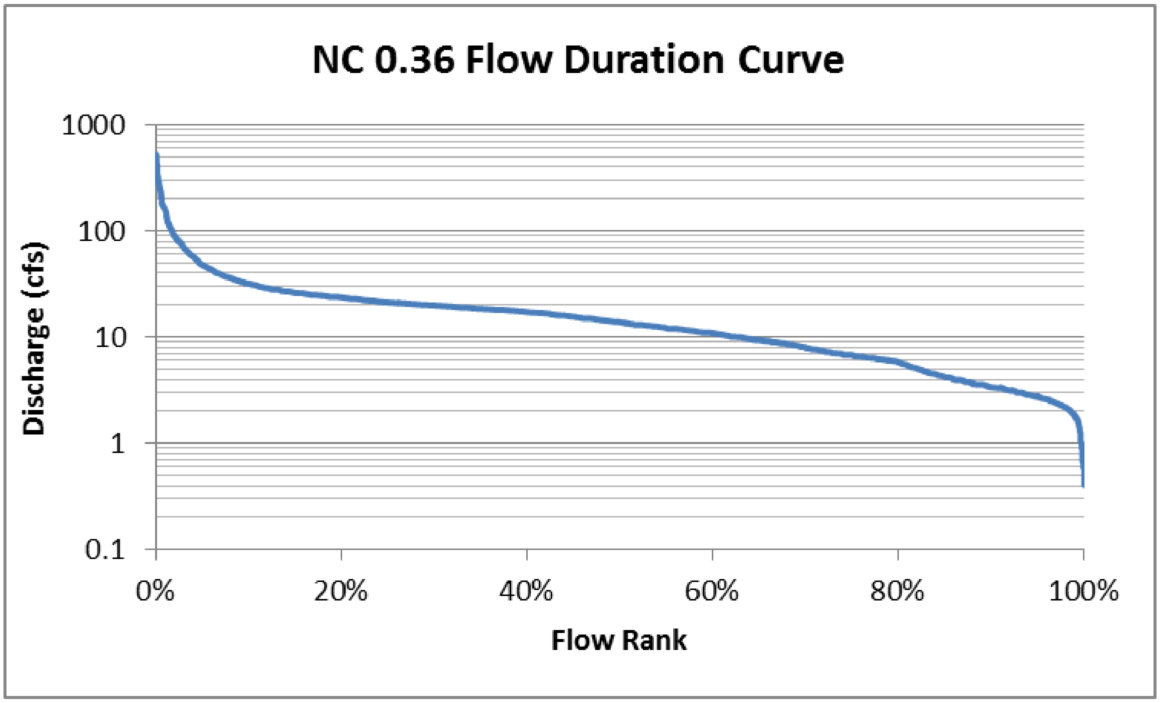



**Figure 3-10. Flow duration curve for the flow monitoring site on North Creek within Reach 545.**

### 3.3.4 Habitat Fragmentation

Two aspects of habitat fragmentation may affect the biota on the Vermillion River and its tributaries.

First, the 90-foot falls at Hastings limits fish recolonization potential by cutting off the Vermillion River system from the Mississippi River. The presence of the falls has the beneficial impact of preventing invasive species from migrating from the Mississippi River into the Vermillion System.

Second, segments of the Vermillion and some tributaries are incised and do not have good access to floodplain or offline wetlands or pools. Offline pools and wetlands serve as valuable refugia during high flow events for taxa that do not have the ability to withstand higher velocities. Access to floodplains is essential to some taxa that require terrestrial habitat for some parts of their cycle.

The falls at Hastings, Minnesota.
(Image: Wikipedia Commons.)

## 3.4 PHYSICAL AND CHEMICAL STRESSORS THAT CANNOT BE RULED OUT

In the CADDIS Stressor Identification process, after screening potential stressors and eliminating those that are unlikely to be the cause of biotic impairment, data from the case is assembled for each remaining candidate causes and analyzed with two goals in mind:

- To develop consistent and credible evidence that will allow the confident elimination of very improbable causes, or to use symptoms to refute or diagnose a cause, and
- To begin building the body of evidence for the candidate causes that cannot be eliminated or diagnosed, to identify the most probable causes.

Several types of evidence are evaluated, and the degree to which each type of evidence supports or weakens a case is scored using a standard system that is discussed in Appendix A. Data from the case may show that it is impossible or extremely improbable that a candidate cause produced the observed effect; if this happens, that candidate cause can be eliminated from further consideration. Certain symptoms may allow for a confident diagnosis or refutation of a candidate cause.

In the following sections, data regarding each of the four remaining candidate causes – dissolved oxygen, turbidity, temperature, and altered habitat – is reviewed by site and reach to determine if the stressor is present and whether there appears to have been a biotic response to that stressor.

Data are then analyzed in terms of associations that might support, weaken or refute the case for a candidate cause. This Strength of Evidence analysis is a systematic approach that sorts through the available data to determine the most probable cause or causes based on weight of evidence. Each of the types of evidence is scored based on the degree to which it supports or weakens the case using pluses (++) or minuses (--). The number of pluses or minuses depends on the likelihood that an association might be observed by chance rather than because of the true cause. A score of O indicates that the evidence neither supports nor weakens the case for the cause, a D is diagnostic of the cause and an R refutes the case for the cause.

### 3.4.1 Dissolved Oxygen

Living aquatic organisms such as fish and macroinvertebrates require oxygen to sustain life. This oxygen is supplied by molecules of gas dissolved in water. Oxygen enters the water by absorption directly from the atmosphere or by aquatic plant and algae photosynthesis. Oxygen is removed from the water by respiration and decomposition of organic matter. Dissolved oxygen (DO) fluctuates over the course of the day. As vegetation photosynthesizes throughout the daylight hours, the production of DO exceeds the use of DO by respiration and decomposition, and DO increases. Overnight, photosynthesis ceases and DO falls as a result of ongoing respiration and decomposition, and DO levels are at their lowest in the early morning. This pattern is the DO diurnal cycle.

The volume of DO is measured in milligrams of $O_2$ per liter of water, and is dependent on temperature, air pressure, and other factors influencing aeration and deoxygenation. These factors may include physical factors such as stream temperature and velocity, water clarity, and reaeration structures such as riffles; or chemical factors such as sediment oxygen demand and nutrients. The State of Minnesota standard for dissolved oxygen in Class 2A coldwaters is to maintain not less than 7 mg/L of DO as a daily minimum and in Class 2B warmwaters is to maintain not less than 5 mg/L of DO as a daily minimum.

Decreases in DO levels can cause changes in the types and numbers of fish and aquatic macroinvertebrates in surface waters, and shift the community composition to species that are tolerant of lower levels or wider diel swings in DO.

### 3.4.1.1 Causal Pathways Model for Dissolved Oxygen

Figure 3-11 models the likely temperature alteration sources and causal pathways resulting in biotic impairment at some locations in the Vermillion River and tributaries.

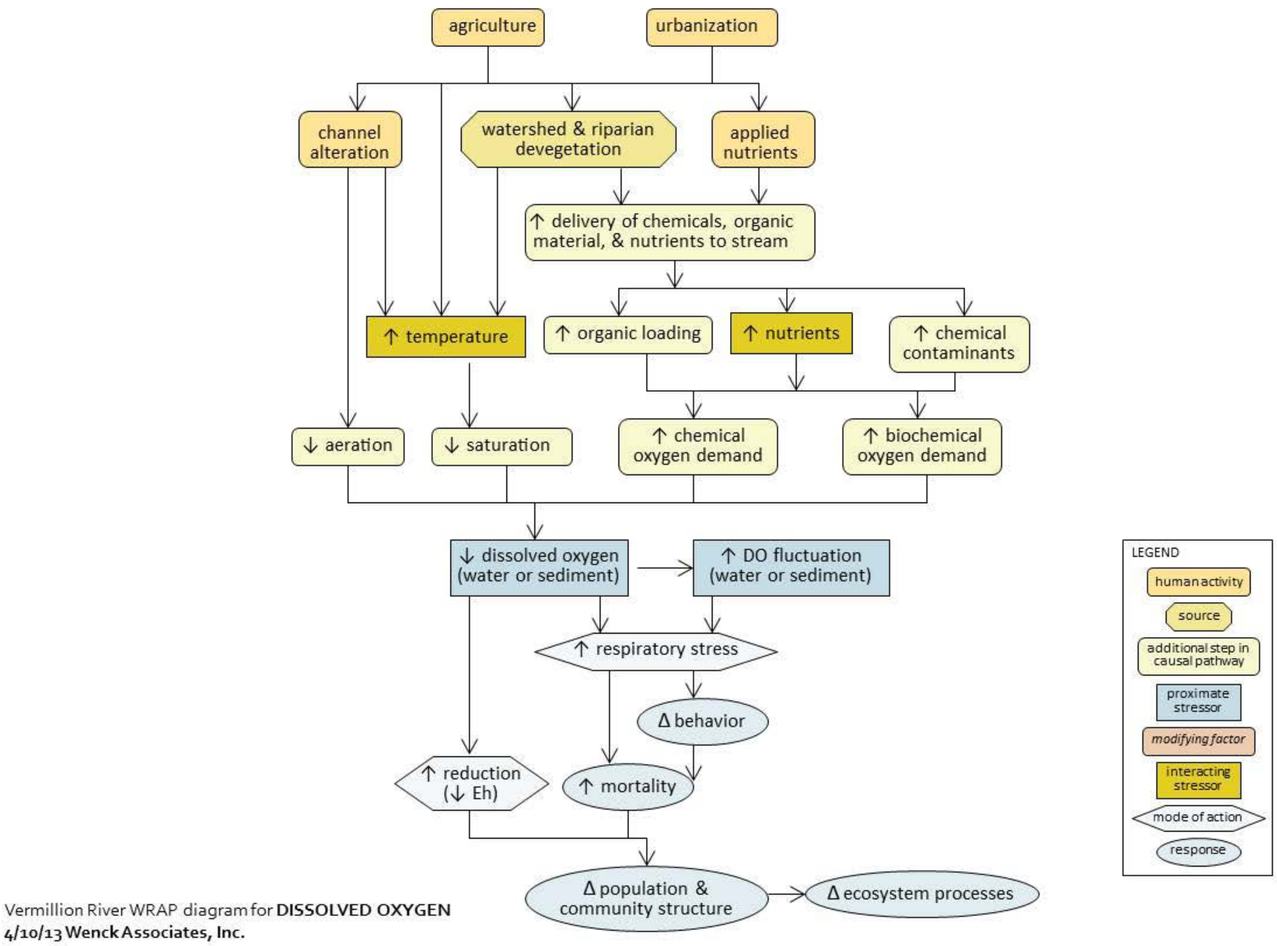



**Figure 3-11. Causal pathway model for dissolved oxygen.**

### 3.4.1.2 Dissolved Oxygen on the Vermillion River and Tributaries

One Vermillion River reach – Reach 517 – does not meet the state standard for dissolved oxygen. A tributary reach – reach 545 – also does not meet the state standard, but it is not listed as impaired for biotic integrity. Figure 3-12 summarizes the 2001-2012 DO data by reach.

Figure 3-13 shows all data collected between 2001 and 2010 by flow regime. While most of this data was not collected before 9 am, when DO levels are typically at their daily lowest, most was collected before 11 am, well before DO would typically reach its peak. The non-impaired cold water reaches generally maintain DO above the 7 mg/L state standard for Class 2A coldwater streams, and the warm water reach is greater than the 5 mg/L Class 2B warm water standard under nearly all flow conditions. Many of the lower values, for both the non-impaired reaches and impaired reach 517, occurred at high or very high flows, suggesting the impairment may be related to rain event runoff.

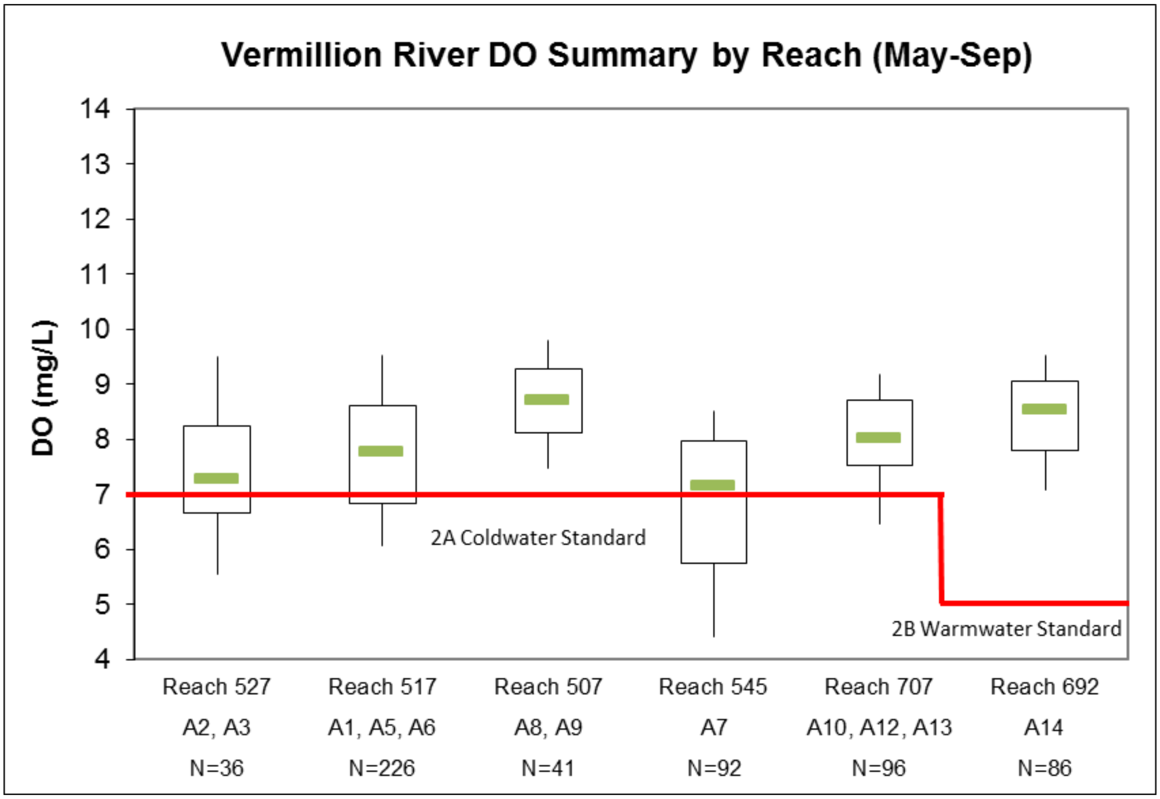



**Figure 3-12. 2001-2012 dissolved oxygen data by reach for the Vermillion River and tributaries.**
Note. The upper and lower edge of each box represents the 75th and 25th percentile of the data range for each site. Error bars above and below each box represent the 95th and 5th percentile of the dataset. The green dash is the median concentration of all data collected.

*Reach 517, Stations A1, A5 and A6.* As part of the monitoring conducted in 2012 to complete the DO TMDL, continuous DO, temperature, pH, and conductivity was recorded at 15-minute intervals at three sites on this reach. Results indicate that the most upstream station (VR7.8, site A1) at the Cedar Avenue crossing had lower levels of DO compared to the downstream stations (Figure 3-14). The daily DO flux was moderate, ranging from 1 to 5 mg/L. The most significant precipitation event during sonde deployment was 1.73 inches of rainfall on August 16, 2012. Dissolved oxygen response to this storm event shows a sharp decrease in DO levels and a break in the diurnal DO pattern.

Results of four early morning (pre 9:00 am) dissolved oxygen longitudinal profiles are shown in Figure 3-15. Also shown are the minimum and maximum daily DO values recorded by the data sondes at stations VR7.8 (site A1), VR3.6 (site A5) and VR0.1 (site A6). These profiles show a general increase in DO from upstream to downstream through the impaired reach. It should be noted that no DO violations were recorded downstream of the VR3.6 station during the four longitudinal profiles.

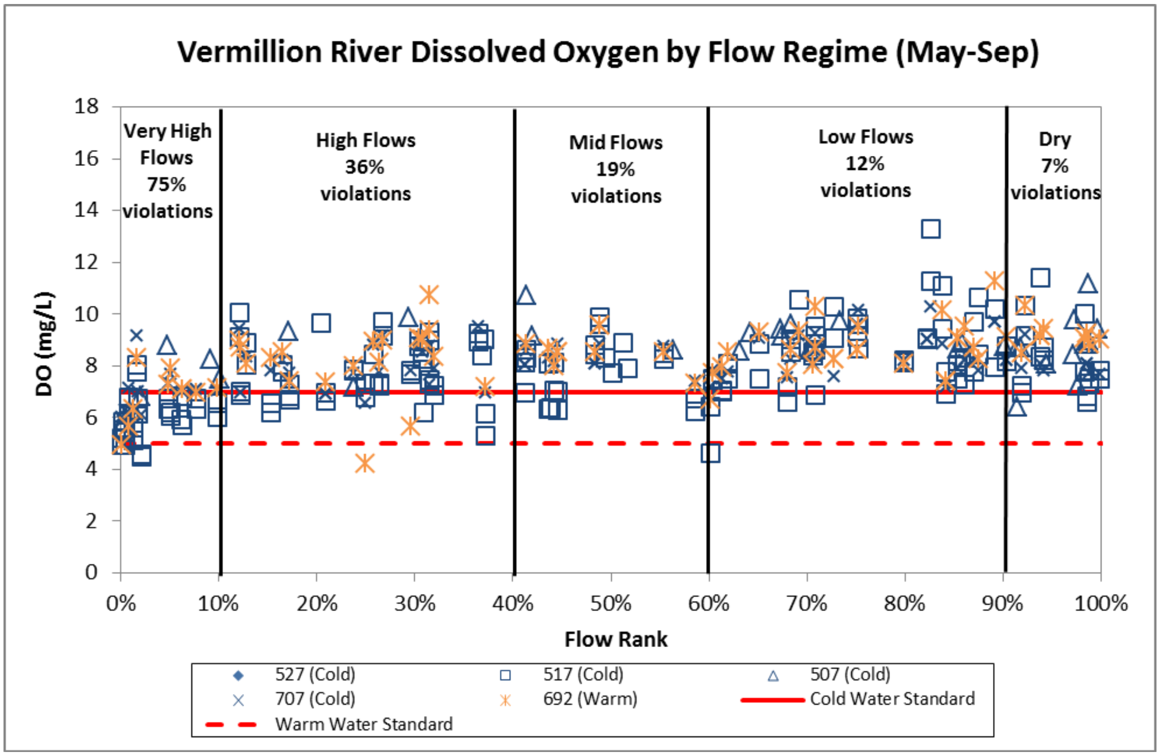



**Figure 3-13. 2001-2010 dissolved oxygen data by flow regime for the Vermillion River and tributaries.**

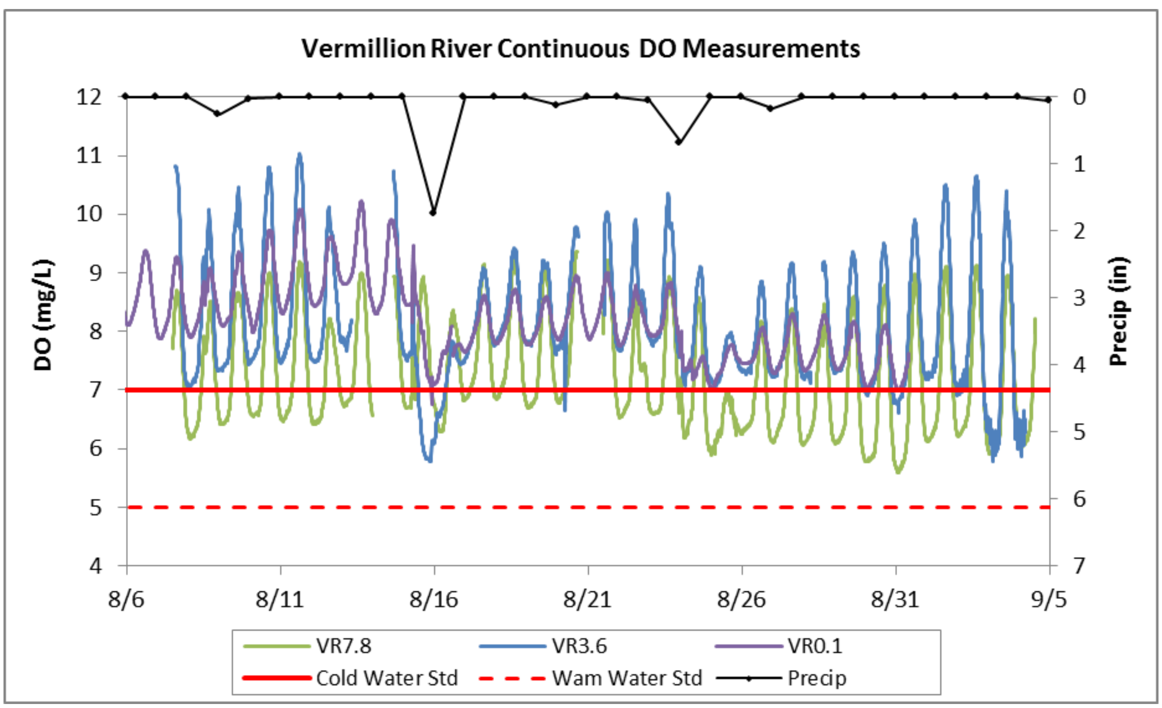



**Figure 3-14. August 7 through September 4, 2012 Reach 517 continuous DO measurements.**

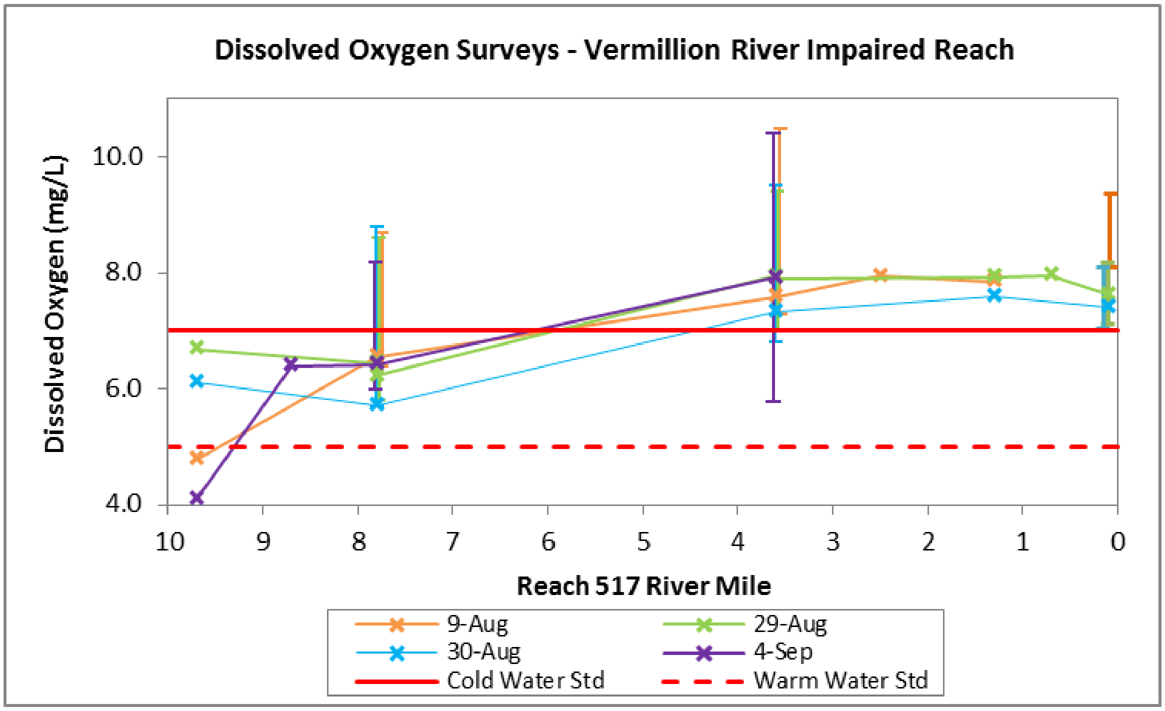


**Figure 3-15. Reach 517 longitudinal DO profiles measured during the August-September 2012 synoptic survey.**

#### 3.4.1.3 Causal Analysis -Biological Response to Low Dissolved Oxygen

Literature and experiments conducted elsewhere confirm that low levels of dissolved oxygen can adversely affect biotic community composition and richness. The macroinvertebrate and fish taxa present in Vermillion River watershed exhibit some tolerance of low oxygen conditions. However, there are also invertebrate and fish species moderately sensitive to low dissolved oxygen concentrations found within the watershed, including within the reaches listed as impaired for dissolved oxygen.

