Screening Level Causal Analysis and Assessment of an Impaired Reach of the Groundhouse River, Minnesota

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U.S. Environmental Protection Agency
National Exposure Research Lab
26 W. Martin Luther King Dr.
Cincinnati OH 45268

and

Minnesota Pollution Control Agency
520 Lafayette Rd.
St. Paul, MN 55155

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DISCLAIMER

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Primary Authors:
US EPA Office of Research and Development,
National Exposure Research Laboratory, Ecological Exposure Research Division
Charles Lane, PhD.[1] and Susan Cormier, PhD.[2]

Contributing Authors:
US EPA Office of Research and Development,
National Center for Environmental Assessment
Scott Freeman, PhD.; Susan Norton, PhD., and Glenn Suter II, PhD.
National Human and Environmental Effects Research Laboratory
John Paul, Ph.D.

Minnesota Pollution Control Agency
Scott Niemela; Mike Feist; Joel Chirhart; Craig Affeldt; Daniel Helwig; James Klang; and Joseph Magner

Snake River Watershed Management Board, Minnesota
Jason Neuman

Minnesota Department of Natural Resources
Dave Wright; Jack Enblom; Roger Hugill and Dean Paron

US Department of Agriculture
Sam Martin (Pine County SWCD); Kelly Osterdyk (Kanabec County SWCD)

[1] Contact email: Lane.Charles@epa.gov
[2] Contact email: Cormier.Susan@epa.gov

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EXECUTIVE SUMMARY

Three fish sampling sites on the Groundhouse River, in the St. Croix River basin in central Minnesota did not meet Minnesota's minimum criteria for aquatic life and beneficial uses under Clean Water Act (CWA) Section 303(d), and were listed as impaired under CWA 305(b). A screening-level causal assessment was completed in lieu of a complete assessment as fish and parameter data were collected synoptically over a seven year interval, thus the data were temporally compromised. The main goals of the screening level assessment were (1) to organize and assess the available data to eliminate possible causes and to identify gaps in the data to be filled by additional sampling, (2) to provide an example of a causal analysis that Minnesota could build on for additional impaired waterbodies, and (3) to examine and explore additional methodologies for associating measured biotic response to quantified environmental variables.

A screening-level causal analysis was performed for the site with the lowest fish and benthic macroinvertebrate scores, referenced in this report as site 3. Four candidate causes were examined by comparing causal agents and fish metric responses between site 3 and an upstream site (site 2): (1) loss of habitat from unstable or unsuitable substrates, (2) decreased dissolved oxygen availability associated with excessive nutrient loading, (3) altered food source caused by excessive nutrient loading, and (4) chronic or acute toxicity from chemical compounds.

Chronic or acute toxicity was an unlikely candidate cause because there were no known point sources, and ammonia levels were below concentrations reported to cause effects. However, measurements were not continuously monitored, nor were water samples tested for additional toxicants. The sediment was not analyzed for toxicants.

Hypoxia associated with excessive nutrients was considered an unlikely cause because excessive algal growth and/or decaying material were not observed, and dissolved oxygen levels were above levels reported to cause effects (> 5.0 mg/L). However, dissolved oxygen levels were not continuously monitored.

Altered food resources changing fish and invertebrate assemblages was considered an unlikely candidate cause because although phosphorus levels were exceeded by both sites, excessive algal growth was not observed, and overall nutrient levels at site 3 were similar at site 2 (where the impairment was not observed). However, amounts of leaf litter and woody debris were not well-characterized.

The most probable cause of the biological impairment at site 3 on the Groundhouse River, given the data in hand, is the loss of suitable habitat from unstable or unsuitable substrates caused by excess fines less than 2 mm in diameter. The abundance of fines at site 3 was almost 50% greater than published maximums (albeit for west coast salmonids), and three-fold from the nearest sampled up-stream location. The median particle size (D50) decreased from 22 mm up-stream to 1 mm at site 3, and was substantially less than published minimums of 37 mm.

Recommendations for additional sampling, including targeted sampling upstream and downstream of the impaired site 3, and sampling within the same time frame were given. A reiteration of the causal analysis process, incorporating additional data, is anticipated, and a final identification of the main source of stress on the biota of the Groundhouse River expected.