*Fish Community.* There are no obvious differences in the IBI scores comparing impaired versus unimpaired dissolved oxygen reaches on the main stem of the Vermillion River. Sites A1 and A5 are located within the reach impaired for dissolved oxygen (Reach 517) while sites A8 and A9 are located outside of the reach listed as impaired for dissolved oxygen (Reach 507). For all four of these sites the average IBI scores are below the IBI listing threshold of 45 for southern coldwater streams. Brown trout are a coldwater species that can be sensitive to low dissolved oxygen levels (Raleigh, et. al., 1986). Brown trout were not been collected during surveys conducted at A1 within Reach 517 from 2009 through 2012 which is impaired for dissolved oxygen; however, brown trout were also not been collected from Site A9 located in Reach 507 from 2010 through 2012 where dissolved oxygen levels are adequate. Limited numbers of brown trout have been collected from Sites A5 and A6 within Reach 517, similar in number to the amount of trout collected from Site A8 in Reach 507. The fact that brown trout, a coldwater species sensitive to dissolved levels, have never been collected in the upper reaches of the Reach 517 that is impaired for dissolved oxygen indicates that dissolved oxygen may be contributing to fish community impairment in this area. All of these sites on Reach 517 (A1, A5 & A6) and Reach 507 (A8 and A9) have seen a fairly high number of species tolerant of low dissolved oxygen levels collected, including green sunfish, white suckers and central mudminnows. However these species area also tolerant of other water quality conditions such as warm temperatures or increased silt and turbidity levels. As a result the presence of these tolerant species may not be solely driven by dissolved oxygen levels and instead a combination of multiple environmental factors.

Reach 545 on North Creek is also listed as impaired for dissolved oxygen. The biological monitoring site A7 is located just upstream of Reach 545, within Reach 671. Review of the dissolved oxygen data from Reach 671 of North Creek indicates this reach could also be listed as impaired for dissolved oxygen based on the coldwater standard of 7.0 mg/L (Wenck, 2013), with approximately 26 percent of the discrete samples resulting in dissolved oxygen violations. The fish community at Site A7 has included brown trout which is a species sensitive to dissolved oxygen levels. However this site has also included several species tolerant low dissolved oxygen levels including green sunfish and central mudminnows.

*Macroinvertebrate Community.* At many of the sites, the macroinvertebrate community is dominated by taxa that can thrive in low oxygen conditions. However, many of those species are also tolerant of turbidity and other conditions resulting from disturbance.

All three sites on Reach 517 scored low on the metric "Ratio of Chironomidae abundance to total Dipteran abundance," meaning that ratio is high. Chironomidae are very tolerant of low oxygen conditions, and a greater than expected abundance of these taxa is consistent with the observed periods of low dissolved oxygen. Figure 3-16 shows DO data recorded at the three biological monitoring sites on Reach 517. Data recorded at Site A1 very often was less than the 7 mg/L daily minimum, while Sites A5 and A6 periodically but less frequently were below that minimum. Moderately tolerant Ephemeroptera taxa, which are typically sensitive to low oxygen levels, were relatively abundant in the samples taken there, as well as the occasional very sensitive Plecopteran individual.

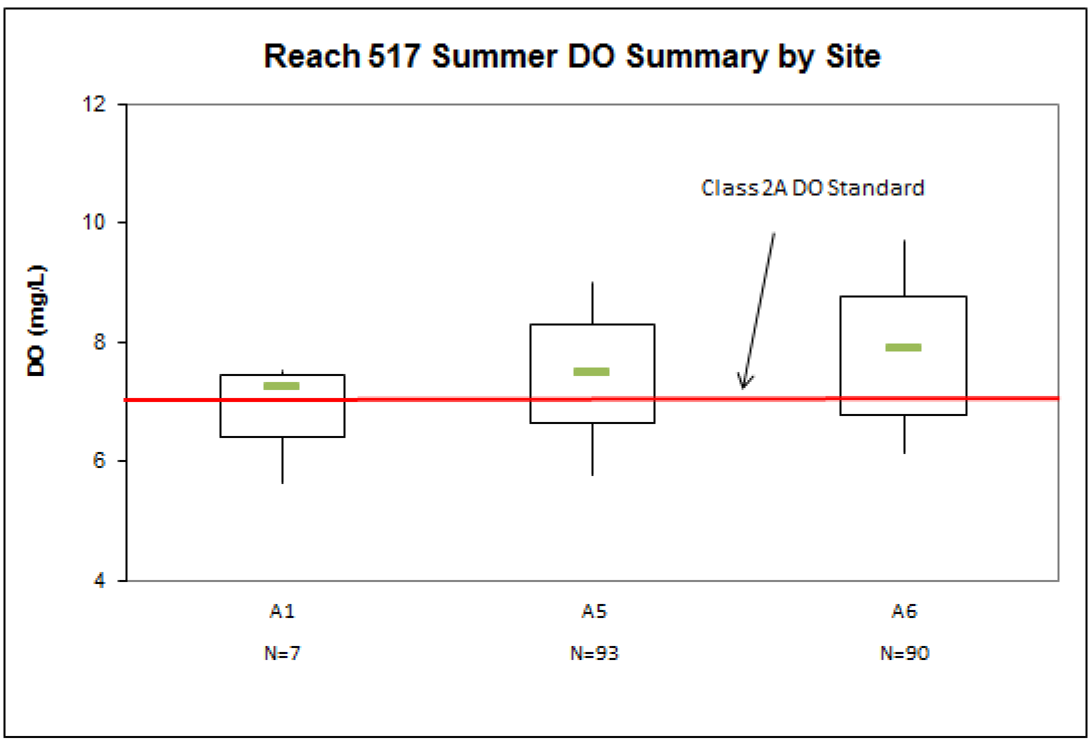



**Figure 3-16. DO data at monitoring sites on Reach 517 of the Vermillion River.**
Note. The upper and lower edge of each box represents the 75$^{th}$ and 25$^{th}$ percentile of the data range for each site. Error bars above and below each box represent the 95$^{th}$ and 5$^{th}$ percentile of the dataset. The green dash is the median concentration of all data collected

Reach 545 is also listed as an Impaired Water for low DO. Site A7 on North Creek, just upstream of the very short Reach 545, also scores low on this metric. The remaining coldwater tributary sites also scored low on this metric, although monitoring data indicates that those sites likely rarely fall below the 7 mg/L cold water minimum standard. Chironomidae are tolerant of nutrient enrichment and turbidity, so those conditions may also be affecting the abundance of Chironomidae.

Summary tables exploring metrics that are sensitive to dissolved oxygen were prepared for the fish and invertebrate communities (Tables 3-3 through 3-6). The metrics used within an IBI differ depending on the stream category (i.e., not all of the metrics used for the southern headwater streams IBI are also used for the southern coldwater streams IBI). However, each stream category has a variety of metrics that may be sensitive to specific stressors such as dissolved oxygen. For example, in the southern coldwater streams category a poor score for the percent of sensitive coldwater individuals of the fish community or percent of very tolerant individuals from the invertebrate community may be the result of a biotic response to dissolved oxygen as a stressor.

Table 3-3 and Table 3-4 explore the metrics from the coldwater main stem and tributary sites, respectively, which are potentially influenced by dissolved oxygen. The Biotic Response column indicates if the scores from the individual monitoring sites for the selected metrics are exhibiting a potential response to the identified stressor. For the coldwater sites on both the main stem of the Vermillion and the tributary streams there are biotic responses seen in the metric scores with low metrics scores for the low percent of sensitive coldwater individuals and low metrics scores for the high percent of tolerant coldwater taxa present. For the invertebrate communities there is a biotic response seen in the with the low metrics scores for the percent of very tolerant individuals present for both main stem and tributary coldwater sites. The biotic response is mixed for the invertebrate community for the ratio of Chironomidae to Diptera metric with moderately high metric scores on the main stem but low metrics scores on the tributary sites.

**Table 3-3. Scores for metrics sensitive to dissolved oxygen, Vermillion River coldwater sites.**

| Metric | Type | Max Score | Site A1 | Site A5 | Site A6 | Site A8 | Site A9 | Biotic Response |
|---|---|---|---|---|---|---|---|---|
| % Sensitive Individuals | Fish | 14.3 | 0.07 | 0.8 | 1.9 | 3.9 | 3.2 | Yes |
| # of Coldwater Tolerant Taxa | Fish | 14.3 | 7.7 | 3.0 | 3.4 | 3.2 | 2.1 | Yes |
| % of Very Tolerant Individuals | Invert | 16.67 | 4.4 | 4.9 | 7.7 | n/a | n/a | Yes |
| Ratio of Chironomidae to Diptera | Invert | 16.67 | 11.2 | 5.5 | 10.9 | n/a | n/a | No/Mixed |

**Table 3-4. Scores for metrics sensitive to dissolved oxygen, tributary coldwater sites.**

| Metric | Type | Max Score | Site A2 | Site A3 | Site A7 | Site A12 | Site A13 | Biotic Response |
|---|---|---|---|---|---|---|---|---|
| % Sensitive Individuals | Fish | 14.3 | 5.2 | 6.1 | 1.87 | 5.1 | 3.0 | Yes |
| # of Coldwater Tolerant Taxa | Fish | 14.3 | 3.9 | 6.7 | 2.9 | 6.8 | 3.9 | Yes |
| % of Very Tolerant Individuals | Invert | 16.67 | 0.2 | 4.5 | 5.4 | 1.2 | 5.8 | Yes |
| Ratio of Chironomidae to Diptera | Invert | 16.67 | 2.4 | 5.2 | 4.0 | 2.5 | 8.9 | Yes |

The warm water sites also scored low on metrics that are sensitive to dissolved oxygen. However, these metrics are also sensitive to other conditions such as increased turbidity. The DO data for Site A14, for example, shows all values well above the 5 mg/L warmwater minimum standard yet both fish and invertebrate metrics sensitive to DO scored very low. There is more limited DO data available at the other warm water sites, but it is likely that the overabundance of tolerant taxa and lack of sensitive species is caused by overall water quality conditions.

**Table 3-5. Scores for metrics sensitive to dissolved oxygen, Vermillion River warmwater site.**

| Metric | Type | Max Score | Site A14 | Biotic Response |
|---|---|---|---|---|
| % of Sensitive Taxa | Fish | 12.5 | 3.7 | Yes |
| % of Tolerant Taxa | Fish | 12.5 | 5.3 | Yes |
| % of Tolerant Individuals | Fish | 12.5 | 0 | Yes |
| % of Individuals from Dominant 2 Species | Fish | 12.5 | 5.9 | Yes |
| Hilsenhoff Biotic Index | Invert | 11.1 | 4.9 | Yes |

**Table 3-6. Scores for metrics sensitive to dissolved oxygen, tributary warmwater sites.**

| Metric | Type | Max Score | Site A4 | Site A10 | Site A15 | Biotic Response |
|---|---|---|---|---|---|---|
| Taxa Richness of Sensitive Species | Fish | 16.6 | 8.4 | 10.9 | 4.2 | Yes - at A15 |
| % Very Tolerant Taxa | Fish | 16.6 | 9.3 | 10.1 | 7.9 | Yes - at A15 |
| Hilsenhoff Biotic Index | Invert | 12.5 (A4)<br>11.1 (A10) | 5.3 | 6.4 | n/a | Yes |

### 3.4.1.4 Weight of Evidence: Dissolved Oxygen

There is the potential that low dissolved oxygen is having local impacts within the watershed. Within Reach 517, which is listed as impaired for dissolved oxygen, there are a limited amount of sensitive species and individuals collected, which could be a response to dissolved oxygen levels. Brown trout are sensitive to low dissolved oxygen and are collected in low numbers from some sites within Reach 517 and not collected at all from other sites within the reach. However, similar presence/absence patterns of brown trout also occur in Reach 507 where dissolved oxygen levels are adequate. Reach 545 on North Creek is also impaired for dissolved oxygen levels and species tolerant to low dissolved oxygen levels are abundant in the total catch, but some species sensitive to dissolved oxygen levels are also found. Dissolved oxygen does not appear to be a stressor in coldwater Reaches 527 and 707 or the warmwater Reach 692. Dissolved oxygen does appear to be a contributing stressor at localized reaches within the watershed. However, it is likely not be sole driver of the impaired fish and invertebrate communities in the Vermillion River. Table 3-7 and Table 3-8 evaluate the sufficiency of evidence that dissolved oxygen is a cause of impaired fish and macroinvertebrate communities.

**Table 3-7. Weight of evidence table: dissolved oxygen, fish impairment.**

| | Vermillion River, Upstream to Downstream | | | | | | Un-named | South Creek | | Middle Creek | North Creek | South Branch | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Types of Evidence** | **A1** | **A5** | **A6** | **A8[1]** | **A9[1]** | **A14** | **A4** | **A2** | **A3** | **A15** | **A7** | **A10[1]** | **A12[1]** | **A13** |
| **Evidence using data from Vermillion River Watershed** | | | | | | | | | | | | | | |
| Spatial/temporal co-occurrence | + | O | O | O | O | O | O | + | + | O | + | O | O | O |
| Evidence of exposure, biological mechanism | + | + | + | + | + | O | O | + | + | O | + | - | - | - |
| Causal pathway | + | - | - | O | O | O | O | + | + | O | + | O | + | + |
| Field evidence of stressor-response | + | + | - | + | + | O | O | + | + | O | + | - | + | + |
| Field experiments /manipulation of exposure | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Laboratory analysis of site media | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Temporal sequence | O | O | O | O | O | O | O | O | O | O | O | O | O | O |
| Verified or tested predictions | + | O | O | O | O | O | O | + | O | O | + | O | O | O |
| Symptoms | + | + | + | O | O | O | O | + | + | O | + | O | + | + |
| **Evidence using data from other systems** | | | | | | | | | | | | | | |
| Mechanistically plausible cause | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| Stressor-response in other field studies | + | + | + | + | + | O | O | + | + | O | + | O | O | O |
| Stressor-response in other lab studies | + | + | + | O | O | O | O | + | + | O | + | O | O | O |
| Stressor-response in ecological models | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Manipulation experiments at other sites | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Analogous stressors | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | | | | | | | |
| Consistency of evidence | + | O | O | O | O | O | O | + | + | O | + | O | O | O |
| Explanatory power of evidence | + | + | + | O | O | O | O | + | + | O | + | O | + | + |

[1] Water quality inferred from closest monitoring station.

**Table 3-8. Weight of evidence table: dissolved oxygen, macroinvertebrate impairment.**

| Types of Evidence | Vermillion River, Upstream to Downstream | | | | | | Un-named | South Creek | | Middle Creek | North Creek | South Branch | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | A5 | A6 | A8[1] | A9[1] | A14 | A4[2] | A2 | A3 | A15[3] | A7 | A10[3] | A12[3] | A13 |
| **Evidence using data from Vermillion River Watershed** | | | | | | | | | | | | | | |
| Spatial/temporal co-occurrence | + | + | + | O | O | O | N/A | ++ | ++ | O | + | O | O | O |
| Evidence of exposure, biological mechanism | + | + | + | O | O | O | N/A | + | + | O | + | O | O | - |
| Causal pathway | - | - | - | O | - | - | N/A | + | + | O | + | O | O | - |
| Field evidence of stressor-response | + | + | + | O | O | O | N/A | + | + | O | + | O | O | O |
| Field experiments /manipulation of exposure | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Laboratory analysis of site media | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Temporal sequence | O | O | O | O | O | O | N/A | O | O | O | O | O | O | O |
| Verified or tested predictions | O | O | O | O | O | O | N/A | O | O | O | O | O | O | O |
| Symptoms | + | + | + | O | O | O | N/A | + | + | O | + | + | + | + |
| **Evidence using data from other systems** | | | | | | | | | | | | | | |
| Mechanistically plausible cause | + | + | + | + | + | + | N/A | + | + | + | + | + | + | + |
| Stressor-response in other field studies | + | + | + | O | O | O | N/A | + | + | O | + | O | O | O |
| Stressor-response in other lab studies | + | + | + | O | O | O | N/A | + | + | O | + | O | O | O |
| Stressor-response in ecological models | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Manipulation experiments at other sites | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Analogous stressors | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | | | | | | | |
| Consistency of evidence | O | + | O | O | O | O | N/A | + | + | O | + | O | O | O |
| Explanatory power of evidence | + | + | + | O | O | O | N/A | + | + | O | + | O | O | O |

[1]Only one year of macroinvertebrate data available. Water quality inferred from closest monitoring station.
[2]This site has fish data but no macroinvertebrate data.
[3]Water quality inferred from closest monitoring station.
Note: No detailed metrics available for Sites 8, 9, and 15

### 3.4.2 Turbidity

Total suspended solids (TSS) concentrations and turbidity both indicate the amount of solids suspended in the water, whether mineral (e.g., soil particles) or organic (e.g., algae). TSS measures the mass of material per volume of water, while turbidity measures the amount of light scattered from a sample (more suspended particles cause greater scattering).

High concentrations of particulate matter can cause increased sedimentation and siltation in a stream, which can impact available habitat by filling pools and interstitial spaces of streambed gravels and cobble. Suspended sediment can block light needed by rooted aquatic plants, damage gills on fish and invertebrates, and decrease visibility for organisms that must see their prey. Sediments can also carry adhered pollutants.

#### 3.4.2.1 Causal Pathways Model for Turbidity

Figure 3-17 models the likely turbidity and bedded sediment sources and causal pathways resulting in biotic impairment in the Vermillion River and tributaries.

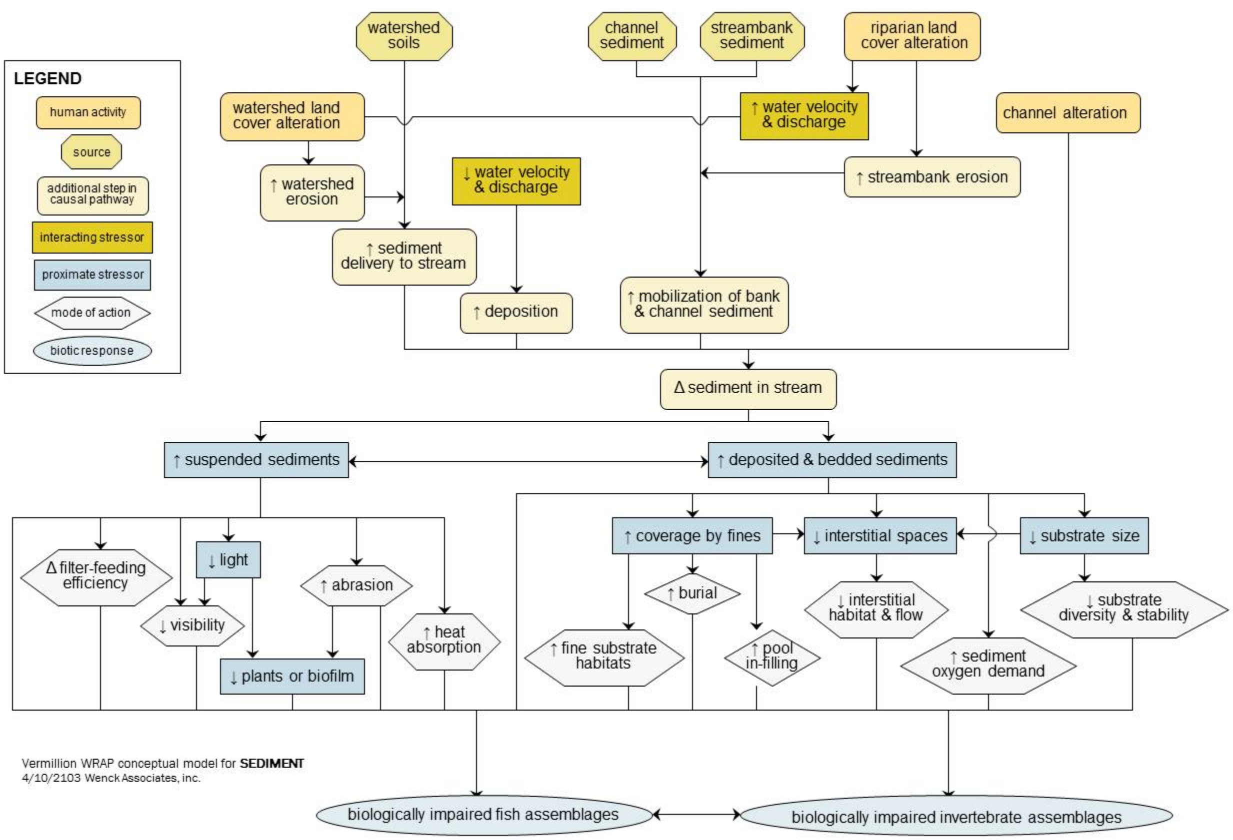



**Figure 3-17. Causal pathway model for sediment.**

### 3.4.2.2 Turbidity on the Vermillion River and Tributaries

One Vermillion River reach – Reach 517 – is listed as impaired for turbidity. Figure 3-18 summarizes the 2001-2012 turbidity data by reach. Reach 692 turbidity at site A14 is better than the state standard, however, there are exceedances of the turbidity standard in the other monitored reaches. Some of this data was collected subsequent to the impairment listing period.