1.0 INTRODUCTION

Stressor Identification

The Clean Water Act (CWA) Section 303(d) mandates that states and tribes assess the condition of their aquatic resources to ensure the maintenance of both aquatic life and beneficial uses. Specific water bodies that fail to meet the criteria developed by states (in CWA 303(d)) are submitted to the United States Environmental Protection Agency (U.S. EPA) under CWA Section 305(b). Once waterbodies are listed, stressors causing impairment must be identified and remediation efforts, including development of total maximum daily loads (TMDL) for identified pollutants, are initiated.

Stressor identification (SI), coupled with biological assessment (viz. CWA Section 303(d)), is a powerful tool for state and tribal water management programs. The SI process is a formal method for identifying the causes of biological impairment of aquatic systems through a step-by-step procedure (U.S. EPA 2000a, Figure 1): detecting biological impairment, assembling available data, listing candidate causes, analyzing the lines of evidence for each candidate cause, and characterizing the probable cause(s).

In the SI process, existing biological, physical, and chemical data, as well as land use and habitat data, are analyzed and probable causes for impairment identified (U.S. EPA 2000a). While it may often appear that the causes of impairments are obvious, Suter et al. (2002) identified four reasons for the development of a formal SI method: 1) causation is often obscure, even to experienced biologists and managers, 2) informal causal assessments can be prone to biases or logical lapses, 3) formal methods may be more convincing to skeptical stakeholders, and 4) formal methods can allay concerns about costly targeted remediation and restoration efforts. Once the main causal agents of aquatic body perturbation have been formally identified, focused remedial management actions may be undertaken with additional confidence of their efficacy (Cormier et al. 2002, Norton et al. 2002).

In this report, a screening level SI process was applied to the Groundhouse River, in the St. Croix watershed in east-central Minnesota (Figure 2). A screening-level assessment was performed as substantial uncertainty exists because the data (described below) were collected on various dates over a 7-year time span (2 sites in 1996, 2 in 1998, 4 in 2003 with 1 revisit), and most parameters were collected synoptically. Like a screening risk assessment, a screening level causal analysis is performed with available data to eliminate, if possible, some stressors from further consideration and to direct subsequent data collection to generate the information that is most likely to provide the basis for a definitive analysis. While not able to establish causality due to data limitations, the main goals of this report include (1) performing a screening-level assessment of the Groundhouse River, organizing data, and identifying data needs for a full assessment, and (2) demonstrating the SI process to develop a “road map” for future SI examinations for MN and other states and tribes. The screening level SI process was initiated to assist