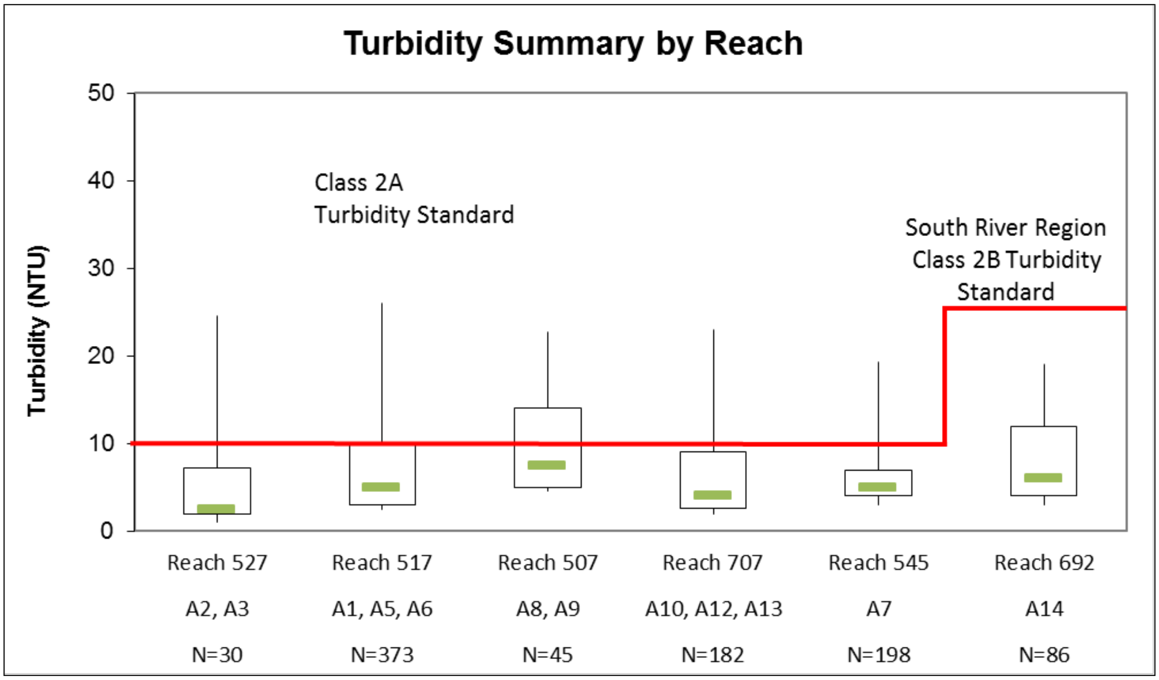



**Figure 3-18. 2001-2012 turbidity data in the Vermillion River and tributaries.**
Note. The upper and lower edge of each box represents the 75th and 25th percentile of the data range for each site. Error bars above and below each box represent the 95th and 5th percentile of the dataset. The green dash is the median concentration of all data collected.

Turbidity can also be measured using TSS as a surrogate. In Minnesota, for TSS, a measurement of more than 60 mg/L in the Western Corn Belt Plains ecoregion is currently used for impairment assessment purposes. The MPCA has proposed a TSS standard for Class 2A streams of 10 mg/L and 65 mg/L for Class 2B streams in the southern ecoregion. Figure 3-19 shows available TSS data by flow regime compared to the proposed TSS standard. TSS violations appear to occur primarily under high and very high flows, which are driven by high rainfall events.

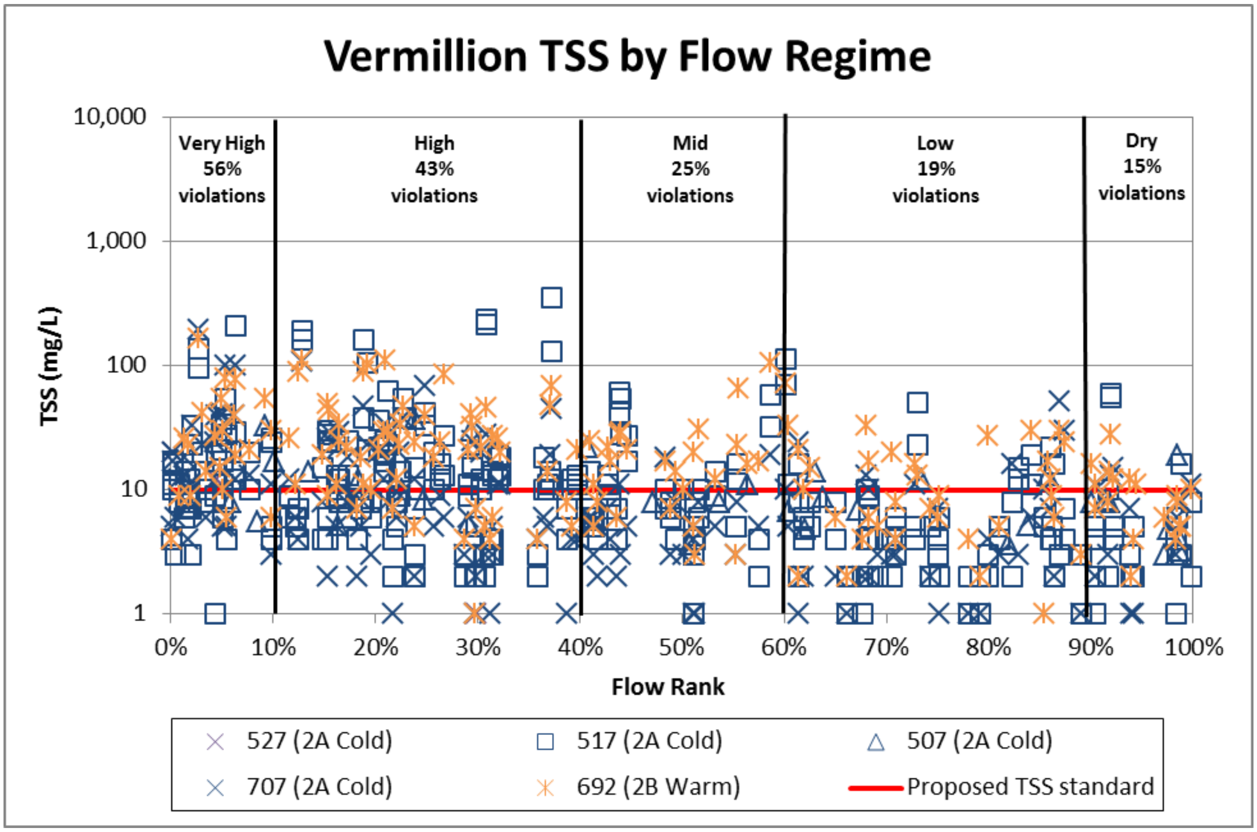



**Figure 3-19. 2001 - 2011 TSS data by flow regime.**

Note: This figure also includes data from Reach 692, for which the proposed TSS standard is 65 mg/L.

*Watershed Sediment Loading.* Modeling and assessment of turbidity in impaired Reach 517 is being completed separately. A significant potential source of sediment is sediment eroded from the landscape and conveyed to the streams through drain tiles, ditches, channels, tributaries, storm sewers, and wind dispersion.

Potential upland sediment loading was modeled using the Universal Soil Loss Equation (USLE). This empirical model provides a means of comparing the potential upland soil loss to the in stream sediment load and stream bank erosion field surveys. The form of the USLE that has widely been used to predict potential soil loss is calculated according to the following equation:

$$A = R \times K \times LS \times C \times P$$

Where A represents the average potential soil loss (ton/acre/year), which is a function of the rainfall erosivity index (R), soil erodibility factor (K), slope-length gradient factor (LS), crop management factor (C), and conservation practice factor (P). According to the USLE calculations the average potential soil loss in the impaired reach of the Vermillion River was calculated to be 0.69 tons/acre/year.

Only a fraction of soil loss will be delivered downstream, which requires the potential soil loss to be corrected by applying a Sediment Delivery Ratio (SDR) (Vanoni 1975) to estimate how much soil loss from a watershed will be delivered downstream.

$$SDR = 0.451(b)^{-0.298}$$

Where b = watershed size in square kilometers

The USLE predicts that the annual potential soil loss in the 48,828 acre Vermillion River main stem watershed is 30,931 tons per year. The sediment delivery ratio is 0.09 as calculated by the SDR equation listed above and results in an annual estimated mass of sediment delivered from upland sources to the river is 2,887 tons per year. The calculated sediment loss potential is relatively high but is not reached on a yearly basis since based on the TSS by flow regime data, most sediment loss and delivery to the stream occurs during isolated storm events. The TMDL will establish a load duration curve expressing allowable load by flow regime.

*Streambank Sediment Loading.* A streambank assessment was completed for the WRAPS study to assess bank conditions as a potential source of turbidity. Reaches 517 and 527 and part of Reach 507 were walked, and erosion features were noted and measured. This data will be used to estimate the annual streambank soil loss for the turbidity TMDL.

Streambank conditions were variable, with some banks relatively stable, and others with significant slumping and sloughing, especially on outer bends. The photos below show the range of conditions.

**Figure 3-20. Typical stable grassland segment, Reach 527.**

Figure 3-20 shows a typical stable grassland segment on Reach 527, with moderately sloped banks and 1-2 feet of exposed soil at the toe. Minor undercutting is occurring on outer bends. Figure 3-21 shows a slumped bank in the grassland with entire segments of bank cutoff and slowly eroding away. Most of this activity was in the grasslands of the Flagstaff to CO RD 31/Denmark reach and especially the grasslands at the end of the 225$^{th}$ to 220$^{th}$ segment of Reach 517. The slumped pieces would get very large: 3'-5' wide and 30' to 50' long. Figure 3-22 shows typical woodland conditions encountered on Reach 517, both stable and eroding. Most of the eroding features were on the outside bends. On average, the height of the eroded feature was from 2' to 3'.

There were some woodland locations where both sides of the channel were eroding as pictured, especially in the first couple hundred feet of the Highview to Cedar/CO RD 23 segment, and the 225th to 220$^{th}$ segment.

**Figure 3-21. Slumped banks on Reach 517.**

**Figure 3-22. Typical woodland segment on Reach 517.**

Stream bottom sediments ranged from very fine muck to small gravel, often within the same subreach. Some pools observed in previous years' fish monitoring were found to be filled with sediment, and conversely, some previously filled pools were found in later years to be scoured. Aggradation and deposition was observed on the stream walking survey, but in most locations that appeared to be associated with either bank sloughing /mass wasting or with deadfall, leaf pack, or accumulated debris causing flow to be slowed or diverted and sediment to be deposited. By observation during the stream walking survey and fish monitoring, the streambed on Reach 707 (South Branch) is mucky with filled pools and accumulated sediment. On the main stem of the Vermillion, geomorphology assessments found Reaches 507 and 692 aggrading with some sediment deposition and some filled pools.

The fish data collected both as part of ongoing biologic monitoring and also specifically for the WRAPS study reveal a low presence of species that require gravel for spawning, suggesting that excess bedded sediment may be limiting the biota. Streams do experience some sediment loss per year from natural processes. A preliminary analysis of annual soil loss from streambank erosion on Reaches 517 and 527 estimates an annual erosion loss of 20.9 tons per year, compared to an estimated 3.46 tons based on rates typically seen on stable streams. The difference, or 17.44 tons per year, could be considered "excess" sediment load from streambanks in the two reaches. While this is small compared to the potential load from the watershed as described above, there appear to be localized occurrences of aggradation and braiding, pool filling and scouring. Sediment from streambank erosion may pose more of a bedded sediment issue than a significant source of excess suspended solids in the water column.

#### 3.4.2.3 Causal Analysis -Biological Response to Turbidity

Field research and available literature from across the Midwest confirm that increased turbidity can adversely affect biotic community composition and richness. Reach 517 is listed as impaired for excess turbidity, potentially affecting sites A1, A5, and A6. Figure 3-23 and Figure 3-24 summarize turbidity and TSS data recorded at the three sites on Reach 517. At sites A5 and A6, while the median of samples were less than the proposed standards, there were a number of samples that exceeded that value. In addition, there is observational evidence of increased turbidity and in-stream silt throughout the watershed in both the coldwater and warmwater reaches.

Fish and macroinvertebrate species tolerant of increased turbidity and silt are found throughout the watershed. For example, the most common fish species in terms of total catch during the last four years of monitoring include green sunfish and central mudminnows, both tolerant of increased turbidity and silt. These species have been found at all fourteen monitoring sites in both coldwater and warmwater reaches.

Many of the monitoring sites are dominated by chironomids, which are very tolerant of turbid waters, and support a limited diversity of filter-feeding taxa. Table 3-9, Table 3-10, Table 3-11, and Table 3-12 show the IBI metrics sensitive to turbidity and scores for each site.

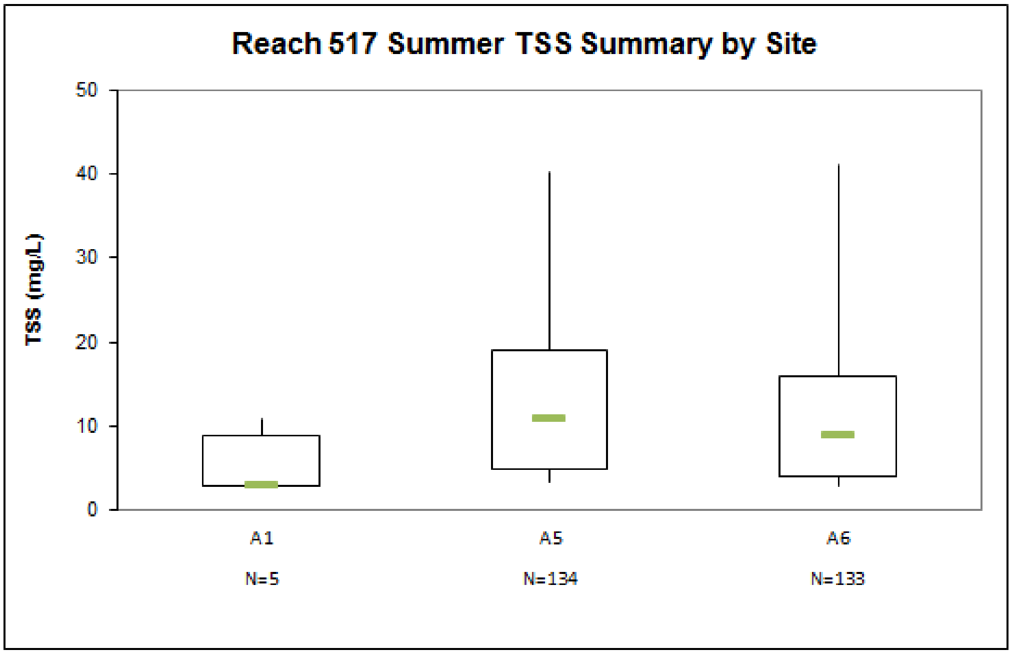



**Figure 3-23. TSS data at monitoring sites on Reach 517 of the Vermillion River.**

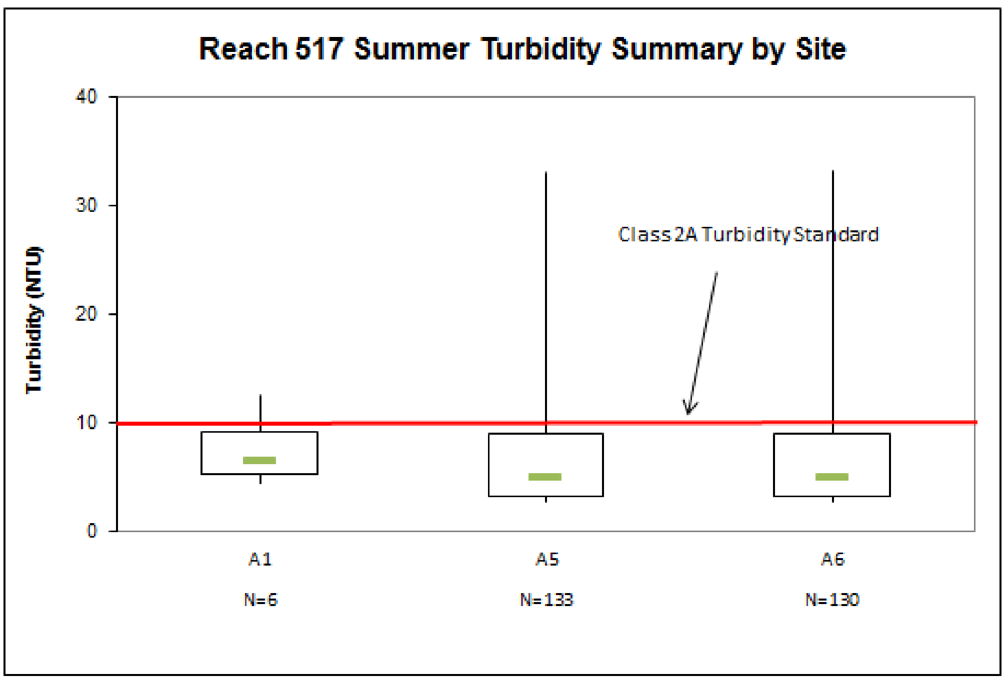



**Figure 3-24. Turbidity data at monitoring sites on Reach 517 of the Vermillion River.**

Summary tables exploring metrics that are sensitive to turbidity were prepared for the fish and invertebrate communities (Table 3-9, Table 3-10, Table 3-11, and Table 3-12). The tables include those specific IBI metrics that are potentially sensitive to a biotic response as a result of turbidity. For the coldwater fish community the metrics explored included the percent of sensitive individuals, number of coldwater tolerant taxa and the percentage of native coldwater taxa and individuals.

**Table 3-9. Scores for metrics sensitive to turbidity, Vermillion River coldwater sites.**

| Metric | Type | Max Score | Site A1 | Site A5 | Site A6 | Site A8 | Site A9 | Biotic Response |
|---|---|---|---|---|---|---|---|---|
| % Sensitive Individuals | Fish | 14.3 | 0.07 | 0.8 | 1.9 | 3.9 | 3.2 | Yes |
| # of Coldwater Tolerant Taxa | Fish | 14.3 | 7.7 | 3.0 | 3.4 | 3.2 | 2.1 | Yes |
| % of Native Coldwater Individuals | Fish | 14.3 | 0 | 0 | 0 | 0 | 0 | * |
| % of Native Coldwater Taxa | Fish | 14.3 | 2.5 | 3.9 | 5.1 | 6.5 | 6.9 | Yes |
| Hilsenhoff Biotic Index | Invert | 16.67 | 11.24 | 3.0 | 8.3 | -- | -- | Yes |
| % Collector-filterer Individuals | Invert | 16.67 | 5.19 | 1.7 | 2.5 | -- | -- | Yes |

*Native coldwater species were likely not naturally present at these sites. The score of 0 is not a response specifically to turbidity.

**Table 3-10. Scores for metrics sensitive to turbidity, tributary coldwater sites.**

| Metric | Type | Max Score | Site A2 | Site A3 | Site A7 | Site A12 | Site A13 | Biotic Response |
|---|---|---|---|---|---|---|---|---|
| % Sensitive Individuals | Fish | 14.3 | 5.2 | 6.1 | 1.87 | 5.1 | 3.0 | Yes |
| # of Coldwater Tolerant Taxa | Fish | 14.3 | 3.9 | 6.7 | 2.9 | 6.8 | 3.9 | Yes |
| % of Native Coldwater Individuals | Fish | 14.3 | 0 | 0 | 0 | 0 | 0 | * |
| % of Native Coldwater Taxa | Fish | 14.3 | 1.7 | 2.5 | 3.6 | 3.4 | 3.5 | Yes |
| Hilsenhoff Biotic Index | Invert | 16.67 | 1.2 | 4.6 | 3.9 | 7.0 | 6.6 | Yes |
| % Collector-filterer Individuals | Invert | 16.67 | 0.4 | 2.6 | 7.7 | 9.7 | 3.1 | Yes |

*Native coldwater species were likely not naturally present at these sites. The score of 0 is not a response specifically to turbidity.

**Table 3-11. Scores for metrics sensitive to turbidity, Vermillion River warmwater site.**

| Metric | Type | Max Score | Site A14 | Biotic Response |
|---|---|---|---|---|
| % of Sensitive Taxa | Fish | 12.5 | 3.7 | Yes |
| % of Tolerant Taxa | Fish | 12.5 | 5.3 | Yes |
| % of Tolerant Individuals | Fish | 12.5 | 0 | Yes |
| % of Individuals from Dominant 2 Species | Fish | 12.5 | 5.9 | Yes |
| % of Benthic Insectivore Taxa | Fish | 12.5 | 5.9 | Yes |
| Hilsenhoff Biotic Index | Invert | 11.1 | 4.9 | Yes |
| Taxa Richness of Predators | Invert | 11.1 | 1.9 | Yes |

**Table 3-12. Scores for metrics sensitive to turbidity, tributary warmwater sites.**

| Metric | Type | Max Score | Site A4 | Site A10 | Site A15 | Biotic Response |
|---|---|---|---|---|---|---|
| Taxa Richness of Sensitive Species | Fish | 16.6 | 8.4 | 10.9 | 4.2 | Yes - At A15 |
| % Very Tolerant Taxa | Fish | 16.6 | 9.3 | 10.1 | 7.9 | Yes - At A15 |
| Hilsenhoff Biotic Index | Invert | 12.5 (A4)<br>11.1 (A10) | 5.26 | 6.4 | n/a | Yes |
| Taxa Richness of Predators | Invert | 12.5 (A4)<br>11.1 (A10) | 1.4 | 2.7 | n/a | Yes |

### 3.4.2.4 Weight of Evidence: Turbidity

Field research and available literature from across the Midwest confirm that increased turbidity can adversely affect biotic community composition and richness. There are two portions of the main stem of the Vermillion River that are listed as impaired for excess turbidity. This includes reach 517 in the upper watershed from Highview Ave to Rambling River Park in Farmington and the lower river reach 504 from the Hastings Dam to the Mississippi River. Biological monitoring surveys have revealed that there is evidence of increased turbidity and in-stream silt throughout the watershed in both the coldwater and warmwater reaches. Species tolerant of increased turbidity and silt are found throughout the watershed and dominate the total catch at most sites. For example, the most common species in terms of total catch during the fish monitoring include green sunfish and central mudminnows, both tolerant of increased turbidity and silt. These species have been found at all fourteen monitoring sites in both coldwater and warmwater reaches. The abundance of tolerant species in the watershed is resulting in the low scores for metrics tied to tolerant species. There are also a limited number of both sensitive fish and invertebrate species found in coldwater and warmwater reaches. This is likely a response to the increased turbidity across the watershed. Brown trout are the most abundant sensitive species in the watershed and are sensitive to increases in turbidity. Overall, turbidity and increased silt conditions are likely the main driver of the impaired fish and macro invertebrate communities in the watershed. Table 3-13 and Table 3-14 evaluate the sufficiency of evidence that increased turbidity is a cause of impaired fish and macroinvertebrate communities.

**Table 3-13. Weight of evidence table: turbidity, fish impairment.**

| Types of Evidence | Vermillion River, Upstream to Downstream | | | | | | Un-named | South Creek | | Middle Creek | North Creek | South Branch | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | A5 | A6 | A8[1] | A9[1] | A14 | A4 | A2 | A3 | A15 | A7 | A10[1] | A12[1] | A13 |
| **Evidence using data from Vermillion River Watershed** | | | | | | | | | | | | | | |
| Spatial/temporal co-occurrence | + | ++ | ++ | + | + | ++ | + | O | O | ++ | ++ | O | + | + |
| Evidence of exposure, biological mechanism | ++ | ++ | ++ | + | + | ++ | + | + | + | ++ | ++ | + | + | + |
| Causal pathway | ++ | + | + | + | + | ++ | + | O | + | + | + | O | + | + |
| Field evidence of stressor-response | + | ++ | ++ | + | + | ++ | + | + | o | + | ++ | O | + | + |
| Field experiments /manipulation of exposure | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Laboratory analysis of site media | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Temporal sequence | ++ | + | + | + | + | ++ | + | + | + | ++ | ++ | + | + | + |
| Verified or tested predictions | ++ | ++ | ++ | + | + | ++ | + | + | + | + | + | O | + | + |
| Symptoms | + | + | + | + | + | + | + | + | + | + | + | O | + | + |
| **Evidence using data from other systems** | | | | | | | | | | | | | | |
| Mechanistically plausible cause | ++ | ++ | ++ | ++ | ++ | + | + | + | + | ++ | + | o | + | + |
| Stressor-response in other field studies | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| Stressor-response in other lab studies | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Stressor-response in ecological models | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Manipulation experiments at other sites | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Analogous stressors | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | | | | | | | |
| Consistency of evidence | + | ++ | + | + | + | ++ | + | + | + | + | + | O | + | + |
| Explanatory power of evidence | ++ | ++ | ++ | + | + | ++ | + | + | + | + | + | + | + | + |

[1] Water quality inferred from closest monitoring station.