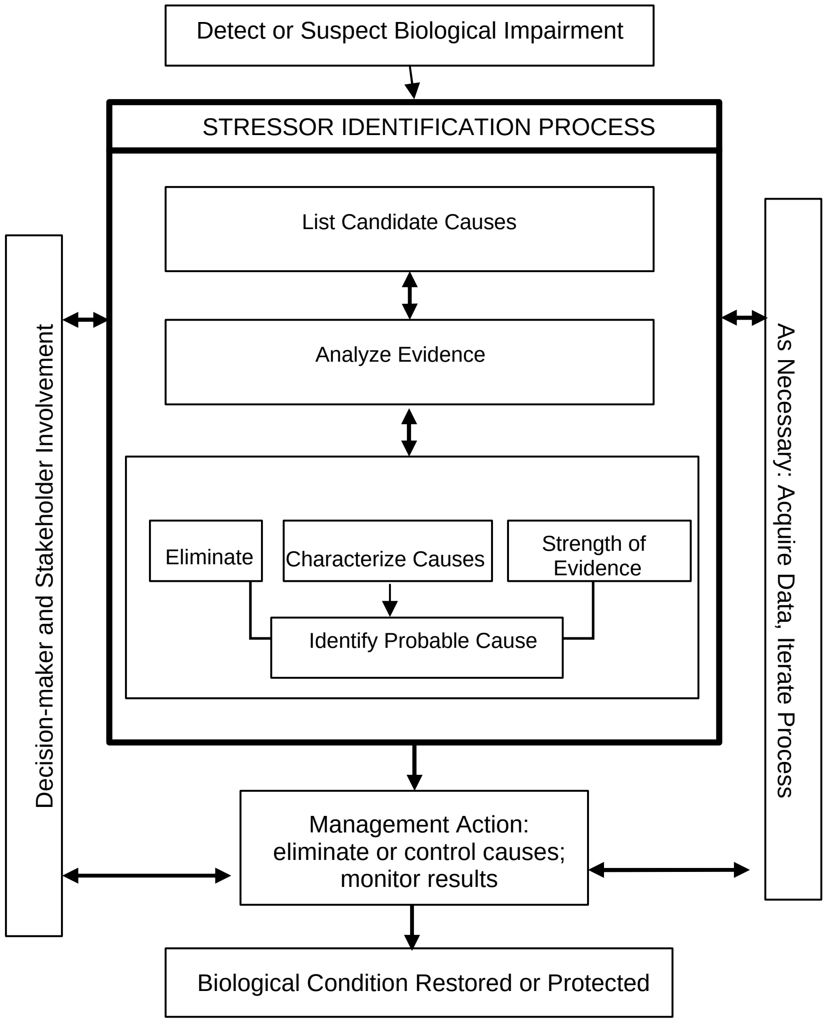

Figure 1. The stressor identification process. The parts involved include defining the biological impairment, assembling available data, listing candidate causes, analyzing the lines of evidence for each candidate cause, and characterizing the probable cause(s).

MNPCA in determining causal mechanisms deleteriously affecting the aquatic and beneficial uses of the Groundhouse River through a training workshop convened by the Minnesota Pollution Control Agency in Hinckley, Minnesota (October 15-16, 2003).

Background: Groundhouse River, St. Croix River Basin, Minnesota

To assist in identifying streams and rivers that do not meet CWA 303(d) standards, the Minnesota Pollution Control Agency (MNPCA) developed an index of biological integrity (IBI, *sensu* Karr 1981) for coolwater rivers and streams of the St. Croix River basin in central Minnesota (Niemela and Feist 2000). They identified 12 fish metrics

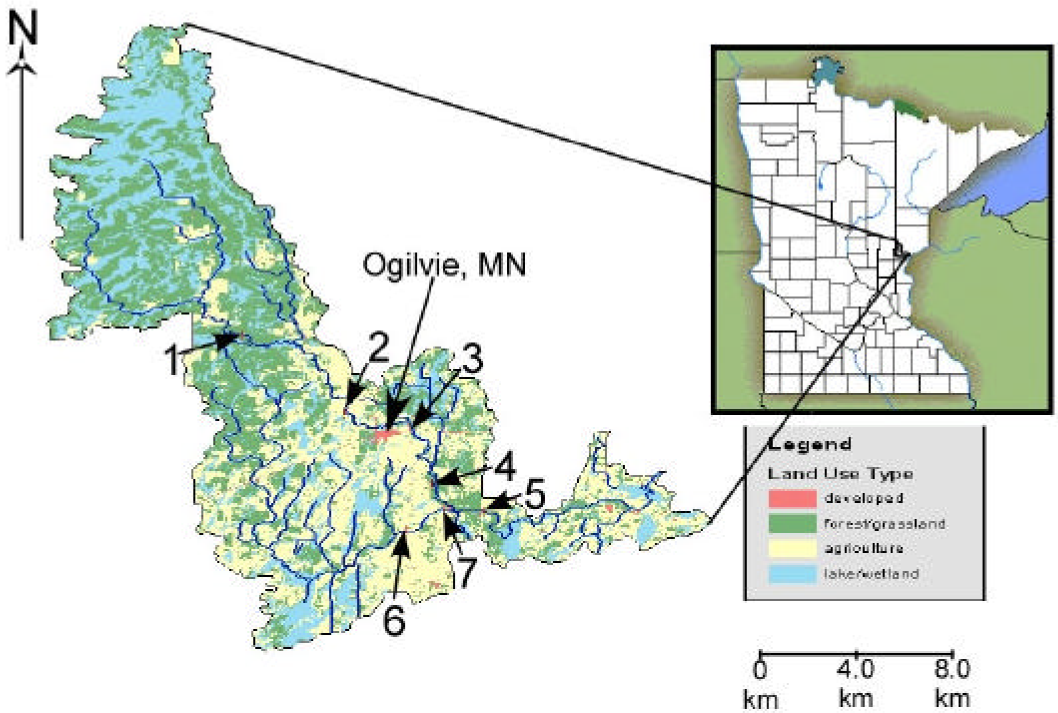

Figure 2. Groundhouse River basin, land use, and approximate sampling locations.

(Table 1), or measurable biological components of streams within this watershed, that respond to increasing anthropogenic disturbance in small and moderate stream classes (including chemical, physical, and nutrient changes, habitat alteration, and changes in basin land use). Sites within the Groundhouse River were sampled in 1996, 1998, or 2003, and one site sampled in 1998 was resampled in 2003 (site 3). MNPCA determined that a 42.3 km reach of the Groundhouse did not meet water quality standards, and the river was listed in Minnesota's 2002 CWA 305(b) report to the U.S. EPA.