**Table 3-14. Weight of evidence table: turbidity, macroinvertebrate impairment.**

| Types of Evidence | Vermillion River, Upstream to Downstream | | | | | | Un-named | South Creek | | Middle Creek | North Creek | South Branch | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | A5 | A6 | A8[1] | A9[1] | A14 | A4[2] | A2 | A3 | A15[3] | A7 | A10[3] | A12[3] | A13 |
| **Evidence using data from Vermillion River Watershed** | | | | | | | | | | | | | | |
| Spatial/temporal co-occurrence | ++ | ++ | ++ | + | ++ | + | N/A | ++ | ++ | + | + | + | + | ++ |
| Evidence of exposure, biological mechanism | ++ | ++ | ++ | + | + | O | N/A | ++ | ++ | + | + | O | O | ++ |
| Causal pathway | + | + | + | + | + | + | N/A | + | + | + | + | + | + | + |
| Field evidence of stressor-response | ++ | ++ | ++ | + | ++ | + | N/A | ++ | ++ | + | + | + | + | ++ |
| Field experiments /manipulation of exposure | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Laboratory analysis of site media | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Temporal sequence | ++ | ++ | ++ | + | + | + | N/A | ++ | ++ | + | + | + | + | ++ |
| Verified or tested predictions | ++ | ++ | ++ | + | + | + | N/A | ++ | ++ | + | + | + | + | + |
| Symptoms | + | + | + | + | + | + | N/A | + | + | + | + | + | + | + |
| **Evidence using data from other systems** | | | | | | | | | | | | | | |
| Mechanistically plausible cause | ++ | ++ | ++ | + | ++ | + | N/A | ++ | ++ | + | + | + | + | ++ |
| Stressor-response in other field studies | + | + | + | + | + | + | N/A | + | + | + | + | + | + | + |
| Stressor-response in other lab studies | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Stressor-response in ecological models | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Manipulation experiments at other sites | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Analogous stressors | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | | | | | | | |
| Consistency of evidence | + | ++ | + | + | + | + | N/A | ++ | ++ | + | + | + | + | + |
| Explanatory power of evidence | ++ | ++ | ++ | + | + | + | N/A | ++ | ++ | + | + | + | + | ++ |

[1]Only one year of macroinvertebrate data available. Water quality inferred from closest monitoring station.
[2]This site has fish data but no macroinvertebrate data.
[3]Water quality inferred from closest monitoring station.
Note: No detailed metrics available for Sites 8, 9, and 15

### 3.4.3 Temperature

The Vermillion River watershed includes both warmwater and coldwater streams spread throughout the watershed. The coldwater reaches are located in the upper half of the watershed upstream of approximately Highway 52 and include the main stem of the Vermillion River as well as major and minor tributary streams (Figure 3-26). There are warmwater streams throughout the watershed including numerous small tributaries in the upper watershed that drain directly into coldwater reaches and also include the main stem of the Vermillion River downstream of approximately Highway 52 and major and minor tributaries in the lower watershed.

#### 3.4.3.1 Causal Pathways Model for Temperature

Figure 3-25 models the likely temperature alteration sources and causal pathways resulting in biotic impairment in the Vermillion River and tributaries.

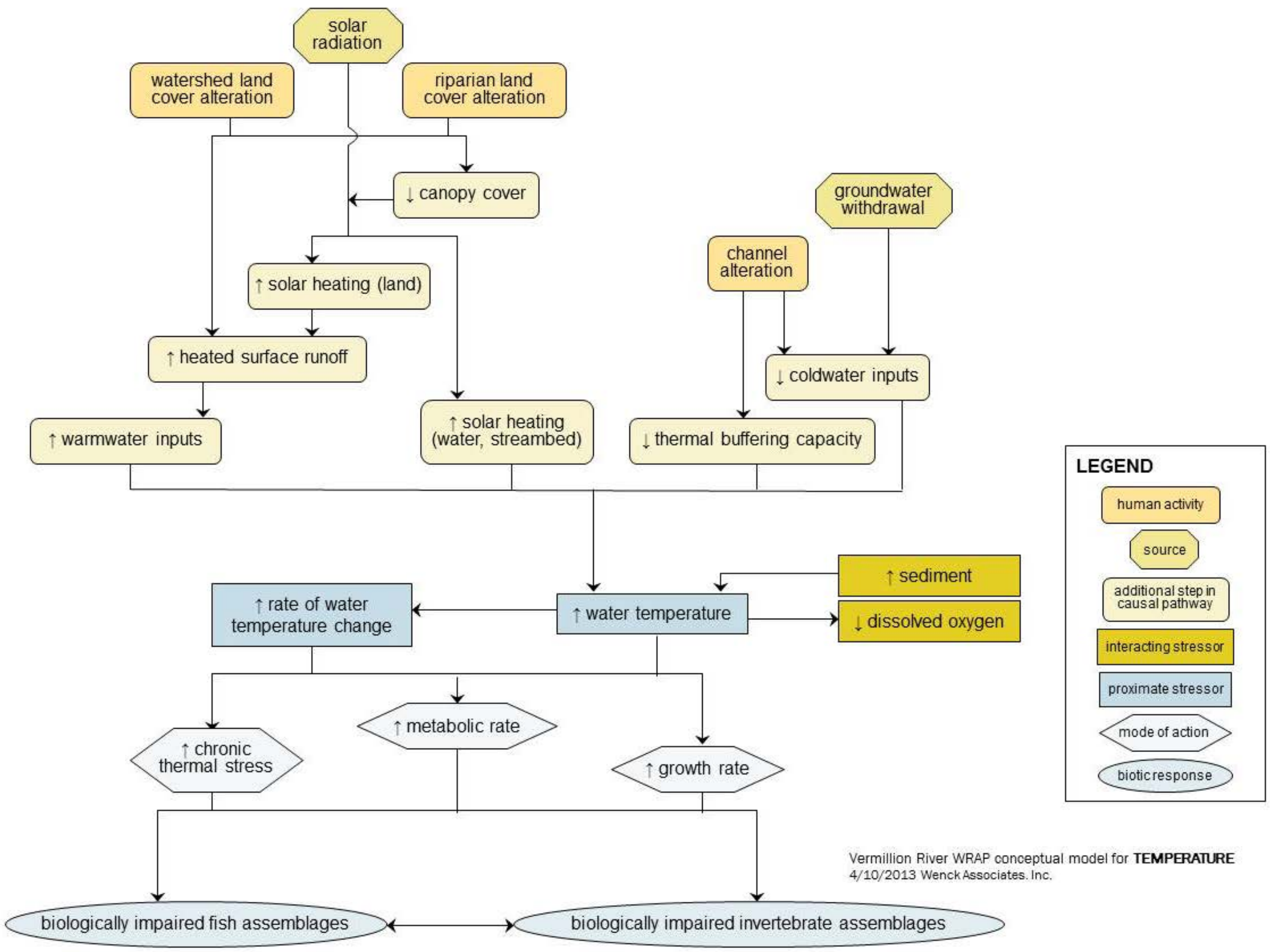



**Figure 3-25. Causal pathway model for temperature.**

### 3.4.3.2 Temperature on the Vermillion River and Tributaries

The alteration of the native landscape has included the conversion of native prairies to agricultural and urban uses throughout much of the watershed. The urban areas in the watershed can alter temperature patterns by increases in storm flow runoff from warm impervious surfaces and also flushing of warm water from storm water ponds during precipitation events. Both of these items can lead to an increase of in-stream temperatures. Agricultural land uses can alter temperature patterns by increasing runoff temperature and also by creating additional miles of warmwater channels through the construction of drainage ditches. These ditches manage flood flows from agricultural fields but can also deliver warmwater directly into coldwater streams within the watershed. Additionally both urban and agricultural uses can remove riparian vegetation which reduces channel shading and can lead to an increase in stream water temperatures.

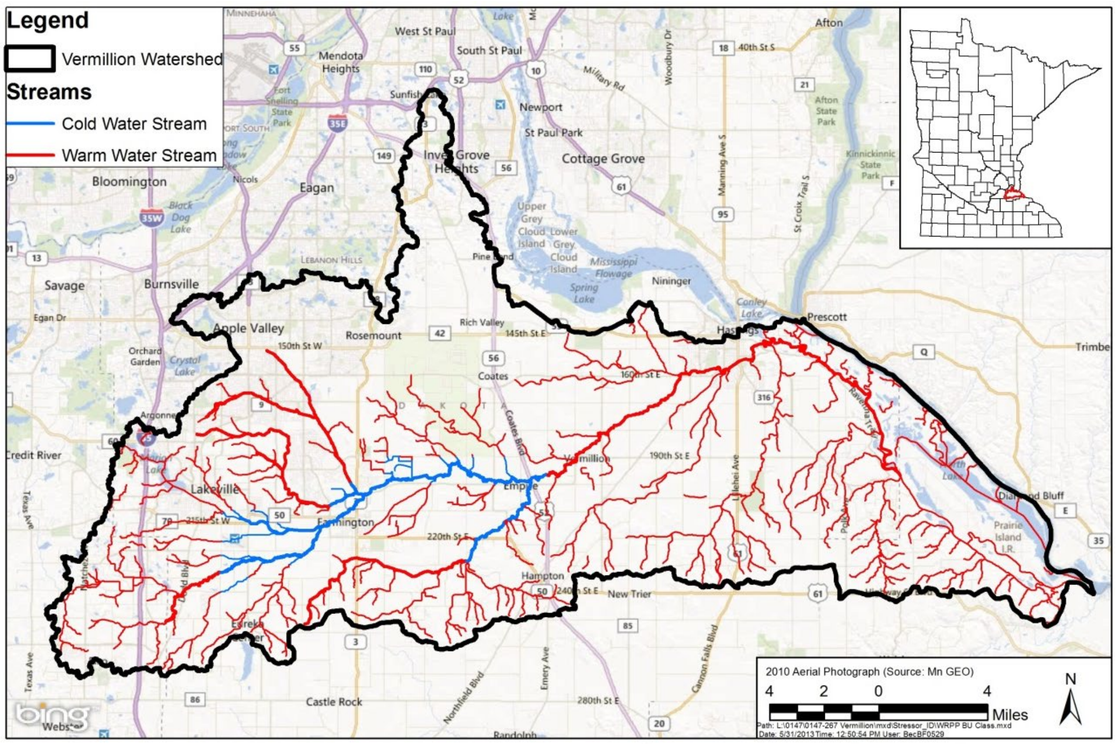



**Figure 3-26. Beneficial Use Classifications for the Vermillion River and major tributaries.**

The brown trout is the most widespread coldwater species found in the Vermillion River and also the main recreational species sought by anglers. There is also a significant amount of research that has been done on this species in terms of its habitat needs and tolerance to temperature fluctuations or increases. As a result, study of stream temperature regimes or fluctuations within the Vermillion River has focused on how stream temperatures are potentially impacting the existing brown trout population in the watershed.

The VRWJPO has conducted extensive monitoring and analysis of temperature data within the watershed and the overall stream temperature dataset covers a period of more than a decade. Annual monitoring reports for the Vermillion River prepared by the Dakota County Soil and Water Conservation District (SWCD) for the VRWJPO include analysis of temperature data in the watershed. The 2010 annual report showed that mean summer temperatures range from 17.6 $^{o}$C to 19.6 $^{o}$C for the eight stations in the VRWJPO monitoring network. Temperatures from 17 $^{o}$C to 19 $^{o}$C are considered the upper end of normal temperature ranges for brown trout, which has been defined as an optimal range of 12 $^{o}$C to 19 $^{o}$C (Raleigh, Zuckerman & Nelson, 1986) to support growth and survival. The range of temperature values observed across the monitoring years from 2005 through 2010 extend from 8.3 $^{o}$C to as high as 28.9 $^{o}$C, with all of the reaches approaching or exceeding 25 $^{o}$C at various times during different monitoring years. A literature review of the influence of stream temperature on habitat selection, growth, reproduction and mortality was performed by Bell (2006). The findings of the literature review summarized that healthy brown trout populations are largely bound by a temperature of 19 $^{o}$C and that temperatures from 19-22 $^{o}$C are stressful to trout, at the upper metabolic limit for the species, where no growth occurs. This literature review defined an optimal range for brown trout of 12-18 $^{o}$C , consistent with other publications. The temperature data presented in the VRWJPO annual monitoring reports shows that at times, the steam temperatures approach or exceed values that are considered lethal for brown trout, the main coldwater species present in the watershed, and therefore the temperature regime is a potential stressor on the fish community.

In addition to annual monitoring sites, the VRWJPO maintains a temperature monitoring network that includes 32 stations throughout the watershed. In 2007 over 2,000,000 temperature records were summarized and analyzed by the VRWJPO (Limnotech, 2007). This of this extensive temperature dataset determined that the stream temperatures are generally within the acceptable range for brown trout in the main stem of the Vermilion River and the major tributaries. However, maximum temperatures on a monthly or seasonal basis approach or exceed published lethal thresholds for brown trout, indicating that during certain summer low flow periods with warm conditions temperature is a potential stressor to the coldwater fish community. This data summary agrees with the observed stream temperatures ranges and maximums provided in the annual monitoring reports discussed above.

Stream data indicates that temperatures in the Vermillion River can at times exceed levels that would be limiting to coldwater species, specifically brown trout. However, while the long term temperature monitoring datasets are quite extensive in relation to the total number of measurements and their distribution across the watershed, each individual monitoring site only captures a small snapshot of the reach as compared to the total miles of stream length. Within the Vermillion River brown trout have been observed within a reach where temperatures exceed the lethal limit for brown trout, indicating that lethal temperature at a specific monitoring probe location does not necessarily mean the entire reach is unfavorable for trout (Nerbonne and Chapman 2007).

An intensive longitudinal temperature survey of the Vermillion River was conducted (Olsen 2008) in an attempt to define influences of the contribution of groundwater base flow on stream temperatures. The survey found that there are many pockets of thermal refugia within coldwater reaches of the Vermillion River and its tributaries, where cold ground water is presumably flowing into the stream. The differences in temperature between reaches were relatively small, on the order of one to two degrees Celsius during the survey. The study also suggested that there are two distinct zones in portions of the Vermillion River defined as “warm zones” where stream bed temperature was similar to the average river temperature and “cold zones” where the bed temperature was similar to the presumed groundwater temperature. This study provides evidence that there is a potential mechanism for brown trout and other coldwater species to either seek localized areas of thermal refugia provided by groundwater inflow during times of high summer temperatures or possibly a mechanism for coldwater species, such as brown trout, to disperse throughout the watershed from one cold groundwater fed area to another.

The temperature monitoring data shows that temperatures within the Vermillion River are normally within the normal ranges favorable to brown trout. This is supported by the widespread occurrence of the species across the watershed. However, the data also indicates that there is variability within the watershed for specific reaches to support coldwater fish due to high mean summer temperatures above the limits that cause brown trout stress and mortality. Nerbonne and Chapman (2007) defined three categories of trout reaches within watershed. The categories were based on MNDNR trout monitoring collection records from 1998 through 2006 and compared to temperature data from the same monitoring reaches. The three trout reach categories were defined as:

- Natural Reproduction/Refuge Reach: Adult and young-of-year brown trout documented in the reach with stream temperatures exceeding 20 $^{o}$C less than ten days per year and not exceeding 23 $^{o}$C (lethal limit for young-of-year brown trout).
- Adult Trout Reach: Adult brown trout present but young of year trout absent or limited to a few individuals with stream temperatures exceeding 20 $^{o}$C for more than ten days per year and at times exceeding 23 $^{o}$C.
- Non-trout Reach: Brown trout have not been documented on a regular basis or are restricted to a few individuals with stream temperatures exceeding 20 $^{o}$C for more than 30 days per year and also exceeding 25 $^{o}$C.

The study concluded that the refuge reaches have great value because they are the places where trout are likely to persist long term in the watershed and that the adult trout reaches add value by extending the overall area of the watershed where trout can persist, likely leading to a larger overall trout population than if the trout were limited to the refuge reaches alone.

#### 3.4.3.3 Causal Analysis -Biological Response to Temperature

Temperature can be limiting to coldwater aquatic communities. As temperature regimes are altered by land use changes or discharges, increases in stream temperature can lead to a decrease in the abundance of coldwater species and an expansion or intrusion of warmwater species into a system. The Vermillion River watershed contains streams with both warmwater and coldwater designations and stream temperature has been monitored and studied extensively.

An evaluation of the temperature data across the Vermillion River watershed reveals that within the coldwater reaches, in general the typical stream temperatures are within the range required to support growth and survival of coldwater species, specifically brown trout. There are also reaches where the temperature approaches or exceeds levels that would be lethal to brown trout. In some instances brown trout have been found within the reaches with high summer stream temperatures. This may be due to two factors including the ability of the species to survive short periods of high temperatures or due to the nature of the groundwater inputs into the stream providing pockets of cold thermal refuge for brown trout and other species. These groundwater pockets of cold thermal refuge may also be occurring in warmwater reaches, and have allowed brown trout to expand across the watershed and become established in warmwater reaches.

There are a limited number of coldwater fish species found in the watershed, with brown trout being the most common. Recent collections have found three native coldwater fish species in the watershed and review of available data indicates that other coldwater species may have never existed within the Vermillion River. These factors suggests that temperature may be a contributing stressor to the biological community in some coldwater reaches but that the Vermillion River may be more accurately described as a coolwater system capable of supporting a variety of species. Temperature does not appear to be a contributing stressor in warmwater reaches of the watershed.

*Fish Community.* The various datasets and studies described above provide evidence that temperature is a potential stressor impacting the coldwater community. Brown trout are a coldwater species that has been introduced into the watershed and now is present as a widespread self-sustaining recreational fishery. However, stream temperature data collected from the watershed displays that temperatures with the Vermillion River and its tributaries often approach or exceed published values that are known to cause stress or mortality to brown trout. Additionally, brown trout have also been found in the warmwater reaches of the lower portion of the watershed which indicates that temperature may only be a local stressor from reach to reach and not a stressor that is ubiquitous across all portions of the watershed.

Beyond brown trout, only three other coldwater species have been documented by recent (2008-2012) monitoring efforts, including pearl dace, brook stickleback and longnose dace. Currently these species are found in low numbers and also low overall distribution in the watershed. It is not known if these species previously were more widespread across the watershed or if temperature is a key factor limiting their current distribution. Longnose dace have been found in streams with temperatures ranging from 12 to 21.1 $^{O}$C and from 5 to 22.7 $^{O}$C from different collection efforts (Edwards, et. al., 1983). These documented ranges of temperatures are commonly observed in the coldwater sections of the Vermillion River but certain reaches can at times exceed these ranges. Longnose dace are typically found in high gradient streams with higher amounts of gravel and cobble substrates than are present in the Vermillion River so the limited occurrence of this species may be influenced by factors beyond temperature. Brook stickleback have a normal temperature range similar to both brown trout and longnose dace, with a range of 4 to 22 $^{O}$C. Pearl dace have been stated to prefer a temperature of 16 $^{O}$C, which is within the preferred range for brown trout discussed above (Cunningham, 2006). Both brook stickleback and pearl dace can be influenced by increases in turbidity. It is possible that these species have responded to a number of environmental factors beyond temperature within the watershed.

Although evidence documents that brook trout were observed in the Vermillion River from 1880 through at least 1930, it is not known if brook trout were ever naturally occurring in the stream and the population was never sustained in the absence of stocking programs. There are no recent records of the other native coldwater species used within the southern coldwater streams metric and it is not known if these species ever occurred within the watershed. Overall stream temperatures in the Vermillion River are found to be within the range to support a coldwater fish community and the widespread distribution of brown trout support this but there is also evidence that high observed stream temperatures are a contributing stressor on the aquatic community within the Vermillion River.

*Reach 517, Stations A1 and A5.* Temperature data was collected as part of the WRAPS study synoptic survey for the DO impaired reaches of the Vermillion River. Continuous data loggers were deployed at three locations on reach 517, a coldwater reach impaired for dissolved oxygen. Data loggers were deployed for a four week period from early August to early September in 2012. Observed temperature values ranged 12 to 24 degrees C at three monitoring locations (Figure 3-27). The daily temperature flux during the 2012 monitoring ranged from just over one degree up to as high as seven degrees. In general the daily temperature values were highest in the middle of reach 517 (compared to the other two monitoring locations. At this location near 225$^{th}$ street there is less channel shading due to limited riparian forest cover as compared to the other two locations. The temperatures observed in August

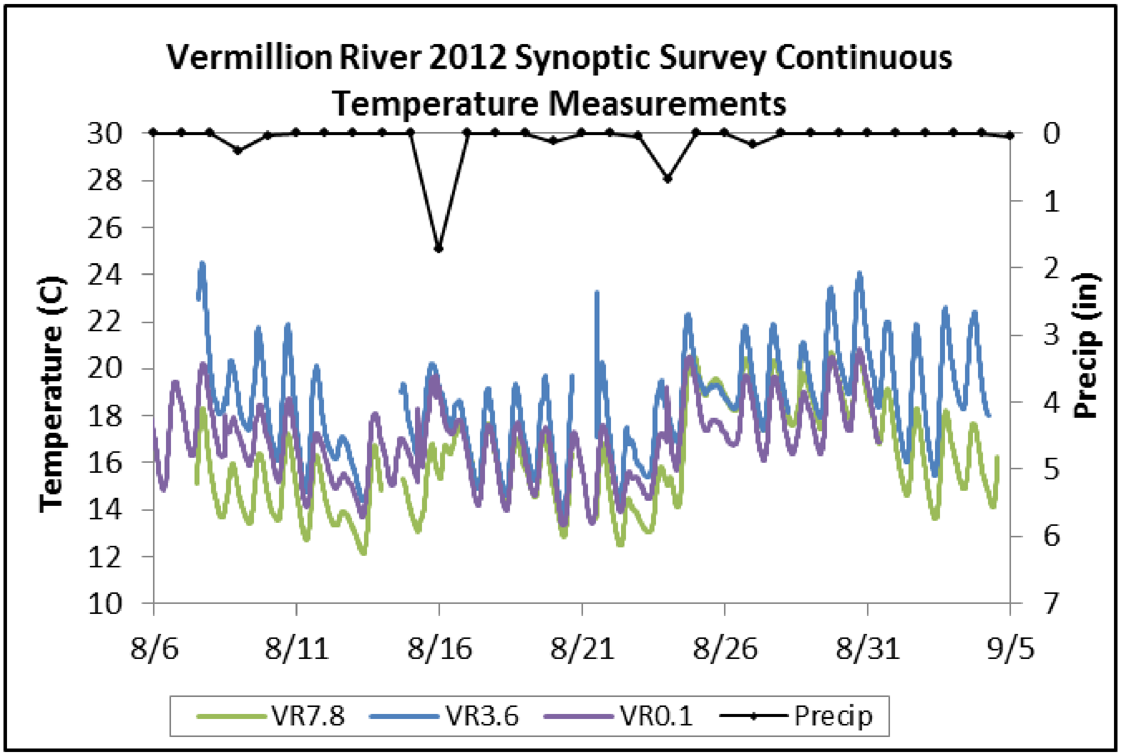



**Figure 3-27. Continuous temperature monitoring for Reach 517, August 2012.**

stream temperatures approached limits that would be considered stressful to brown trout as well as other coldwater fish species. 2012 from Reach 517 is similar to the overall temperatures trends summarized by Limnotech (2007), with daily temperatures generally within the acceptable range for brown trout. However, at times

Figure 3-28 demonstrates a negative relationship on Reach 517 between DO and temperature. This relationship, combined with the negative relationship between DO and flow, suggests rainfall events deliver water that has higher temperature and lower DO than ambient (base-flow) conditions in this cold water reach. The delivery of storm event driven high temperature water to coldwater reaches is a potential stressor to the coldwater fish community and has been suggested in other studies (Nerbonne and Chapman 2007).