The Groundhouse River, located in the St. Croix River Watershed, drains an area of approximately 139 km^2 in east-central Minnesota. The headwaters of the Groundhouse are found in a mostly undeveloped wetland/forested matrix, much of which is located within Rum River State Forest. Several small tributaries drain into the Groundhouse River, most notably the South Fork of the Groundhouse (hereafter called the South Fork). Land use within the basin is generally composed of forest and grassland, agriculture, lake and wetland matrices, and developed lands. Significant development is sparse within the watershed, with the greatest density in the city of Ogilvie, which also maintains a publicly-owned waste water treatment works (POTW) located at the intersection of MN State Highway 23 and the Groundhouse River. Images of the Groundhouse River may be found in Appendix A.

Table 1. Fish metrics identified for cool water rivers and streams of the St. Croix River basin.

Metrics	Stream Size Class: Small Streams (52-141 km^2)	Stream Size Class: Moderate Streams (142-700 km^2)
Count of taxa	**X**	**X**
Number of minnow species	**X**	
Number of intolerant species	**X**	**X**
Number of darter species		**X**
Percent tolerant species	**X**	**X**
Percent dominant two species	**X**	
Number of benthic insectivore species	**X**	**X**
Number of omnivores species		**X**
Percent piscivore species		**X**
Percent simple and lithophilic spawners	**X**	**X**
Number of fish per 100 m (not incl. tolerant)	**X**	**X**
Percent DELT anomalies	**X**	**X**

Data Used for Screening Level Causal Assessment

Fish data from 7 sites (see Figure 2) were collected by the MNPCA during the development of indices of biological integrity for coolwater rivers and streams of the St. Croix River basin (Niemela and Feist 2000). Initially, one site was randomly selected through the U.S. EPA's EMAP program and sampled during June 1996 (site 2). Additional sites were sampled (1996, 1998, 2003) on the Groundhouse River because site 2 did not attain MNPCA water quality standards (see Lyons et al. 1996, Niemela and Feist 2000). The methods outlined in Niemela and Feist (2000) were followed for electrofishing sampling events (1996-2003). Macroinvertebrate data were also collected from perennially flowing sites (sites 3-7) during various years, but were not included in this screening-level SI analysis because data were not available for all sites. Macroinvertebrate data were used to develop regional plots relating biotic response to local and landscape parameters, with potential application to the SI process (see Appendix B).

In addition to collecting fish and macroinvertebrate data, grab samples for water chemistry analyses were taken and habitat data were collected at each site with adequate flow during the sampling event. The following water chemistry parameters were measured: water temperature (^{o}C), conductivity (µmhos/cm), dissolved oxygen (DO, mg/L), pH, turbidity (NTU), total suspended solids (TSS, mg/L), nitrite plus nitrate nitrogen (NO_2+NO_3 – N, mg/L), and total phosphorous (TP, mg/L). The habitat parameters measured included sinuosity, percent riffles, percent pools, river gradient, percent fine substrates, percent embeddedness, average bank erosion, number of stream features per 100 m, percent fish cover, and percent disturbed land use. Median particle size (D50) was also quantified at site 3 and at a location near site 2. Evidence of algal growth at site 3 was visually examined during a site visit in October 2003. See MNPCA "Physical Habitat and Water Chemistry Assessment Protocol for Wadeable Stream Monitoring Sites" (available at www.pca.state.mn.us/water/biomonitoring/sf-sop-habitat.pdf) and Simonson et al. (1994) for specific methods related to water chemistry sampling and habitat characterization.

For purposes of biological assessment, MNPCA classifies coolwater streams based on drainage area, and has identified metrics that differ slightly, depending on the drainage area class (see Table 1, Niemela and Feist 2000). The mainstem of the Groundhouse River, as it meanders from its headwaters, has a small drainage area for site 1 (52-141 km^2, classified as "small stream"). The South Fork is also classified as a "small stream" for sites 6 and 7. Sites 2-5 on the main stem of the river are classified as "moderate size streams," with a drainage area of approximately 142-700 km^2. Impairment thresholds for CWA 303(d) listing also differ slightly depending on drainage area: non-attaining sites have IBI scores <68 for streams with a drainage area of 52-141 km^2, and <69 for streams with a drainage area of 142-700 km^2.

The metrics that comprise the MNPCA fish IBI for streams of the St. Croix River basin are scored based on a 0, 2, 5, 7, and 10 rubric and compiled into a final score that can range from 0-100. (The 9 metrics that comprise the small stream IBI are multiplied by 1.11 to normalize the data on a 0-100 scale comparable to the moderate stream class.) In the SI process, combined metrics are disaggregated to maximize the biological information content and help to identify causal mechanisms and agents (U.S. EPA 2000a).

As the data were collected over a period of several years, repeat visits were made to only one site, and grab samples were synoptically collected, there is substantial uncertainty as to suitability of the data for stressor identification as described by U.S. EPA (2000a). Thus, this analysis was completed as a screening-level assessment, as the SI process can aid in organizing data and may assist in identifying additional data collection needs.

Potential Sources of Stressors

The Groundhouse River drains an area with various land uses, including urban, moderate industrial, rural, agricultural (including crops, pasture, and feed lots), mining (gravel), and forestry. The largest city in the drainage area, Ogilvie (population ca. 500), is near the Groundhouse River and utilizes the river for end-point discharge from an NPDES-permitted POTW. Records from MNPCA indicate that the POTW, a trickling filter/chlorine disinfection plant designed and permitted for 757,000 liters per day discharge, has had operational and maintenance deficiencies that have interfered with the removal of carbonaceous biochemical oxygen demand (CBOD) and total suspended solids (TSS) removal and have resulted in periodic bypassing of partially treated sewage. In addition, at the onset of the study it was not known if during high-rainfall events (the definition of which varies depending on ground water levels), wastewater from Ogilvie bypassed the POTW through a combined sewer overflow (CSO) or pumping station bypass at the POTW. The frequency of potential bypass events, as well as the existence and location of a combined sewer overflow (CSO), were investigated as part of this SI process (see section 7.0, Uncertainty and Causal Considerations, for additional information). Potential stream effects from the POTW and the bypassing include increased nutrient and metal loading, increases in dissolved and particulate organic material, and changes in chemical (i.e., toxics, petroleum distillates) and physical (i.e., pH, dissolved oxygen levels) conditions.

Other potential point-sources of stressors for the Groundhouse River include feedlots and gravel/sand mining operations. Thirty-six animal feeding operations (AFOS) are permitted in the Groundhouse River drainage, with approximately 3100 animal units maintained (Figure 3). AFOS have the potential to affect stream ecology mainly through nutrient loading and subsequent changes in the stream physical and chemical parameters. Ancillary effects of AFOS on stream ecology can include loadings associated with bovine

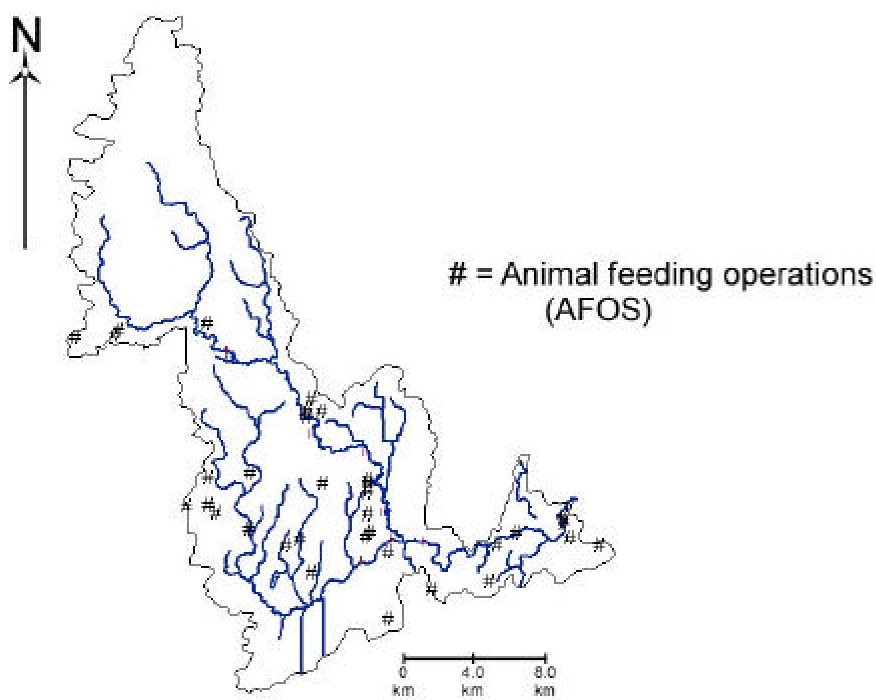

Figure 3. Location of animal feeding operations (AFOS) in the Groundhouse River basin. The 36 permitted AFOS in the basin are indicated by (#).