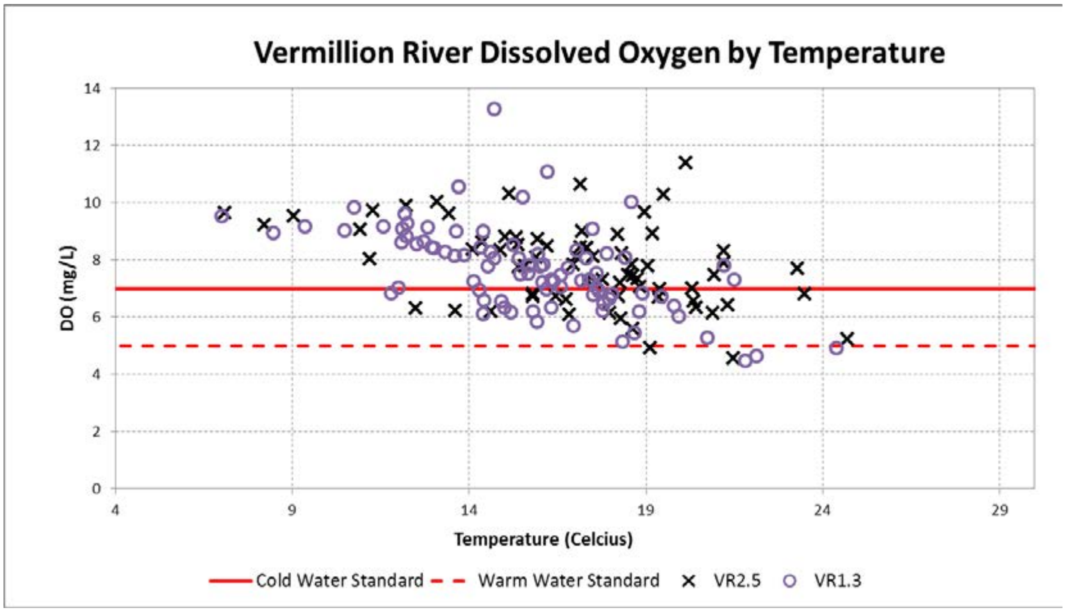


**Figure 3-28. Comparison of DO to stream temperature in Reach 517.**

*Reach 507, Stations A8 and A9*. Temperature data from the VRWJPO monitoring network was analyzed for Reach 507 which contains two biological monitoring stations. The median temperature value from May through September for Reach 507 was 17 $^{O}$C which is at the upper end of the optimal range for growth and survival of brown trout (Figure 3-29). The maximum data values within reach 507 extend to as high as 28 $^{O}$C which is above the lethal limit for brown trout, and higher than the maximum values for reach 517. The majority of the temperature values within reach 507 are within the range that support brown trout but at times, the high temperatures could be contributing to the impairment of the coldwater community.

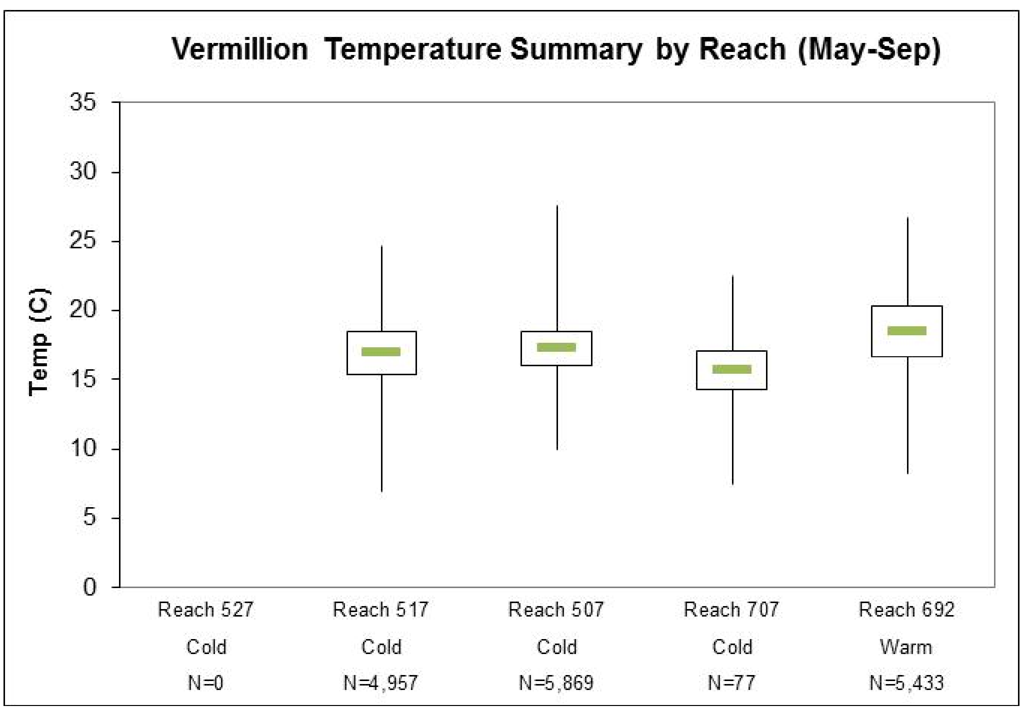


**Figure 3-29. Range of May to September stream temperatures for reaches of the Vermillion River.**

*Reach 707, Stations A12 and A13*. There a limited number of temperature readings available from a monitoring station on the South Branch of the Vermillion River in Reach 707. Most of the available temperature readings were grab samples collected during water quality monitoring efforts. A summary of the grab samples from reach 707 shows the range of values is similar to the range for Reach 517 and 527, where the sample size is considerably larger. The median temperature value of all samples in Reach 707 was 16 $^{O}$C, slightly lower than the median value of 17 $^{O}$C for Reaches 507 and 517. This is potentially a result of the smaller sample size. Overall the range of temperature data observed on Reach 707 is capable of supporting coldwater communities and coldwater fish species such as brown trout and pearl dace have been found in recent collections in this reach.

*Reach 692 Station A14.* While temperature is potentially one of the contributing stressors in the coldwater reaches, it is unlikely that temperature is a significant stressor to the biota in the warmwater reaches. In smaller Southern Headwater Streams, the fish IBI scores are well above the impairment threshold. Additionally, brown trout have been observed in these warmwater tributary streams, indicating that these reaches are "coolwater" streams with temperatures low enough to support coldwater species such as brown trout. The warmwater reaches on the Vermillion River in the lower watershed have also been observed to sustain brown trout. While not abundant these large brown trout (15 to 22 inches in length) have been observed in the warmwater reaches of the lower watershed in deeper pools that likely receive groundwater inputs. Additionally, during 2012 monitoring efforts, young-of-year brown trout were found at site A14 within the warmwater reach on the main stem below Highway 52. This information again suggests that warmwater reaches of the Vermillion River could be accurately described as coolwater streams and capable of supporting some coldwater stream fish.

*Macroinvertebrate Community.* Some of the coldwater reaches do not appear to support temperature-sensitive macroinvertebrate species. However, many of these species are also sensitive to other water quality parameters such as dissolved oxygen, turbidity, and suspended sediment, so it is difficult to say with certainty that temperature is the primary factor limiting those taxa.

Table 3-15 and Table 3-16 show the IBI metrics sensitive to temperature and scores for each coldwater site. For the fish community the individual metrics that were selected from the coldwater IBI's include the percent of sensitive individuals as well as the abundance of native coldwater individuals and taxa metrics. For all sites on both the main stem of the Vermillion River and in the coldwater tributaries, the selected metrics exhibit a potential biotic response to temperature. All ten of the sites have low scores for the abundance of sensitive coldwater species and abundance of native coldwater taxa. Additionally, all ten sites received a zero for all monitoring years for the abundance of native coldwater species metrics. Temperature is likely one of the stressors contributing to the impairment of the fish community.

For the invertebrate community, the Hilsenhoff Biotic Index and the coldwater biotic index were the metrics selected for potential biotic response to temperature. Review of the individual metrics score for the coldwater monitoring sites reveals a mixed biotic response for the invertebrate community. Site A5 on the main stem and most of the tributary sites have low metric scores for the Hilsenhoff and coldwater biotic index metrics where two sites on the main stem A1 and A6, score well on these two metrics and do not indicate a potential biotic response.

**Table 3-15. Scores for metrics sensitive to temperature, Vermillion River coldwater sites.**

| Metric | Type | Max Score | Site A1 | Site A5 | Site A6 | Site A8 | Site A9 | Biotic Response |
|---|---|---|---|---|---|---|---|---|
| % Sensitive Individuals | Fish | 14.3 | 0.07 | 0.8 | 1.9 | 3.9 | 3.2 | Yes |
| # of Coldwater Tolerant Taxa | Fish | 14.3 | 7.7 | 3.0 | 3.4 | 3.2 | 2.1 | Yes |
| % of Native Coldwater Individuals | Fish | 14.3 | 0 | 0 | 0 | 0 | 0 | * |
| % of Native Coldwater Taxa | Fish | 14.3 | 2.5 | 3.9 | 5.1 | 6.5 | 6.9 | Yes |
| Hilsenhoff Biotic Index | Invert | 16.67 | 11.2 | 3 | 8.3 | -- | -- | Yes – A5 |
| Coldwater Biotic Index | Invert | 16.67 | 11.2 | 5.5 | 10.9 | -- | -- | Yes – A5 |

*Native coldwater species were likely not naturally present at these sites. The score of 0 is not a response specifically to temperature.

**Table 3-16. Scores for metrics sensitive to temperature, tributary coldwater sites.**

| Metric | Type | Max Score | Site A2 | Site A3 | Site A7 | Site A12 | Site A13 | Biotic Response |
|---|---|---|---|---|---|---|---|---|
| % Sensitive Individuals | Fish | 14.3 | 5.2 | 6.1 | 1.87 | 5.1 | 3.0 | Yes |
| # of Coldwater Tolerant Taxa | Fish | 14.3 | 3.9 | 6.7 | 2.9 | 6.8 | 3.9 | Yes |
| % of Native Coldwater Individuals | Fish | 14.3 | 0 | 0 | 0 | 0 | 0 | * |
| % of Native Coldwater Taxa | Fish | 14.3 | 1.7 | 2.5 | 3.6 | 3.4 | 3.5 | Yes |
| Hilsenhoff Biotic Index | Invert | 16.67 | 1.2 | 4.6 | 3.9 | 7.0 | 6.6 | Yes |
| Coldwater Biotic Index | Invert | 16.67 | 2.4 | 5.2 | 4.0 | 2.5 | 9.0 | Yes |

*Native coldwater species were likely not naturally present at these sites. The score of 0 is not a response specifically to temperature.

### 3.4.3.4 Weight of Evidence: Temperature

Temperature can be limiting to coldwater aquatic communities. An evaluation of the temperature data across the Vermillion River watershed reveals that within the coldwater reaches, in general the typical range of stream temperatures are within the range required to support growth and survival of coldwater species, specifically brown trout. There are also reaches where the temperature approaches or exceeds levels that would be lethal to brown trout. In some instances brown trout have been found within the reaches with high summer stream temperatures. This may be due to the ability of the species to survive short periods of high temperatures or due to the nature of the groundwater inputs into the stream providing pockets of cold thermal refuge for brown trout and other species. Summary of temperature data for Reaches 517 and 507 exhibit this trend (Figure 3-29), with the median temperature within the optimal growth range for coldwater species but the summer maximum reaching or exceed lethal limits for brown trout. Pockets of cold groundwater input may also be occurring in warmwater reaches, allowing brown trout to expand across the watershed and become established in warmwater reaches. There are a limited number of coldwater species found in the watershed, with brown trout being the most common. It is not known if the limited number of coldwater species and individuals is the result of increased temperatures or if these species were historically present in low numbers or absent from the watershed. These combined factors suggest that temperature may be a contributing stressor to the biological community in some coldwater reaches of the Vermillion River and its tributaries. Temperature does not appear to be a contributing stressor in warmwater reaches of the watershed, such as Reach 692. Table 3-17 and Table 3-18 evaluate the sufficiency of evidence that temperature is a cause of impaired fish and macroinvertebrate communities.

**Table 3-17. Weight of evidence table: temperature, fish impairment.**

| Types of Evidence | Vermillion River, Upstream to Downstream | | | | | | Un-named | South Creek | | Middle Creek | North Creek | South Branch | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | A5 | A6 | A8[1] | A9[1] | A14 | A4 | A2 | A3 | A15 | A7 | A10[1] | A12[1] | A13 |
| **Evidence using data from Vermillion River Watershed** | | | | | | | | | | | | | | |
| Spatial/temporal co-occurrence | + | + | + | O | O | - | O | + | + | O | + | - | + | + |
| Evidence of exposure, biological mechanism | + | + | + | O | O | O | O | + | + | O | + | O | + | + |
| Causal pathway | + | + | + | O | O | O | O | + | + | O | + | O | O | + |
| Field evidence of stressor-response | + | + | + | + | + | O | O | O | O | O | + | - | O | + |
| Field experiments /manipulation of exposure | ++ | ++ | ++ | ++ | ++ | - | O | ++ | ++ | O | ++ | - | + | + |
| Laboratory analysis of site media | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Temporal sequence | + | + | + | + | + | O | O | + | + | O | + | O | + | + |
| Verified or tested predictions | + | + | + | O | O | O | O | + | o | O | + | O | O | + |
| Symptoms | + | + | + | O | O | O | O | + | o | O | + | O | O | + |
| **Evidence using data from other systems** | | | | | | | | | | | | | | |
| Mechanistically plausible cause | + | + | O | O | O | O | O | + | + | O | + | O | + | + |
| Stressor-response in other field studies | + | + | O | O | O | O | O | + | + | O | + | O | + | + |
| Stressor-response in other lab studies | + | + | O | O | O | O | O | O | O | O | + | O | O | + |
| Stressor-response in ecological models | + | + | O | O | O | O | O | O | O | O | + | O | O | + |
| Manipulation experiments at other sites | + | + | + | + | + | O | O | + | + | O | + | O | + | + |
| Analogous stressors | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | | | | | | | |
| Consistency of evidence | + | + | + | O | O | O | O | + | + | O | O | O | O | + |
| Explanatory power of evidence | + | + | + | O | O | - | O | + | + | O | - | - | O | + |

[1] Water quality inferred from closest monitoring station.

**Table 3-18. Weight of evidence table: temperature, macroinvertebrate impairment.**

| Types of Evidence | Vermillion River, Upstream to Downstream | | | | | | Un-named | South Creek | | Middle Creek | North Creek | South Branch | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | A5 | A6 | A8[1] | A9[1] | A14 | A4[2] | A2 | A3 | A15[3] | A7 | A10[3] | A12[3] | A13 |
| **Evidence using data from Vermillion River Watershed** | | | | | | | | | | | | | | |
| Spatial/temporal co-occurrence | O | O | O | O | O | - | N/A | O | O | - | O | - | O | O |
| Evidence of exposure, biological mechanism | O | O | - | O | O | O | N/A | O | O | O | O | O | O | - |
| Causal pathway | O | O | O | O | O | O | N/A | O | O | O | O | O | O | O |
| Field evidence of stressor-response | O | + | O | O | O | O | N/A | + | + | O | + | O | + | O |
| Field experiments /manipulation of exposure | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Laboratory analysis of site media | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Temporal sequence | O | O | O | O | O | O | N/A | O | O | O | O | O | O | O |
| Verified or tested predictions | O | O | O | O | O | O | N/A | O | O | O | O | O | O | O |
| Symptoms | O | + | - | O | O | O | N/A | + | + | O | + | O | + | - |
| **Evidence using data from other systems** | | | | | | | | | | | | | | |
| Mechanistically plausible cause | O | O | O | O | O | O | N/A | O | O | O | O | O | O | O |
| Stressor-response in other field studies | O | O | O | O | O | O | N/A | O | O | O | O | O | O | O |
| Stressor-response in other lab studies | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Stressor-response in ecological models | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Manipulation experiments at other sites | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Analogous stressors | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | | | | | | | |
| Consistency of evidence | O | O | O | O | O | O | N/A | O | O | O | O | O | O | O |
| Explanatory power of evidence | O | O | O | O | O | O | N/A | O | O | O | O | O | O | O |

[1]Only one year of macroinvertebrate data available. Water quality inferred from closest monitoring station.
[2]This site has fish data but no macroinvertebrate data.
[3]Water quality inferred from closest monitoring station.
Note: No detailed metrics available for Sites 8, 9, and 15

### 3.4.4 Habitat Alteration

Habitat describes the place where an organism lives or occurs. In streams, habitat for macroinvertebrates and fish includes the rocks and sediments of the stream bottom and banks; the plants growing in the stream or attached to rocks or debris in the stream; grasses and leaf litter and other organic material that falls into the stream; and logs, sticks, twigs, and other woody debris. Habitat also includes elements of stream structure: streambed depressions that provide deeper pools of water; side channels, backwaters or other stream formations that are places outside the primary flow channel; and the vegetation on and adjacent to the stream bank.

Each species has a specific set of habitat requirements, but can often tolerate conditions that are not quite ideal. Habitat complexity is necessary to provide an environment with a variety of attributes that can support robust assemblage of organisms. For example, a streambed with areas of sand, gravel, and cobble provides a more complex habitat than a streambed that is dominated by sand.

Stream habitat condition is often measured by the number of habitat types present; the quality of the habitat (e.g., frequency and depth of pools; $D_{50}$ particle size of streambed materials; embeddedness); and the amount of habitat (e.g., volume of organic debris available; amount of in-stream cover). Several habitat indices are available, including the Ohio Qualitative Habitat Evaluation Index, the EPA Rapid Bioassessment Protocol, and the Minnesota Stream Habitat Assessment Protocol. These indices rate various attributes of a stream that are important components of habitat complexity, and are useful when comparing various sites.

#### 3.4.4.1 Causal Pathways Model for Habitat Alteration

Figure 3-30 models the likely habitat alteration sources and causal pathways resulting in biotic impairment in the Vermillion River and tributaries.

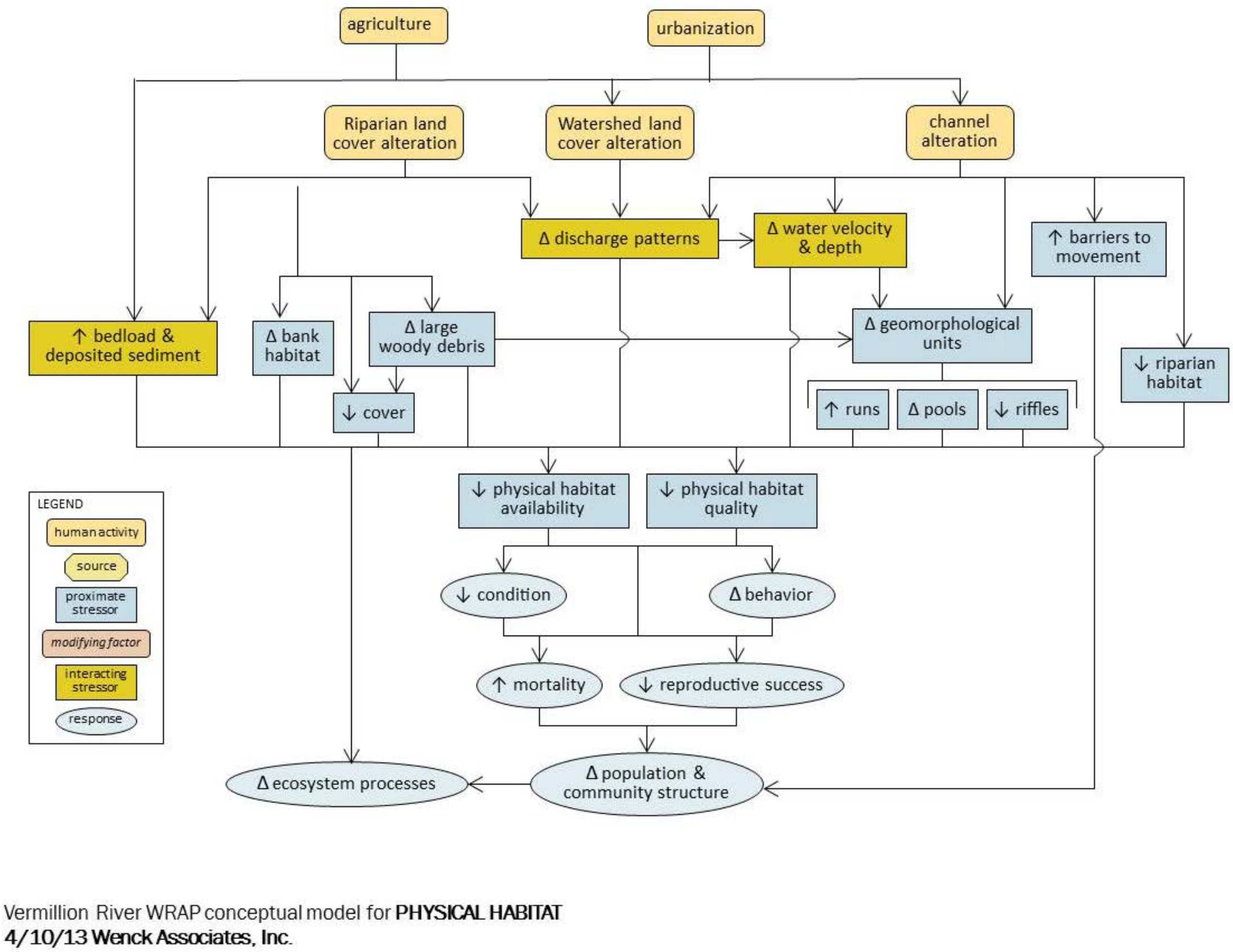



**Figure 3-30. Causal pathway model for habitat alteration.**

### 3.4.4.2 Habitat Alteration on the Vermillion River and its Tributaries

Habitat on the Vermillion River and its tributaries has been altered by ditching the streams, which removes or modifies in-stream habitat such as riffle-pools, snags, meanders, and backwaters and changes streambed composition; removing trees and native vegetation from the banks, which destabilizes the banks, reduces shading, and reduces inputs from woody and herbaceous sources; and increasing inputs of sediment, nutrients, and other pollutants from the watershed and streambanks which alters water chemistry and physical condition. However, there are areas of good habitat on the streams, with complexity, stable banks of native vegetation, and unaltered morphology.