hormones and anti-biotics (Halling-Sorensen et al. 1998). Mining activities, principally gravel extraction, sorting and washing, also occur within the basin. Gravel mining operations have the potential to affect stream ecology through increases in TSS and associated turbidity (Kondolf et al. 2002), although additional changes such as alterations to stream pH or conductivity as a result of interactions between varying exposed rock media and wash-water or precipitation may also occur (Allan 1995). While the direct stream effect from these activities varies with distance or connectivity to the Groundhouse River, ancillary effects such as decreased water table from withdrawals associated with these land uses can modify stream ecology (Wechsung et al. 2000). An additional potential stressor point-source for the Groundhouse River could include activities associated with a power company right-of-way, located just upstream of site 3. Likely activities associated with the right-of-way include herbicide application and pruning of vegetation to insure minimal interaction between the power lines and vegetation. Herbicides, if used, could be washed into the river or inadvertently applied to the water surface, possibly affecting stream organisms (Paul and Meyer 2001).

Potential non-point sources (NPS) of stressors for the Groundhouse River include hay and pasture lands (approximately 21% of the drainage), row crops – namely corn and soybeans (approximately 13%), and silvicultural operations. Landscape loading of nutrients from cattle wastes can percolate through interstitial spaces until reaching low-lying aquatic systems, and cattle may change stream morphology and character through bank erosion caused by vegetation trampling and/or physical modification of bank structure. Tiling and ditches associated with agricultural landscapes can increase flashiness and cause erosion of stream bed and bank sediments, as well as provide an immediate pathway for agrochemicals (i.e., pesticides, herbicides, and fertilizers) to enter the stream. Changes in stream morphology associated with cropping operations, namely channelization, also affect stream characteristics such as flow, erosive potential, and substrate characteristics (Trimble and Crosson 2000). In addition, the loss of tree cover typically associated with cropping operations also has ramifications for stream characteristics and ecology.

2.0 IMPAIRMENTS

Trigger for Causal Analysis

Fish IBI scores for sites 2, 3, and 4 were < 69 (threshold limit for CWA 303(d) acceptable waters classification), whereas sites 1, 5, 6, and 7 scored substantially higher (Table 2). Site 1 was located in Rum River State Forest with a minimum of disturbed land use (i.e., cropland, pasture, or developed; Niemela and Feist 2000) within the riparian buffer. Sites 5, 6, and 7 were located in the highest disturbed riparian land use matrix, ranging from approximately 30% to 50%. Sites 2 and 4, scoring 60 and 67, respectively, were located in riparian land use matrices composed of approximately 10-20% disturbed lands.

Table 2. Fish Index of Biological Integrity (IBI) scores for sites sampled in the Groundhouse River. Site 3 was sampled in both 1998 and 2003.

Site Name (Year Sampled)	Fish IBI Score
Site 1 (1996)	84
Site 2 (1996)	60
Site 3 (1998)	44
Site 3 (2003, revisit)	41
Site 4 (2003)	67
Site 5 (2003)	80
Site 6 (2003)	79
Site 7 (1998)	80

Site 3 was located closest to Ogilvie, and scored the lowest of all sites sampled. The substantial increase in fish IBI score at site 4 (several km downstream from site 3) may indicate a dilution effect and/or chemical/biological processes ameliorating perturbations. Site 2, located several stream kilometers upstream of Ogilvie, would not be directly affected by point and non-point perturbations associated with Ogilvie, but like the other sites would be affected by upstream land use and known (and unknown) point sources. In this screening-level analysis, causes related to impairments of site 3 were examined due to the exceptionally low scores. Mechanisms responsible for non-attainment at site 3 were examined by comparing causal agents and fish indicator response between sites 2 and 3. This comparison was made due to the spatial proximity between sites 2 and 3 and the relatively similar approximate drainage area (ca. 155 km^2).

As sites 2, 3, and 4 were sampled in 1996, 1998/2003, and 2003, respectively, it is important to note that differences in IBI score are not necessarily indicative of decreased point/non-point source inflows or dilution/riverine processes. Differences in IBI score, like other measured parameters in this screening level assessment, may be temporal sampling artifacts.

Characterization of Specific Biotic Effects

While IBIs are useful tools for assessing the relative condition of stream reaches, information germane to determining specific causes may be hidden due to the agglomerative nature of the IBI metrics. Thus, in the SI process the raw data that comprises the IBI metrics are used to increase the data resolution. Characteristics of biological measurements that are most useful in identifying causal mechanisms from among the available data (Cormier *in preparation*) include:

1. Magnitude of the shift from the nearest upstream and/or reference site(s),
2. Independent behavior of the measurement compared to other measurements,
3. Clear and directly measured endpoints rather than metrics that can vary from the increase or decrease of one or more measurements (i.e., proportional measures),
4. Relevance of the measurement to ecological processes or environmental values,
5. Highest practical level of measurement resolution to narrowly define the effect and the specificity of the cause (species and alteration).

The following measurements (Table 3) were calculated by MNPCA to assess stream biotic integrity: percent piscivore (Figure 4), percent tolerant (Figure 5)(e.g., tolerant of high siltation, high turbidity, low dissolved oxygen, or high levels of ammonia; Niemela and Feist 2000), percent simple and lithophilic spawners (Figure 6), percent with deformities, eroded fins, lesions, or tumors (not shown; DELTs), percent benthic insectivores (Figure 7), number of sensitive taxa (Figure 8; see Niemela and Feist 2000), number of fish per meter of stream reach not including tolerant (Figure 9), and count of taxa (Figure 10). Of particular interest were metrics that demonstrated a substantial difference between sites 2 and 3. For the screening level SI process the following metrics were selected by the participants of the Hinckley, MN, TMDL workshop because of the large change between site 2 and 3: count of taxa, percent tolerant, percent simple

Table 3. Difference in metric values and direction of change between sites 2 and 3.

Metric	Site 2 Value	Site 3 Value (StDev)	Direction of Change Between Sites 2 and 3
Percent Piscivore (%)	5.9 %	2.0 % (2.8)	Decrease
Percent Tolerant (%)	34.5 %	58.9 % (9.6)	Increase
Percent Smple and Lthophilic Spawners (%)	44.1 %	26.0 % (12.8)	Decrease
Percent w/DELTs (%)	0.0 %	0.0 % (0)	n/a
Number of Benthic Insectivores	7	3.0 (1.4)	Decrease
Number of Sensitive Taxa	5	4.0 (1.4)	Decrease
No. Fish/Meter Stream Reach (not incl. tolerant)	1.8	0.5 (0.3)	Decrease
Count of Taxa	22	13.5 (0.7)	Decrease

and lithophilic spawners, and number of benthic insectivores. Richness measures, such as the count of taxa metric, are substantiated indicators of general disturbance (Leonard and Orth 1986). Twenty-two taxa were collected from site 2, while an average of 13.5 taxa were collected from site 3. Almost 60% of the fish collected at site 3 were categorized as tolerant, while approximately 35% of fish from site 2 were tolerant. Twenty-six percent of the fish from site 3 were simple and lithophilic spawners, which deposit their eggs over clean gravel substrates, while 44% were deposit breeders at site 2. Three organisms collected at site 3 were benthic insectivores that, "…rely on undisturbed benthic habitats to feed and reproduce" (Niemela and Feist 2000, p. 9), while 7 species were benthic insectivores at site 2. These metrics were useful in developing candidate causes for non-attainment at site 3.