The Vermillion River Monitoring Network conducted water quality, fish and macroinvertebrate assessments, and habitat assessments on the Vermillion and some of its tributaries (Dakota County SWCD 2011). Habitat assessments were completed for each biological monitoring location using the MPCA's Stream Habitat Assessment (MSHA). Total scores for the MSHA assessments are shown in Figure 3-31, which can be interpreted using the MPCA's MSHA scoring table shown in Table 3-19.

**Table 3-19. Interpretation of MPCA MSHA scores.**

| MPCA MSHA Habitat Score | Habitat Quality |
|---|---|
| 67-100 | Good |
| 45-66 | Fair |
| 0-44 | Poor |

Sites with the highest MSHA habitat scores, or the best habitat conditions, were A8 on Reach 507 and A12 on Reach 707. Sites with the lowest MSHA scores were sites A15 and A10, both of which are located on unimpaired reaches. According to the MSHA scoring table, most sites received a "fair" habitat quality score, with only site A15 receiving "poor" scores. The general pattern of MSHA results appears to be relatively consistent among the four monitoring years. However, there is a fair amount of year to year variability within these results. Table 3-20 describes the general habitat characteristics and quality at each site.

**Table 3-20. Habitat characteristics by reach using the MSHA, 2009-2012.**

| Site | Description |
|---|---|
| A1 | Moderately stable, moderately sinuous, gravel-sand substrate, low to moderate bank erosion, light embeddedness. |
| A2 & A3 | Moderately stable, low sinuosity, segments with low to moderate bank erosion. Pool depth and substrate and embeddedness changes year to year, suggesting alternating sediment deposition and flushing, lack of riffles. |
| A4 | Narrow riparian zone, pool depth and substrate and embeddedness changes year to year, suggesting alternating sediment deposition and flushing, riffles present, lack of multiple types of cover. |
| A5 | Low to moderate stability, high sinuosity segment, with gravel-sand bottom and changeable pool depths and substrates. Moderate to severe bank erosion in some locations. |
| A6 | Moderately stable, highly sinuous, gravel-sand bottom, shallow pools |
| A7 | Stable segment, with narrow riparian zone, adequate cover and substrate, deep pools with sand-silt bottom, boulder-cobble riffles. |
| A8 | Stable segment, moderate sinuosity, adequate cover and substrate, deep pools with sand-silt bottom, boulder-cobble riffles. |
| A9 | Uniform gravel-sand bottom, moderate erosion, lack of riffles and multiple substrates, some deep pools. |
| A10 | Uniform, sand-silt bottom, lack of riffles and substrate complexity, moderate embeddedness. |
| A12 | Shifting bottom substrate and pool depths, suggesting alternating sediment deposition and flushing. Boulder-cobble riffles with moderate embeddedness. |
| A13 | Narrow riparian zone, sand-silt bottom, changing pool depths with moderate embeddedness. |
| A14 | Uniform gravel-cobble-sand bottom with changing pool depths and moderate embeddedness, suggesting alternating sediment deposition and flushing. |
| A15 | Moderately stable, low sinuosity, silt-filled, shallow pools, lack of different substrates. Stream quality and channel morphology components dropped in 2011. The creek channel widens at this location, and the site appears to receive a large amount of sediment from the upstream watershed. Precipitation in the early months of 2011 may have deposited excess sediment within site A15, lowering habitat scores. |

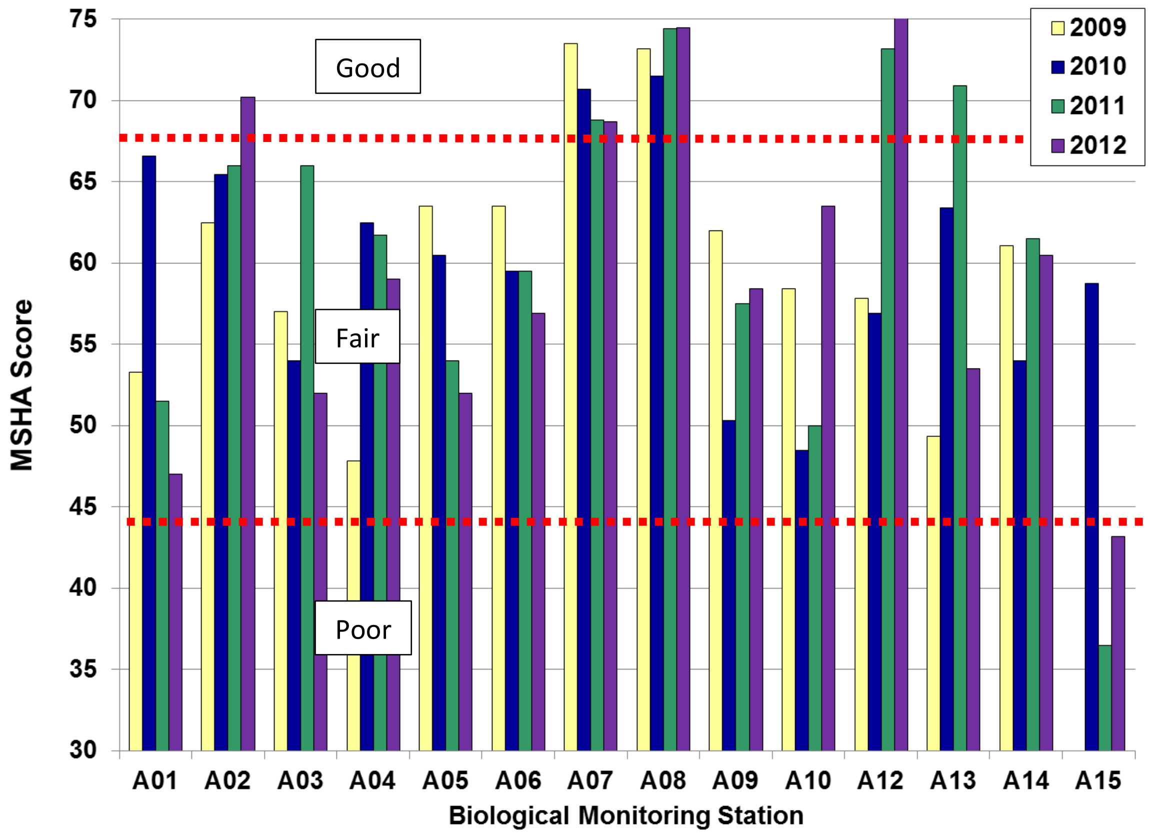



**Figure 3-31. Stream habitat assessment results.**
Source: Dakota County Soil and Water Conservation District. 2012. Vermillion River Monitoring Network 2011 Report.

### 3.4.4.3 Causal Analysis -Biological Response to Habitat Alteration

Reaches of the Vermillion River and its tributaries have been altered through a variety of historic and current land use practices, including agricultural production and pasturage throughout much of the watershed and a significant amount of suburban development in the upper watershed. Segments of the main stem of the Vermillion River as well as the tributaries have been previously channelized. The creation of ditches to aide in agriculture has created additional miles of channel beyond what was historically present. The creation of storm water ponds to manage runoff in urban areas in the upper watershed has increased the presence and distribution of pond or lake fish species within the streams that are likely flushed from the ponds into the Vermillion River during storm events.

Within the stream channels erosion of the steam bank as well as in adjacent upland areas has resulted in increased delivery of fine sediment to the channel. The fine sediments have filled in pools and covered the hard substrates (i.e., gravel and cobble areas). The reduction of the pool and riffle habitats has led to a decrease in the species that require these habitats. The overall changes in habitat with the watershed have resulted in an increase in the presence and abundance of tolerant fish and macroinvertebrate species as well as a reduction of sensitive species.

*Reach 517.* This is the most upstream impaired reach on the Vermillion River, with monitoring sites A1, A5, and A6. Habitat in the reach is adequate, with gravel-sand substrates. Pool depth and embeddedness changes year to year, suggesting alternating sediment deposition and flushing. The stream walking survey found a number of locations in this reach with significant bank erosion. This reach is also impaired for turbidity and dissolved oxygen, which are interacting stressors.

*Reach 507.* This is the middle reach of the Vermillion River, from Farmington to Highway 52 with monitoring sites A8 and A9. Habitat in the reach is generally good; gravel and cobbles are abundant in the steeper, lower reach and sand dominates the upper reach. In addition to good spawning habitat, an island in the middle of the reach provides habitat complexity for a variety of fish life stages. Major stressors are sediment accumulation, lack of riparian quality and lack of channel complexity.

*Reach 692.* This is the most downstream reach on the Vermillion, with monitoring site A14. The channel bed composition is primarily sand with some gravels interspersed. There is limited spawning habitat, and there are few backwater or shallow depth areas for young to escape larger fish. The channel bottom contains at least one foot of unconsolidated sand deposits in most places. Site A14 scored low on the invert metric "Taxa richness of predators." Predators rely on a variety of quality habitat, including submerged aquatic vegetation, large woody debris, and riffles, all of which are lacking in this reach. This site also scored low in "Taxa richness of clinger taxa," suggesting a lack of substrate such as overhanging vegetation and large woody debris.

*Reach 527.* Sites A2 and A3 are located on South Creek. Pool depth and substrate and embeddedness changes year to year, suggesting alternating sediment deposition and flushing, lack of riffles. These sites scored poorly on the percent of invert individuals in the collector-filterer functional feeding group. These taxa feed on organic material processed by shredders. Filterer individuals attach to substrate and capture particles as they float by, while collectors are more mobile. Lack of taxa in this feeding group could indicate lack of substrate for attachment, or a lack of organic material from the riparian zone.

*Reach 707.* This is the lower reach of South Branch, where sites A10, A12, and A13 are located. Low gradient contributes to the thin layer of organic matter on top of the channel bed. The habitat in the reach is poor due to excessive siltation of the channel bed and shifting pool depths. As above, Site 10 on this reach scored low on predator richness, reflecting the lack of quality habitat characteristics shown in Table 3-20.

Table 3-21, Table 3-22, Table 3-23, and Table 3-24 show the IBI metrics sensitive to habitat alteration and scores for each site.

**Table 3-21. Scores for metrics sensitive to habitat alteration, Vermillion River coldwater sites.**

| Metric | Type | Max Score | Site A1 | Site A5 | Site A6 | Site A8 | Site A9 | Biotic Response |
|---|---|---|---|---|---|---|---|---|
| % Sensitive Individuals | Fish | 14.3 | 0.07 | 0.8 | 1.9 | 3.9 | 3.2 | Yes |
| # of Coldwater Tolerant Taxa | Fish | 14.3 | 7.7 | 3.0 | 3.4 | 3.2 | 2.1 | Yes |
| % of Native Coldwater Individuals | Fish | 14.3 | 0 | 0 | 0 | 0 | 0 | * |
| % of Native Coldwater Taxa | Fish | 14.3 | 2.5 | 3.9 | 5.1 | 6.5 | 6.9 | Yes |
| Ratio of Chironomidae to Diptera | Invert | 16.67 | 11.2 | 5.5 | 10.9 | -- | -- | Yes – A5 |
| Hilsenhoff Biotic Index | Invert | 16.67 | 11.2 | 3 | 8.3 | -- | -- | Yes – A5 |

*Native coldwater species were likely not naturally present at these sites. The score of 0 is not a response specifically to habitat conditions.

**Table 3-22. Scores for metrics sensitive to habitat alteration, tributary coldwater sites.**

| Metric | Type | Max Score | Site A2 | Site A3 | Site A7 | Site A12 | Site A13 | Biotic Response |
|---|---|---|---|---|---|---|---|---|
| % Sensitive Individuals | Fish | 14.3 | 5.2 | 6.1 | 1.87 | 5.1 | 3.0 | Yes |
| # of Coldwater Tolerant Taxa | Fish | 14.3 | 3.9 | 6.7 | 2.9 | 6.8 | 3.9 | Yes |
| % of Native Coldwater Individuals | Fish | 14.3 | 0 | 0 | 0 | 0 | 0 | * |
| % of Native Coldwater Taxa | Fish | 14.3 | 1.7 | 2.5 | 3.6 | 3.4 | 3.5 | Yes |
| Hilsenhoff Biotic Index | Invert | 16.67 | 2.4 | 5.2 | 4.0 | 2.5 | 8.9 | Yes |
| % Collector-filterer Individuals | Invert | 16.67 | 1.2 | 4.6 | 3.9 | 7.0 | 6.6 | Yes |

*Native coldwater species were likely not naturally present at these sites. The score of 0 is not a response specifically to habitat conditions.

**Table 3-23. Scores for metrics sensitive to habitat alteration, Vermillion River warmwater site.**

| Metric | Type | Max Score | Site A14 | Biotic Response |
|---|---|---|---|---|
| % of Sensitive Taxa | Fish | 12.5 | 3.7 | Yes |
| % of Tolerant Taxa | Fish | 12.5 | 5.3 | Yes |
| % of Tolerant Individuals | Fish | 12.5 | 0 | Yes |
| % of Individuals from Dominant 2 Species | Fish | 12.5 | 5.9 | Yes |
| Taxa Richness of Short Lived Species | Fish | 12.5 | 5.4 | Yes |
| Hilsenhoff Biotic Index | Invert | 11.1 | 4.9 | Yes |
| Taxa richness of clinger taxa | Invert | 11.1 | 6.1 | No |
| Taxa Richness of Predators | Invert | 11.1 | 1.9 | Yes |

**Table 3-24. Scores for metrics sensitive to habitat alteration, tributary warmwater sites.**

| Metric | Type | Max Score | Site A4 | Site A10 | Site A15 | Biotic Response |
|---|---|---|---|---|---|---|
| Taxa Richness of Sensitive Species | Fish | 16.6 | 8.4 | 10.9 | 4.2 | No |
| % Very Tolerant Taxa | Fish | 16.6 | 9.3 | 10.1 | 7.9 | No |
| % of Generalist Taxa | Fish | 16.6 | 13.9 | 15.8 | 16 | No |
| Hilsenhoff Biotic Index | Invert | 12.5 (A4) 11.1 (A10 | 5.3 | 6.4 | n/a | Yes |
| Taxa richness of clinger taxa | Invert | 12.5 (A4) 11.1 (A10 | 8.0 | 4.1 | n/a | Yes |
| Taxa Richness of Predators | Invert | 12.5 (A4) 11.1 (A10) | 1.4 | 2.7 | n/a | Yes |

### 3.4.4.4 Weight of Evidence: Altered Habitat

Reaches of the Vermillion River and its tributaries have been altered through a variety of historic and current land use practices, including agricultural production and pasturage throughout much of the watershed. There is also a significant amount of urban development in the upper watershed. Segments of the main stem of the Vermillion River as well as the tributaries have been previously channelized. The creation of ditches to aid in agriculture has created additional miles of channel beyond what was historically present. The creation of storm water ponds to manage runoff in urban areas in the upper watershed has increased the presence and distribution of pond or lake fish species within the streams that are likely flushed from the ponds into the Vermillion River during storm events.

Within the stream channels erosion of the steam bank as well as in adjacent upland areas has resulted in increased delivery of fine sediment to the channel. The fine sediments have filled in pools and covered the hard substrates (i.e. gravel and cobble areas). The reduction of the pool and riffle habitats has led to a decrease in the species that require these habitats. The overall changes in habitat with the watershed have resulted in an increase in the presence and abundance of tolerant fish and invertebrate species as well as a reduction of sensitive species. A large factor contributing to the low fish IBI scores for the coldwater reaches is the low number of native coldwater species and individuals found in the system. The alteration in habitat conditions has potentially influenced the coldwater species abundance and distribution but it is also very likely that very few native coldwater species ever existed within the Vermillion River watershed. Table 3-25 and Table 3-26 evaluate the sufficiency of evidence that altered habitat is a cause of impaired fish and macroinvertebrate communities.

**Table 3-25. Weight of evidence table: altered habitat, fish impairment**

| Types of Evidence | Vermillion River, Upstream to Downstream | | | | | | Un-named | South Creek | | Middle Creek | North Creek | South Branch | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | A5 | A6 | A8[1] | A9[1] | A14 | A4 | A2 | A3 | A15 | A7 | A10[1] | A12[1] | A13 |
| **Evidence using data from the Vermillion River** | | | | | | | | | | | | | | |
| Spatial/temporal co-occurrence | + | O | + | - | - | O | O | + | + | O | + | O | + | + |
| Evidence of exposure, biological mechanism | ++ | + | + | + | + | O | O | + | + | ++ | ++ | O | + | + |
| Causal pathway | + | + | + | O | O | O | O | + | + | + | + | + | O | O |
| Field evidence of stressor-response | + | + | + | + | + | + | + | + | O | + | + | O | O | + |
| Field experiments /manipulation of exposure | O | O | O | - | O | O | O | O | O | o | O | O | O | O |
| Laboratory analysis of site media | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Temporal sequence | + | + | + | O | O | + | O | + | + | + | + | O | O | + |
| Verified or tested predictions | O | O | O | + | O | O | O | O | O | + | + | O | O | O |
| Symptoms | + | O | O | + | O | + | O | + | O | + | + | O | O | + |
| **Evidence using data from other systems** | | | | | | | | | | | | | | |
| Mechanistically plausible cause | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| Stressor-response in other field studies | + | + | + | ++ | ++ | + | O | + | O | O | + | O | O | + |
| Stressor-response in other lab studies | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Stressor-response in ecological models | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| Manipulation experiments at other sites | O | O | O | + | + | O | O | O | O | O | O | O | O | O |
| Analogous stressors | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | | | | | | | |
| Consistency of evidence | + | + | + | + | + | + | O | + | + | + | + | O | O | + |
| Explanatory power of evidence | + | O | + | - | - | O | O | + | + | O | + | O | + | + |

[1] Water quality inferred from closest monitoring station.

**Table 3-26. Weight of evidence table: altered habitat, macroinvertebrate impairment.**

| Types of Evidence | Vermillion River, Upstream to Downstream | | | | | | Un-named | South Creek | | Middle Creek | North Creek | South Branch | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | A5 | A6 | A8[1] | A9[1] | A14 | A4[2] | A2 | A3 | A15[3] | A7 | A10[3] | A12[3] | A13 |
| **Evidence using data from Vermillion River Watershed** | | | | | | | | | | | | | | |
| Spatial/temporal co-occurrence | + | + | + | O | O | + | N/A | + | + | O | + | O | + | + |
| Evidence of exposure, biological mechanism | + | + | + | + | + | + | N/A | + | + | + | ++ | O | + | + |
| Causal pathway | + | + | + | O | O | O | N/A | + | + | O | + | + | + | + |
| Field evidence of stressor-response | + | + | + | + | + | + | N/A | + | + | + | + | O | O | + |
| Field experiments /manipulation of exposure | O | O | O | O | O | O | N/A | O | O | O | O | O | O | O |
| Laboratory analysis of site media | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Temporal sequence | + | + | + | O | O | + | N/A | + | + | O | + | O | O | + |
| Verified or tested predictions | O | O | O | O | O | O | N/A | O | O | O | + | O | O | O |
| Symptoms | + | O | O | + | O | + | N/A | + | + | + | + | O | O | + |
| **Evidence using data from other systems** | | | | | | | | | | | | | | |
| Mechanistically plausible cause | + | + | + | + | + | + | N/A | + | + | + | ++ | O | O | + |
| Stressor-response in other field studies | + | + | + | + | + | + | N/A | + | + | + | + | O | O | + |
| Stressor-response in other lab studies | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Stressor-response in ecological models | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| Manipulation experiments at other sites | O | O | O | + | + | O | N/A | O | O | O | O | O | O | O |
| Analogous stressors | NE | NE | NE | NE | NE | NE | N/A | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | | | | | | | |
| Consistency of evidence | + | + | + | O | O | + | N/A | + | + | O | + | O | O | + |
| Explanatory power of evidence | + | + | + | + | + | + | N/A | + | + | + | + | O | O | + |

[1]Only one year of macroinvertebrate data available. Water quality inferred from closest monitoring station.
[2]This site has fish data but no macroinvertebrate data.
[3]Water quality inferred from closest monitoring station.
Note: No detailed metrics available for Sites 8, 9, and 15

# 4.0 Probable Causes

The strength of evidence for the four candidate causes – low dissolved oxygen, turbidity, altered habitat, and temperature is summarized in the following tables. In general across all the assessed reaches of the Vermillion River and tributaries, the evidence for turbidity is strongest followed closely by dissolved oxygen and altered habitat. While the temperature of the river and its tributaries is a plausible stressor and is likely contributing to the impairment, there is less direct evidence of its role. The probable causes established in this stressor identification process will be addressed in the Vermillion River Watershed Restoration and Protection Strategies report.

<u>Vermillion River Reach 517, Sites A1, A5, and A6.</u> For fish, the weight of evidence varies between the three sites. In general turbidity appears to present the strongest evidence, and this is true for both fish and macroinvertebrates across the entire reach. Low dissolved oxygen is a contributing stressor in this reach, especially in the upper portions at Site A1. Dissolved oxygen conditions improve moving downstream and levels are generally adequate with few violations at the lower end of the reach. Many of the fish and macroinvertebrate species present are tolerant of both turbid and low oxygen conditions, making it difficult to separate these interacting stressors. This reach is the headwaters of the Vermillion River, and receives runoff from a network of ditches draining agricultural lands as well as some urban areas. During runoff events the cold water base flow is easily diluted by the warmer inflow. The increased stream resulting from these runoff events also causes a drop in the dissolved oxygen concentration, which is stressor on the fish but has less of an impact on the macroinvertebrate community. Habitat limitations that are stressing the biotic community include a dominance of soft substrates and limited pools with significant depth. Additionally, large snags are clogging the stream channel in portions of the upper reach, slowing stream flow in some areas while also causing scouring and widening of the channel around the snags.

<u>Vermillion River Reach 507, Sites A8 and A9.</u> For both fish and macroinvertebrates, turbidity presents the strongest evidence, with species tolerant of increased turbidity and silt dominating the catch of both the fish and macroinvertebrate communities. The evidence for dissolved oxygen and temperature are not as strong in this reach. However, coldwater species are limited within this reach even though it is part of the main stem of the Vermillion River with adequate perennial flow. There is a lack of habitat complexity in this reach, which is limiting the richness of the fish and macroinvertebrate communities. There have been some habitat improvement projects, however they are relatively new and limited in scope, and there does not yet appear to be a community response due to the relatively short time since the improvement projects were constructed.

<u>Vermillion River Reach 692, Site A14.</u> For both fish and macroinvertebrates, turbidity presents the strongest evidence. There is a significant amount of pool filling and flushing year to year, with a fairly uniform sand bottom. In some areas there are long uniform runs where the channel is very wide and shallow during normal flow conditions, which results in very limited habitat complexity for the biota. Sediment is conveyed to this downstream reach from the upper watershed and from a network of agricultural ditches. This reach also has some very large snags which create scour pools as habitat in some areas but in other areas the snags are tangled to the point of blocking the channel and slowing

stream flow. This is a warmwater segment of the main stem, and temperature and dissolved oxygen do not appear to be a significant factor in explaining impacts to the biota.

South Creek Reach 527, Sites A2 and A3. This tributary stream to the Vermillion River generally has colder temperatures than the main stem in this portion of the watershed. Brown trout are consistently collected in large numbers from this stream at both locations despite the stressors that are present. For fish, dissolved oxygen and temperature are potential interacting stressors but the primary stressors are turbidity and habitat. This reach has a significant sand and silt in-stream bed load, which is easily moved around during high flow events. This leads to turbid conditions as well as dominance of soft substrates and a filling of pools. For macroinvertebrates turbidity presented the strongest evidence and temperature was less plausible. Another habitat limitation in this reach for both fish and macroinvertebrates is the fact that the majority of South Creek has been channelized, which has also reduced the habitat complexity in the reach. There are some areas at the lower ends of this reach where swifter flows have kept the gravel substrates clean and free of fine silt and sand, providing improved habitat for the biota.

South Branch Reach 707, Sites A10, A11, and A12. For fish, the consistency and explanatory evidence for all four stressors was mixed, with the weight of evidence tending toward turbidity. This reach is channelized, and there is a wide network of warm water tributaries conveying sediment and nutrients to the stream. In spite of the agricultural drainage and channelized sections of the stream, the fish community at site A10 scores above the impairment threshold, with a mix of coldwater species present. For macroinvertebrates, turbidity clearly stands out as the primary stressor in this reach. Nitrate concentrations are higher in South Branch than in other reaches, and could be a potential interacting stressor.

Unnamed Tributary Reach 667, Site 4. Only fish data was available for this site, and currently it scores above the impairment threshold for all years of data. However, there is the potential for turbidity to stress the community in the future, as species tolerant of turbid conditions have dominated the recent catch. This small tributary stream is relatively narrow and contains a mix of soft substrates along with hard-pan clay in some areas and a gravel mix in other areas. This tributary is a warmwater stream and is not currently limited by temperature or dissolved oxygen.

Middle Creek Reach 668, Site A15. The biotic community in this warmwater tributary currently scores above the impairment threshold for all years of data. However, there is the potential for turbidity to stress the community in the future. This is a small, narrow stream with limited pool depth and a soft bottom. There is a lack of habitat complexity that could contribute to future impairments. During the synoptic survey performed for the WRAPS study, some low dissolved oxygen levels were also observed in Middle Creek.

North Creek Reach 545/671, Site A7. Turbidity, dissolved oxygen, and altered habitat appear to be equally plausible stressors on both the fish and macroinvertebrate communities in this reach. North Creek has a very large contributing watershed that drains some agricultural areas but also a significant amount of urban development. This ditch and stream network contributing to North Creek has connected the stream to urban storm water ponds, which is evident when species typical of small lakes or ponds are found in this coldwater stream each year. Portions of North Creek have also been channelized, which has impacted habitat within the channel. Some filling of pools with fine sediments has been observed after high flow events.

**Table 4-1. Weight of evidence table, Reach 517 Vermillion River, fish impairment.**

| Types of Evidence | Dissolved Oxygen | | | Turbidity | | | Altered Habitat | | | Temperature | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | A5 | A6 | A1 | A5 | A6 | A1 | A5 | A6 | A1 | A5 | A6 |
| **Evidence using data from the Vermillion River** | | | | | | | | | | | | |
| Spatial/temporal co-occurrence | + | O | O | + | ++ | ++ | ++ | + | + | + | + | + |
| Evidence of exposure, biological mechanism | + | + | + | ++ | ++ | ++ | + | + | + | + | + | + |
| Causal pathway | + | - | - | ++ | + | + | + | + | + | + | + | + |
| Field evidence of stressor-response | + | + | - | + | ++ | ++ | O | O | O | + | + | + |
| Field experiments/manipulation of exposure | NE | NE | NE | O | O | O | NE | NE | NE | ++ | ++ | ++ |
| Laboratory analysis of site media | NE | NE | NE | O | O | O | + | + | + | NE | NE | NE |
| Temporal sequence | O | O | O | ++ | + | + | O | O | O | + | + | + |
| Verified or tested predictions | + | O | O | ++ | ++ | ++ | + | O | O | + | + | + |
| Symptoms | + | + | + | + | + | + | ++ | + | + | + | + | + |
| **Evidence using data from other systems** | | | | | | | | | | | | |
| Mechanistically plausible cause | + | + | + | ++ | ++ | ++ | + | + | + | + | + | O |
| Stressor-response in other field studies | + | + | + | + | + | + | + | + | + | + | + | O |
| Stressor-response in other lab studies | + | + | + | NE | NE | NE | NE | NE | NE | + | + | O |
| Stressor-response in ecological models | NE | NE | NE | NE | NE | NE | + | + | + | + | + | O |
| Manipulation experiments at other sites | NE | NE | NE | NE | NE | NE | O | O | O | + | + | + |
| Analogous stressors | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | | | | | |
| Consistency of evidence | + | O | O | + | ++ | + | + | + | + | + | + | + |
| Explanatory power of evidence | + | + | + | ++ | ++ | ++ | + | O | + | + | + | + |

**Table 4-2. Weight of evidence table, Reach 517 Vermillion River, macroinvertebrate impairment.**

| Types of Evidence | Dissolved Oxygen | | | Turbidity | | | Altered Habitat | | | Temperature | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | A5 | A6 | A1 | A5 | A6 | A1 | A5 | A6 | A1 | A5 | A6 |
| **Evidence using data from the Vermillion River** | | | | | | | | | | | | |
| Spatial/temporal co-occurrence | + | + | + | ++ | ++ | ++ | + | + | + | O | O | O |
| Evidence of exposure, biological mechanism | + | + | + | ++ | ++ | ++ | + | + | + | O | O | - |
| Causal pathway | - | - | - | + | + | + | + | + | + | O | O | O |
| Field evidence of stressor-response | + | + | + | ++ | ++ | ++ | + | + | + | O | + | O |
| Field experiments/manipulation of exposure | NE | NE | NE | NE | NE | NE | O | O | O | NE | NE | NE |
| Laboratory analysis of site media | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Temporal sequence | O | O | O | ++ | ++ | ++ | + | + | + | O | O | O |
| Verified or tested predictions | O | O | O | ++ | ++ | ++ | O | O | O | O | O | O |
| Symptoms | + | + | + | + | + | + | + | O | O | O | + | - |
| **Evidence using data from other systems** | | | | | | | | | | | | |
| Mechanistically plausible cause | + | + | + | ++ | ++ | ++ | + | + | + | O | O | O |
| Stressor-response in other field studies | + | + | + | + | + | + | + | + | + | O | O | O |
| Stressor-response in other lab studies | + | + | + | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Stressor-response in ecological models | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Manipulation experiments at other sites | NE | NE | NE | NE | NE | NE | O | O | O | NE | NE | NE |
| Analogous stressors | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | | | | | |
| Consistency of evidence | O | + | O | + | ++ | + | + | + | + | O | O | O |
| Explanatory power of evidence | + | + | + | ++ | ++ | ++ | + | + | + | O | O | O |

**Table 4-3. Weight of evidence table, Reach 507 Vermillion River, fish impairment.**

| Types of Evidence | Dissolved Oxygen | | Turbidity | | Altered Habitat | | Temperature | |
|---|---|---|---|---|---|---|---|---|
| | A8 | A9 | A8 | A9 | A8 | A9 | A8 | A9 |
| **Evidence using data from the Vermillion River** | | | | | | | | |
| Spatial/temporal co-occurrence | O | O | + | + | - | - | O | O |
| Evidence of exposure, biological mechanism | + | + | + | + | + | + | O | O |
| Causal pathway | O | O | + | + | O | O | O | O |
| Field evidence of stressor-response | + | + | + | + | + | + | + | + |
| Field experiments/manipulation of exposure | NE | NE | O | O | - | O | ++ | ++ |
| Laboratory analysis of site media | NE | NE | O | O | NE | NE | NE | NE |
| Temporal sequence | O | O | + | + | O | O | + | + |
| Verified or tested predictions | O | O | + | + | + | O | O | O |
| Symptoms | O | O | + | + | + | O | O | O |
| **Evidence using data from other systems** | | | | | | | | |
| Mechanistically plausible cause | + | + | ++ | ++ | + | + | O | O |
| Stressor-response in other field studies | + | + | + | + | ++ | ++ | O | O |
| Stressor-response in other lab studies | O | O | NE | NE | NE | NE | O | O |
| Stressor-response in ecological models | NE | NE | NE | NE | + | + | O | O |
| Manipulation experiments at other sites | NE | NE | NE | NE | + | + | + | + |
| Analogous stressors | NE | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | |
| Consistency of evidence | O | O | + | + | + | + | O | O |
| Explanatory power of evidence | O | O | + | + | - | - | O | O |

**Table 4-4. Weight of evidence table, Reach 507 Vermillion River, macroinvertebrate impairment.**

| Types of Evidence | Dissolved Oxygen | | Turbidity | | Altered Habitat | | Temperature | |
|---|---|---|---|---|---|---|---|---|
| | A8 | A9 | A8 | A9 | A8 | A9 | A8 | A9 |
| **Evidence using data from the Vermillion River** | | | | | | | | |
| Spatial/temporal co-occurrence | O | O | + | ++ | O | O | O | O |
| Evidence of exposure, biological mechanism | O | O | + | + | + | + | O | O |
| Causal pathway | O | - | + | + | O | O | O | O |
| Field evidence of stressor-response | O | O | + | ++ | + | + | O | O |
| Field experiments/manipulation of exposure | NE | NE | NE | NE | O | O | NE | NE |
| Laboratory analysis of site media | NE | NE | NE | NE | NE | NE | NE | NE |
| Temporal sequence | O | O | + | + | O | O | O | O |
| Verified or tested predictions | O | O | + | + | O | O | O | O |
| Symptoms | O | O | + | + | + | O | O | O |
| **Evidence using data from other systems** | | | | | | | | |
| Mechanistically plausible cause | + | + | + | ++ | + | + | O | O |
| Stressor-response in other field studies | O | O | + | + | + | + | O | O |
| Stressor-response in other lab studies | O | O | NE | NE | NE | NE | NE | NE |
| Stressor-response in ecological models | NE | NE | NE | NE | NE | NE | NE | NE |
| Manipulation experiments at other sites | NE | NE | NE | NE | + | + | NE | NE |
| Analogous stressors | NE | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | |
| Consistency of evidence | O | O | + | + | O | O | O | O |
| Explanatory power of evidence | O | O | + | + | + | + | O | O |

**Table 4-5. Weight of evidence table, Reach 692 Vermillion River, fish impairment.**

| Types of Evidence | Dissolved Oxygen A14 | Turbidity A14 | Altered Habitat A14 | Temperature A14 |
|---|---|---|---|---|
| **Evidence using data from the Vermillion River** | | | | |
| Spatial/temporal co-occurrence | O | ++ | O | - |
| Evidence of exposure, biological mechanism | O | ++ | O | O |
| Causal pathway | O | ++ | O | O |
| Field evidence of stressor-response | O | ++ | + | O |
| Field experiments/manipulation of exposure | NE | O | O | - |
| Laboratory analysis of site media | NE | O | NE | NE |
| Temporal sequence | O | ++ | + | O |
| Verified or tested predictions | O | ++ | O | O |
| Symptoms | O | + | + | O |
| **Evidence using data from other systems** | | | | |
| Mechanistically plausible cause | + | + | + | O |
| Stressor-response in other field studies | O | + | + | O |
| Stressor-response in other lab studies | O | NE | NE | O |
| Stressor-response in ecological models | NE | NE | + | O |
| Manipulation experiments at other sites | NE | NE | O | O |
| Analogous stressors | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | |
| Consistency of evidence | O | ++ | + | O |
| Explanatory power of evidence | O | ++ | O | - |

Table 4-6. Weight of evidence table, Reach 692 Vermillion River, macroinvertebrate impairment.

| Types of Evidence | Dissolved Oxygen A14 | Turbidity A14 | Altered Habitat A14 | Temperature A14 |
|---|---|---|---|---|
| **Evidence using data from the Vermillion River** | | | | |
| Spatial/temporal co-occurrence | O | + | + | - |
| Evidence of exposure, biological mechanism | O | O | + | O |
| Causal pathway | - | + | O | O |
| Field evidence of stressor-response | O | + | + | O |
| Field experiments/manipulation of exposure | NE | NE | O | NE |
| Laboratory analysis of site media | NE | NE | NE | NE |
| Temporal sequence | O | + | + | O |
| Verified or tested predictions | O | + | O | O |
| Symptoms | O | + | + | O |
| **Evidence using data from other systems** | | | | |
| Mechanistically plausible cause | + | + | + | O |
| Stressor-response in other field studies | O | + | + | O |
| Stressor-response in other lab studies | O | NE | NE | NE |
| Stressor-response in ecological models | NE | NE | NE | NE |
| Manipulation experiments at other sites | NE | NE | O | NE |
| Analogous stressors | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | |
| Consistency of evidence | O | + | + | O |
| Explanatory power of evidence | O | + | + | O |

Table 4-7. Weight of evidence table, Reach 527 South Creek, fish impairment.

| Types of Evidence | Dissolved Oxygen | | Turbidity | | Altered Habitat | | Temperature | |
|---|---|---|---|---|---|---|---|---|
| | A2 | A3 | A2 | A3 | A2 | A3 | A2 | A3 |
| **Evidence using data from the Vermillion River** | | | | | | | | |
| Spatial/temporal co-occurrence | + | + | O | O | + | + | + | + |
| Evidence of exposure, biological mechanism | + | + | + | + | + | + | + | + |
| Causal pathway | + | + | O | + | + | + | + | + |
| Field evidence of stressor-response | + | + | + | o | + | O | O | O |
| Field experiments/manipulation of exposure | NE | NE | O | O | O | O | ++ | ++ |
| Laboratory analysis of site media | NE | NE | O | O | NE | NE | NE | NE |
| Temporal sequence | O | O | + | + | + | + | + | + |
| Verified or tested predictions | + | O | + | + | O | O | + | o |
| Symptoms | + | + | + | + | + | O | + | o |
| **Evidence using data from other systems** | | | | | | | | |
| Mechanistically plausible cause | + | + | + | + | + | + | + | + |
| Stressor-response in other field studies | + | + | + | + | + | O | + | + |
| Stressor-response in other lab studies | + | + | NE | NE | NE | NE | O | O |
| Stressor-response in ecological models | NE | NE | NE | NE | + | + | O | O |
| Manipulation experiments at other sites | NE | NE | NE | NE | O | O | + | + |
| Analogous stressors | NE | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | |
| Consistency of evidence | + | + | + | + | + | + | + | + |
| Explanatory power of evidence | + | + | + | + | + | + | + | + |

**Table 4-8. Weight of evidence table, Reach 527 South Creek, macroinvertebrate impairment.**

| Types of Evidence | Dissolved Oxygen | | Turbidity | | Altered Habitat | | Temperature | |
|---|---|---|---|---|---|---|---|---|
| | A2 | A3 | A2 | A3 | A2 | A3 | A2 | A3 |
| **Evidence using data from the Vermillion River** | | | | | | | | |
| Spatial/temporal co-occurrence | ++ | ++ | ++ | ++ | + | + | O | O |
| Evidence of exposure, biological mechanism | + | + | ++ | ++ | + | + | O | O |
| Causal pathway | + | + | + | + | + | + | O | O |
| Field evidence of stressor-response | + | + | ++ | ++ | + | + | + | + |
| Field experiments/manipulation of exposure | NE | NE | NE | NE | O | O | NE | NE |
| Laboratory analysis of site media | NE | NE | NE | NE | NE | NE | NE | NE |
| Temporal sequence | O | O | ++ | ++ | + | + | O | O |
| Verified or tested predictions | O | O | ++ | ++ | O | O | O | O |
| Symptoms | + | + | + | + | + | + | + | + |
| **Evidence using data from other systems** | | | | | | | | |
| Mechanistically plausible cause | + | + | ++ | ++ | + | + | O | O |
| Stressor-response in other field studies | + | + | + | + | + | + | O | O |
| Stressor-response in other lab studies | + | + | NE | NE | NE | NE | NE | NE |
| Stressor-response in ecological models | NE | NE | NE | NE | NE | NE | NE | NE |
| Manipulation experiments at other sites | NE | NE | NE | NE | O | O | NE | NE |
| Analogous stressors | NE | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | |
| Consistency of evidence | + | + | ++ | ++ | + | + | O | O |
| Explanatory power of evidence | + | + | ++ | ++ | + | + | O | O |

**Table 4-9. Weight of evidence table, Reach 707 South Branch, fish impairment.**

| Types of Evidence | Dissolved Oxygen | | | Turbidity | | | Altered Habitat | | | Temperature | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A10 | A12 | A13 | A10 | A12 | A13 | A10 | A12 | A13 | A10 | A12 | A13 |
| **Evidence using data from the Vermillion River** | | | | | | | | | | | | |
| Spatial/temporal co-occurrence | O | O | O | O | + | + | O | + | + | - | + | + |
| Evidence of exposure, biological mechanism | - | - | - | + | + | + | O | + | + | O | + | + |
| Causal pathway | O | + | + | O | + | + | + | O | O | O | O | + |
| Field evidence of stressor-response | - | + | + | O | + | + | O | O | + | - | O | + |
| Field experiments/manipulation of exposure | NE | NE | NE | O | O | O | O | O | O | - | + | + |
| Laboratory analysis of site media | NE | NE | NE | O | O | O | NE | NE | NE | NE | NE | NE |
| Temporal sequence | O | O | O | + | + | + | O | O | + | O | + | + |
| Verified or tested predictions | O | O | O | O | + | + | O | O | O | O | O | + |
| Symptoms | O | + | + | O | + | + | O | O | + | O | O | + |
| **Evidence using data from other systems** | | | | | | | | | | | | |
| Mechanistically plausible cause | + | + | + | o | + | + | + | + | + | O | + | + |
| Stressor-response in other field studies | O | O | O | + | + | + | O | O | + | O | + | + |
| Stressor-response in other lab studies | O | O | O | NE | NE | NE | NE | NE | NE | O | O | + |
| Stressor-response in ecological models | NE | NE | NE | NE | NE | NE | + | + | + | O | O | + |
| Manipulation experiments at other sites | NE | NE | NE | NE | NE | NE | O | O | O | O | + | + |
| Analogous stressors | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | | | | | |
| Consistency of evidence | O | O | O | O | + | O | O | O | + | O | O | + |
| Explanatory power of evidence | O | + | + | + | + | + | O | + | + | - | O | + |

**Table 4-10. Weight of evidence table, Reach 707 South Branch, macroinvertebrate impairment.**

| Types of Evidence | Dissolved Oxygen | | | Turbidity | | | Altered Habitat | | | Temperature | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A10 | A12 | A13 | A10 | A12 | A13 | A10 | A12 | A13 | A10 | A12 | A13 |
| **Evidence using data from the Vermillion River** | | | | | | | | | | | | |
| Spatial/temporal co-occurrence | O | O | O | + | + | ++ | O | + | + | - | O | O |
| Evidence of exposure, biological mechanism | O | O | - | O | O | ++ | O | + | + | O | O | - |
| Causal pathway | O | O | - | + | + | + | + | + | + | O | O | O |
| Field evidence of stressor-response | O | O | O | + | + | ++ | O | O | + | O | + | O |
| Field experiments/manipulation of exposure | NE | NE | NE | NE | NE | NE | O | O | O | NE | NE | NE |
| Laboratory analysis of site media | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Temporal sequence | O | O | O | + | + | ++ | O | O | + | O | O | O |
| Verified or tested predictions | O | O | O | + | + | + | O | O | O | O | O | O |
| Symptoms | + | + | + | + | + | + | O | O | + | O | + | - |
| **Evidence using data from other systems** | | | | | | | | | | | | |
| Mechanistically plausible cause | + | + | + | + | + | ++ | O | O | + | O | O | O |
| Stressor-response in other field studies | O | O | O | + | + | + | O | O | + | O | O | O |
| Stressor-response in other lab studies | O | O | O | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Stressor-response in ecological models | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| Manipulation experiments at other sites | NE | NE | NE | NE | NE | NE | O | O | O | NE | NE | NE |
| Analogous stressors | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | | | | | | | | | |
| Consistency of evidence | O | O | O | + | + | + | O | O | + | O | O | O |
| Explanatory power of evidence | O | O | O | + | + | ++ | O | O | + | O | O | O |

Table 4-11.Weight of evidence table, Reach 667 Unnamed Tributary, fish impairment.

| Types of Evidence | Dissolved Oxygen | Turbidity | Altered Habitat | Temperature |
|---|---|---|---|---|
| | A4 | A4 | A4 | A4 |
| **Evidence using data from the Vermillion River** | | | | |
| Spatial/temporal co-occurrence | O | + | O | O |
| Evidence of exposure, biological mechanism | O | + | O | O |
| Causal pathway | O | + | O | O |
| Field evidence of stressor-response | O | + | + | O |
| Field experiments/manipulation of exposure | NE | O | O | O |
| Laboratory analysis of site media | NE | O | NE | NE |
| Temporal sequence | O | + | O | O |
| Verified or tested predictions | O | + | O | O |
| Symptoms | O | + | O | O |
| **Evidence using data from other systems** | | | | |
| Mechanistically plausible cause | + | + | + | O |
| Stressor-response in other field studies | O | + | O | O |
| Stressor-response in other lab studies | O | NE | NE | O |
| Stressor-response in ecological models | NE | NE | + | O |
| Manipulation experiments at other sites | NE | NE | O | O |
| Analogous stressors | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | |
| Consistency of evidence | O | + | O | O |
| Explanatory power of evidence | O | + | O | O |

**Table 4-12.Weight of evidence table, Reach 668 Middle Creek, fish impairment.**

| Types of Evidence | Dissolved Oxygen<br>A15 | Turbidity<br>A15 | Altered Habitat<br>A15 | Temperature<br>A15 |
|---|---|---|---|---|
| **Evidence using data from the Vermillion River** | | | | |
| Spatial/temporal co-occurrence | O | ++ | O | O |
| Evidence of exposure, biological mechanism | O | ++ | ++ | O |
| Causal pathway | O | + | + | O |
| Field evidence of stressor-response | O | + | + | O |
| Field experiments/manipulation of exposure | NE | O | o | O |
| Laboratory analysis of site media | NE | O | NE | NE |
| Temporal sequence | O | ++ | + | O |
| Verified or tested predictions | O | + | + | O |
| Symptoms | O | + | + | O |
| **Evidence using data from other systems** | | | | |
| Mechanistically plausible cause | + | ++ | + | O |
| Stressor-response in other field studies | O | + | O | O |
| Stressor-response in other lab studies | O | NE | NE | O |
| Stressor-response in ecological models | NE | NE | + | O |
| Manipulation experiments at other sites | NE | NE | O | O |
| Analogous stressors | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | |
| Consistency of evidence | O | + | + | O |
| Explanatory power of evidence | O | + | O | O |

**Table 4-13. Weight of evidence table, Reach 668 Middle Creek, macroinvertebrate impairment.**

| Types of Evidence | Dissolved Oxygen | Turbidity | Altered Habitat | Temperature |
|---|---|---|---|---|
| | A15 | A15 | A15 | A15 |
| **Evidence using data from the Vermillion River** | | | | |
| Spatial/temporal co-occurrence | O | + | O | - |
| Evidence of exposure, biological mechanism | O | + | + | O |
| Causal pathway | O | + | O | O |
| Field evidence of stressor-response | O | + | + | O |
| Field experiments/manipulation of exposure | NE | NE | O | NE |
| Laboratory analysis of site media | NE | NE | NE | NE |
| Temporal sequence | O | + | O | O |
| Verified or tested predictions | O | + | O | O |
| Symptoms | O | + | + | O |
| **Evidence using data from other systems** | | | | |
| Mechanistically plausible cause | + | + | + | O |
| Stressor-response in other field studies | O | + | + | O |
| Stressor-response in other lab studies | O | NE | NE | NE |
| Stressor-response in ecological models | NE | NE | NE | NE |
| Manipulation experiments at other sites | NE | NE | O | NE |
| Analogous stressors | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | |
| Consistency of evidence | O | + | O | O |
| Explanatory power of evidence | O | + | + | O |

Table 4-14. Weight of evidence table, Reach 545/671 North Creek, fish impairment.

| Types of Evidence | Dissolved Oxygen | Turbidity | Altered Habitat | Temperature |
|---|---|---|---|---|
| | A7 | A7 | A7 | A7 |
| **Evidence using data from the Vermillion River** | | | | |
| Spatial/temporal co-occurrence | + | ++ | + | + |
| Evidence of exposure, biological mechanism | + | ++ | ++ | + |
| Causal pathway | + | + | + | + |
| Field evidence of stressor-response | + | ++ | + | + |
| Field experiments/manipulation of exposure | NE | O | O | ++ |
| Laboratory analysis of site media | NE | O | NE | NE |
| Temporal sequence | O | ++ | + | + |
| Verified or tested predictions | + | + | + | + |
| Symptoms | + | + | + | + |
| **Evidence using data from other systems** | | | | |
| Mechanistically plausible cause | + | + | + | + |
| Stressor-response in other field studies | + | + | + | + |
| Stressor-response in other lab studies | + | NE | NE | + |
| Stressor-response in ecological models | NE | NE | + | + |
| Manipulation experiments at other sites | NE | NE | O | + |
| Analogous stressors | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | |
| Consistency of evidence | + | + | + | O |
| Explanatory power of evidence | + | + | + | - |

**Table 4-15. Weight of evidence table, Reach 545/671 North Creek, macroinvertebrate impairment.**

| | Dissolved Oxygen | Turbidity | Altered Habitat | Temperature |
|---|---|---|---|---|
| **Types of Evidence** | **A7** | **A7** | **A7** | **A7** |
| **Evidence using data from the Vermillion River** | | | | |
| Spatial/temporal co-occurrence | + | + | + | O |
| Evidence of exposure, biological mechanism | + | + | ++ | O |
| Causal pathway | + | + | + | O |
| Field evidence of stressor-response | + | + | + | + |
| Field experiments/manipulation of exposure | NE | NE | O | NE |
| Laboratory analysis of site media | NE | NE | NE | NE |
| Temporal sequence | O | + | + | O |
| Verified or tested predictions | O | + | + | O |
| Symptoms | + | + | + | + |
| **Evidence using data from other systems** | | | | |
| Mechanistically plausible cause | + | + | ++ | O |
| Stressor-response in other field studies | + | + | + | O |
| Stressor-response in other lab studies | + | NE | NE | NE |
| Stressor-response in ecological models | NE | NE | NE | NE |
| Manipulation experiments at other sites | NE | NE | O | NE |
| Analogous stressors | NE | NE | NE | NE |
| **Multiple lines of evidence** | | | | |
| Consistency of evidence | + | + | + | O |
| Explanatory power of evidence | + | + | + | O |

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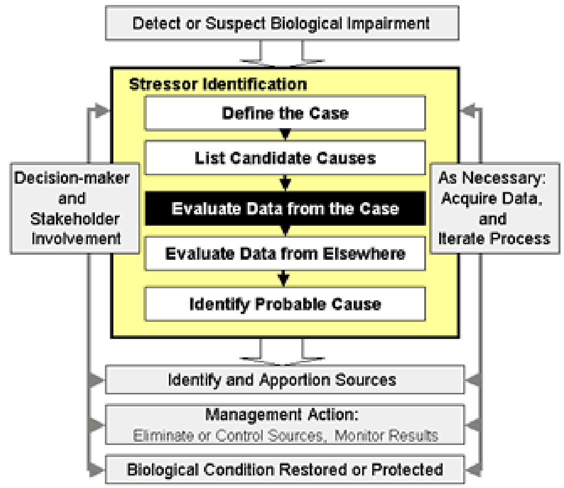
# 6.0 Appendix A

## CADDIS Scoring System

# CADDIS Causal Analysis Scoring




In this CADDIS Stressor Identification step, data from the case is assembled and analyzed with two goals in mind:

- To develop consistent and credible evidence that will allow the confident elimination of very improbable causes, or to use symptoms to refute or diagnose a cause, and
- To begin building the body of evidence for the candidate causes that cannot be eliminated or diagnosed, to identify the most probable causes.

Each type of evidence is evaluated, and the degree to which each type of evidence supports or weakens a case is scored using a standard system. Data from the case may show that it is impossible or extremely improbable that a candidate cause produced the observed effect; if this happens, that candidate cause can be eliminated from further consideration. Certain symptoms may allow for a confident diagnosis or refutation of a candidate cause. The evidence generated by analyzing associations among data or observations from the case will typically fall into one of the types listed in Table A-1.

**Table A-1. Types of evidence that use data from the case.**

| Type of Evidence | Concept |
|---|---|
| **Evidence Using Data From the Case** | |
| Spatial/Temporal Co-Occurrence | The biological effect is observed where and when the causal agent is observed and is not observed in the absence of the agent. |
| Evidence of Exposure or Biological Mechanism | Measurements of the biota show that relevant exposure has occurred or that other biological processes linking the causal agent with the effect have occurred. |
| Causal Pathway | Precursors of a causal agent (components of the causal pathway) provide supplementary or surrogate evidence that the biological effect and causal agent are likely to have co-occurred. |
| Stressor-Response Relationships From the Field | The intensity or frequency of biological effects at the site increases with increasing levels of exposure to the causal agent or decrease with decreasing levels. |
| Manipulation of Exposure | Field experiments or management actions that decrease or increase exposure to a causal agent decrease or increase the biological effect. |
| Laboratory Tests of Site Media | Laboratory tests of site media can provide evidence of toxicity, and Toxicity Identification Evaluation (TIE) methods can provide evidence of specific toxic chemicals, chemical classes, or non-chemical agents. |
| Temporal Sequence | The cause must precede the biological effect. |
| Verified Prediction | Knowledge of the causal agent's mode of action permits prediction of unobserved effects that can be subsequently confirmed. |
| Symptoms | Biological measurements (often at lower levels of biological organization than the effect) can be characteristic of one or a few specific causal agents. A set of symptoms may be diagnostic of a particular cause if they are unique to that cause. |

| Type of Evidence | Concept |
|---|---|
| **Evidence Using Data From Other Systems** | |
| Mechanistically Plausible Cause | The relationship between the cause and biological effect must be consistent with known principles of biology, chemistry and physics, as well as properties of the affected organisms and the receiving environment. |
| Stressor-Response in Other Field Studies | At the impaired sites, the cause must be at levels sufficient to cause similar biological effects in other field studies. |
| Stressor-Response in Other Lab Studies | Within the case, the cause must be at levels associated with related biological effects in laboratory studies. |
| Stressor-Response in Ecological Models | Within the case, the cause must be at levels associated with effects in mathematical models simulating ecological processes. |
| Manipulation Experiments at Other Sites | At similarly impacted locations outside the case sites, field experiments or management actions that increase or decrease exposure to a cause must increase or decrease the biological effect. |
| Analogous Stressors | Agents similar to the causal agent at the impaired site should lead to similar effects at other sites. |
| **Evaluating Multiple Lines of Evidence** | |
| Consistency of Evidence | Confidence in the argument for or against a candidate cause is increased when many types of evidence consistently support or weaken it. |
| Explanatory Power of Evidence | Confidence in the argument for a candidate cause is increased when a post hoc mechanistic, conceptual, or mathematical model reasonably explains any inconsistent evidence. |

Data are analyzed in terms of associations that might support, weaken or refute the case for a candidate cause. This Strength of Evidence analysis is a systematic approach that sorts through the available data to determine the most probable cause or causes based on weight of evidence. Each of the types of evidence is scored based on the degree to which it supports or weakens the case using pluses (++) or minuses (--). The number of pluses or minuses depends on the likelihood that an association might be observed by chance rather than because of the true cause.

A score of O indicates that the evidence neither supports nor weakens the case for the cause, a D is diagnostic of the cause and an R refutes the case for the cause. A score of NE indicates that there is no or insufficient evidence to evaluate. Table A.2 shows the scoring criteria by type of evidence.

**Table A-2. Summary table of scores.**

| Type of Evidence | Finding | Interpretation | Score |
|---|---|---|---|
| **Types of Evidence that Use Data from the Case** | | | |
| Spatial/Temporal Co-ocurrance | The effect occurs where or when the candidate cause occurs, **OR** the effect does not occur where or when the candidate cause does not occur. | This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because the association could be coincidental. | + |
| | It is uncertain whether the candidate cause and the effect co-occur. | This finding *neither supports nor weakens* the case for the candidate cause, because the evidence is ambiguous. | 0 |
| | The effect does not occur where or when the candidate cause occurs, **OR** the effect occurs where or when the candidate cause does not occur. | This finding *convincingly weakens* the case for the candidate cause, because causes must co-occur with their effects. | - - - |

| Type of Evidence | Finding | Interpretation | Score |
|---|---|---|---|
| | The effect does not occur where and when the candidate cause occurs, **OR** the effect occurs where or when the candidate cause does not occur, and the evidence is indisputable. | This finding *refutes* the case for the candidate cause, because causes must co-occur with their effects. | R |
| Temporal Sequence | The candidate cause occurred prior to the effect. | This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because the association could be coincidental. | + |
| | The temporal relationship between the candidate cause and the effect is uncertain. | This finding *neither supports nor weakens* the case for the candidate cause, because the evidence is ambiguous. | 0 |
| | The candidate cause occurs after the effect. | This finding *convincingly weakens* the case for the candidate cause, because causes cannot precede effects (note that this should be evaluated with caution when multiple sufficient causes are present). | - - - |
| | The candidate cause occurs after the effect, and the evidence is indisputable. | This finding *refutes* the case for the candidate cause, because effects cannot precede causes. | R |
| Stressor-Response Relationship from the Field | A strong effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, and the gradient is in the expected direction. | This finding *strongly supports* the case for the candidate cause, but is not convincing due to potential confounding. | + + |
| | A weak effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, **OR** a strong effect gradient is observed relative to exposure to the candidate cause, at non-spatially linked sites, and the gradient is in the expected direction. | This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive due to potential confounding or random error. | + |
| | An uncertain effect gradient is observed relative to exposure to the candidate cause. | This finding *neither supports nor weakens* the case for the candidate cause, because the evidence is ambiguous. | 0 |
| | An inconsistent effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, **OR** a strong effect gradient is observed relative to exposure to the candidate cause, at non-spatially linked sites, but the gradient is not in the expected direction. | This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening due to potential confounding or random error. | - |
| | A strong effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, but the relationship is not in the expected direction. | This finding *strongly weakens* the case for the candidate cause, but is not convincing due to potential confounding. | - - |
| Causal Pathway | Data show that all steps in at least one causal pathway are present. | This finding *strongly supports* the case for the candidate cause, because it is improbable that all steps occurred by chance; it is not convincing because these steps may not be sufficient to generate sufficient levels of the cause. | + + |
| | Data show that some steps in at least one causal pathway are present. | This finding *somewhat supports* the case for the candidate cause. | + |
| | Data show that the presence of all steps in the causal pathway is uncertain. | This finding *neither supports nor weakens* the case for the candidate cause. | 0 |

| Type of Evidence | Finding | Interpretation | Score |
|---|---|---|---|
| | Data show that there is at least one missing step in each causal pathway. | This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening because it may be due to temporal variability, problems in sampling or analysis, or unidentified alternative pathways. | - |
| | Data show, with a high degree of certainty, that there is at least one missing step in each causal pathway. | This finding *convincingly weakens* the case for the candidate cause, assuming critical steps in each pathway are known, and are not found at the impaired site after a well-designed, well-performed, and sensitive study. | - - - |
| Evidence of Exposure or Biological Mechanism | Data show that exposure or the biological mechanism is clear and consistently present. | This finding *strongly supports* the case for the candidate cause, but is not convincing because it does not establish that the level of exposure or mechanistic action was sufficient to cause the effect. | + + |
| | Data show that exposure or the biological mechanism is weak or inconsistently present. | This finding *somewhat supports* the case for the candidate cause. | + |
| | Data show that exposure or the biological mechanism is uncertain. | This finding *neither supports nor weakens* the case for the candidate cause. | 0 |
| | Data show that exposure or the biological mechanism is absent. | This finding *strongly weakens* the case for the candidate cause, but is not convincing because the exposure or the mechanism may have been missed. | - - |
| | Data show that exposure or the biological mechanism is absent, and the evidence is indisputable. | This finding *refutes* the case for the candidate cause. | R |
| Manipulation of Exposure | The effect is eliminated or reduced when exposure to the candidate cause is eliminated or reduced, **OR** the effect starts or increases when exposure to the candidate cause starts or increases. | This finding *convincingly supports* the case for the candidate cause, but it may be given a lower score if it could have resulted from other factors (e.g., removal of more than one agent or other unintended effects of the manipulation). | + + + |
| | Changes in the effect after manipulation of the candidate cause are ambiguous. | This finding *neither supports nor weakens* the case for the candidate cause. | 0 |
| | The effect is not eliminated or reduced when exposure to the candidate cause is eliminated or reduced, **OR** the effect does not start or increase when exposure to the candidate cause starts or increases. | This finding *convincingly weakens* the case for the candidate cause, because such manipulations can avoid confounding. However, effects may continue if there are impediments to recolonization or if another sufficient cause is present. | - - - |
| | The effect is not eliminated or reduced when exposure to the candidate cause is eliminated or reduced, **OR** the effect does not start or increase when exposure to the candidate cause starts or increases, and the evidence is indisputable. | This finding *refutes* the case for the candidate cause, given that data are based on a well-designed and well-performed study. | R |
| Laboratory Tests of Site Media | Laboratory tests with site media show clear biological effects that are closely related to the observed impairment. | This finding *convincingly supports* the case for the candidate cause. | + + + |
| | Laboratory tests with site media show ambiguous effects, **OR** clear effects that are not closely related to the observed impairment. | This finding *somewhat supports* the case for the candidate cause. | + |

| Type of Evidence | Finding | Interpretation | Score |
|---|---|---|---|
| | Laboratory tests with site media show uncertain effects. | This finding *neither supports nor weakens* the case for the candidate cause. | 0 |
| | Laboratory tests with site media show no toxic effects that can be related to the observed impairment. | This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening, because test species, responses or conditions may be inappropriate relative to field conditions. | - |
| Verified Predictions | Specific or multiple predictions of other effects of the candidate cause are confirmed. | This finding *convincingly supports* the case for the candidate cause, because predictions confirm a mechanistic understanding of the causal relationship, and verification of a predicted association is stronger evidence than associations explained after the fact. | + + + |
| | A general prediction of other effects of the candidate cause is confirmed. | This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because another cause may be responsible. | + |
| | It is unclear whether predictions of other effects of the candidate cause are confirmed. | This finding *neither supports nor weakens* the case for the candidate cause. | 0 |
| | A prediction of other effects of the candidate cause fails to be confirmed. | This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening, because other factors may mask or interfere with the predicted effect. | - |
| | Multiple predictions of other effects of the candidate cause fail to be confirmed. | This finding *convincingly weakens* the case for the candidate cause. | - - - |
| | Specific predictions of other effects of the candidate cause fail to be confirmed, and the evidence is indisputable. | This finding *refutes* the case for the candidate cause. | R |
| Symptoms | Symptoms or species occurrences observed at the site are diagnostic of the candidate cause. | This finding is sufficient to *diagnose* the candidate cause as the cause of the impairment, even without the support of other types of evidence. | D |
| | Symptoms or species occurrences observed at the site include some but not all of a diagnostic set, **OR** symptoms or species occurrences observed at the site characterize the candidate cause and a few others. | This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because symptoms or species are indicative of multiple possible causes. | + |
| | Symptoms or species occurrences observed at the site are ambiguous or occur with many causes. | This finding *neither supports nor weakens* the case for the candidate cause. | 0 |
| | Symptoms or species occurrences observed at the site are contrary to the candidate cause. | This finding *convincingly weakens* the case for the candidate cause. | - - - |
| | Symptoms or species occurrences observed at the site are indisputably contrary to the candidate cause. | This finding *refutes* the case for the candidate cause. | R |
| **Types of Evidence that Use Data from Elsewhere** | | | |
| Mechanistically Plausible Cause | A plausible mechanism exists. | This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because levels of the agent may not be sufficient to cause the observed effect. | + |
| | No mechanism is known. | This finding *neither supports nor weakens* the case for the candidate cause. | 0 |
| | The candidate cause is mechanistically implausible. | This finding strongly weakens the case for the candidate cause, but is not convincing because the mechanism could be unknown. | - - |

| Type of Evidence | Finding | Interpretation | Score |
|---|---|---|---|
| Relationships from Laboratory Studies | The observed relationship between exposure and effects in the case agrees quantitatively with stressor-response relationships in controlled laboratory experiments. | This finding *strongly supports* the case for the candidate cause, but is not convincing because the correspondence could be coincidental due to confounding or differences in organisms or conditions between the case and the laboratory. | + + |
| | The observed relationship between exposure and effects in the case agrees qualitatively with stressor-response relationships in controlled laboratory experiments. | This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because the correspondence is only qualitative, and the degree of correspondence could be coincidental due to confounding or differences in organisms or conditions between the case and the laboratory. | + |
| | The agreement between the observed relationship between exposure and effects in the case and stressor-response relationships in controlled laboratory experiments is ambiguous. | This finding *neither supports nor weakens* the case for the candidate cause. | 0 |
| | The observed relationship between exposure and effects in the case does not agree with stressor-response relationships in controlled laboratory experiments. | This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening because there may be differences in organisms or conditions between the case and the laboratory. | - |
| | The observed relationship between exposure and effects in the case does not even qualitatively agree with stressor-response relationships in controlled laboratory experiments, or the quantitative differences are very large. | This finding *strongly weakens* the case for the candidate cause, but is not convincing because there may be substantial and consistent differences in organisms or conditions between the case and the laboratory. | - - |
| Stressor-Response Relationships from Other Field Studies | The stressor-response relationship in the case agrees quantitatively with stressor-response relationships from other field studies. | This finding *strongly supports* the case for the candidate cause, but is not convincing because the correspondence could be coincidental due to confounding or differences in organisms or conditions between the case and elsewhere. | + + |
| | The stressor-response relationship in the case agrees qualitatively with stressor -response relationships from other field studies. | This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because the correspondence is only qualitative, and the degree of correspondence could be coincidental due to confounding or differences in organisms or conditions between the case and elsewhere. | + |
| | The agreement between the stressor-response relationship in the case and stressor-response relationships from other field studies is ambiguous. | This finding *neither supports nor weakens* the case for the candidate cause. | 0 |
| | The stressor-response relationship in the case does not agree with stressor-response relationships from other field studies. | This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening because there may be differences in organisms or conditions between the case and elsewhere. | - |
| | There are large quantitative differences or clear qualitative differences between the stressor-response relationship in the case and the stressor-response relationships from other field studies. | This finding *strongly weakens* the case for the candidate cause, but is not convincing because there may be substantial and consistent differences in organisms or conditions between the case and elsewhere. | - - |

| Type of Evidence | Finding | Interpretation | Score |
|---|---|---|---|
| Relationships from Ecological Simulation Models | The observed relationship between exposure and effects in the case agrees with the results of a simulation model. | This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because models may be adjusted to simulate the effects. | + |
| | The results of simulation modeling are ambiguous. | This finding *neither supports nor weakens* the case for the candidate cause. | 0 |
| | The observed relationship between exposure and effects in the case does not agree with the results of simulation modeling. | This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening, because it may be due to lack of correspondence between the model and site conditions. | - |
| Manipulation of Exposure at Other Sites | At other sites, the effect is consistently eliminated or reduced when exposure to the candidate cause is eliminated or reduced, **OR** the effect is consistently starts or increases when exposure to the candidate cause starts or increases. | This finding *convincingly supports* the case for the candidate cause, because consistent results of manipulations at many sites are unlikely to be due to chance or irrelevant to the site being investigated. | + + + |
| | At other sites, the effect is eliminated or reduced at most sites when exposure to the candidate cause is eliminated or reduced, **OR** the effect starts or increases at most sites when exposure to the cause starts or increases. | This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because consistent results of manipulation at one or a few sites may be coincidental or irrelevant to the site being investigated. | + |
| | Changes in the effect after manipulation of the candidate cause are ambiguous. | This finding *neither supports nor weakens* the case for the candidate cause. | 0 |
| | At other sites, the effect is not consistently eliminated or reduced when exposure to the cause is eliminated or reduced, **OR** the effect does not consistently start or increase when exposure to the cause starts or increases. | This finding *strongly weakens* the case for the candidate cause, but is not convincing because failure to eliminate or induce effects at one or a few sites may be due to poorly conducted studies, or results may be irrelevant due to differences among sites. | - - |
| Analogous Stressors | Many similar agents at other sites consistently cause effects similar to the impairment. | This finding *strongly supports* the case for the candidate cause, but is not convincing because of potential differences among the agents or in conditions among the sites. | + + |
| | One or a few similar agents at other sites cause effects similar to the impairment. | This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because of potential differences among the agents or in conditions among the sites. | + |
| | One or a few similar agents at other sites do not cause effects similar to the impairment. | This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening because of potential differences among the agents or in conditions among the sites. | - |
| | Many similar agents at other sites do not cause effects similar to the impairment. | This finding *strongly weakens* the case for the candidate cause, but is not convincing because of potential differences among the agents or in conditions among the sites. | - - |
| **Evaluating Multiple Lines of Evidence** | | | |
| Consistency of Evidence | All available types of evidence support the case for the candidate cause. | This finding *convincingly supports* the case for the candidate cause. | + + + |
| | All available types of evidence weaken the case for the candidate cause. | This finding *convincingly weakens* the candidate cause. | - - - |

| Type of Evidence | Finding | Interpretation | Score |
|---|---|---|---|
| | All available types of evidence support the case for the candidate cause, but few types are available. | This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because coincidence and errors may be responsible. | + |
| | All available types of evidence weaken the case for the candidate cause, but few types are available. | This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening because coincidence and errors may be responsible. | - |
| | The evidence is ambiguous or inadequate. | This finding *neither supports nor weakens* the case for the candidate cause. | 0 |
| | Some available types of evidence support and some weaken the case for the candidate cause. | This finding *somewhat weakens* the case for the candidate cause, but is not convincing because a few inconsistencies may be explained. | - |
| Explanation of Evidence | There is a credible explanation for any negative inconsistencies or ambiguities in an otherwise positive body of evidence that could make the body of evidence consistently supporting. | This finding can save the case for a candidate cause that is weakened by inconsistent evidence; however, without evidence to support the explanation, the cause is barely strengthened. | + + |
| | There is no explanation for the inconsistencies or ambiguities in the evidence. | This finding neither strengthens nor weakens the case for a candidate cause. | 0 |
| | There is a credible explanation for any positive inconsistencies or ambiguities in an otherwise negative body of evidence that could make the body of evidence consistently weakening. | This finding further weakens an inconsistent case; however, without evidence to support the explanation, the cause is barely weakened. | - |

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