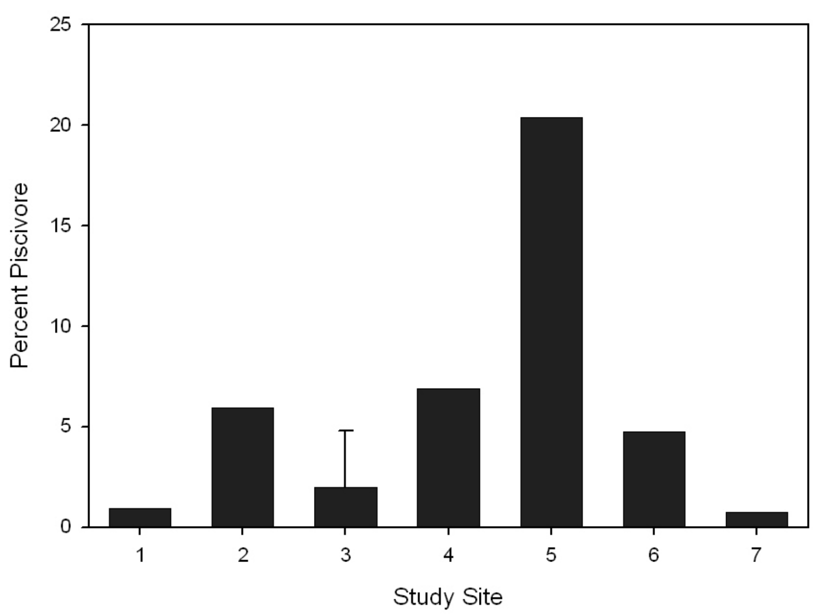

Figure 4. Percent piscivores from sites in the Groundhouse River.

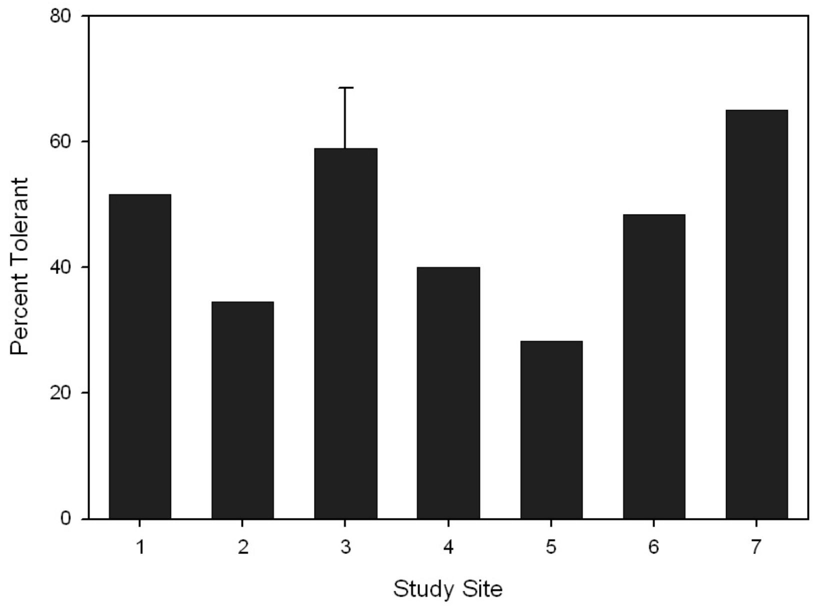

Figure 5. Percent tolerant fish from sites in the Groundhouse River.

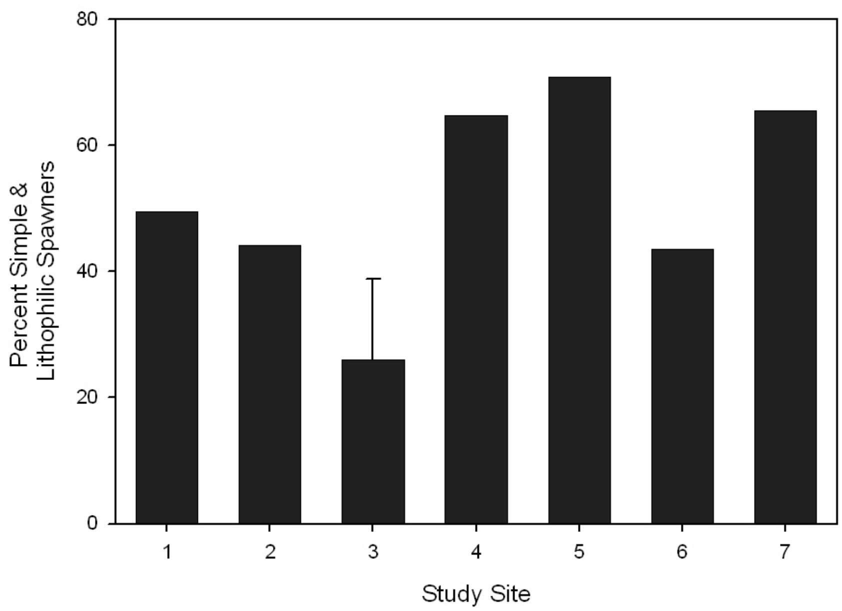

Figure 6. Percent simple and lithophilic spawning fish from sites in the Groundhouse River.

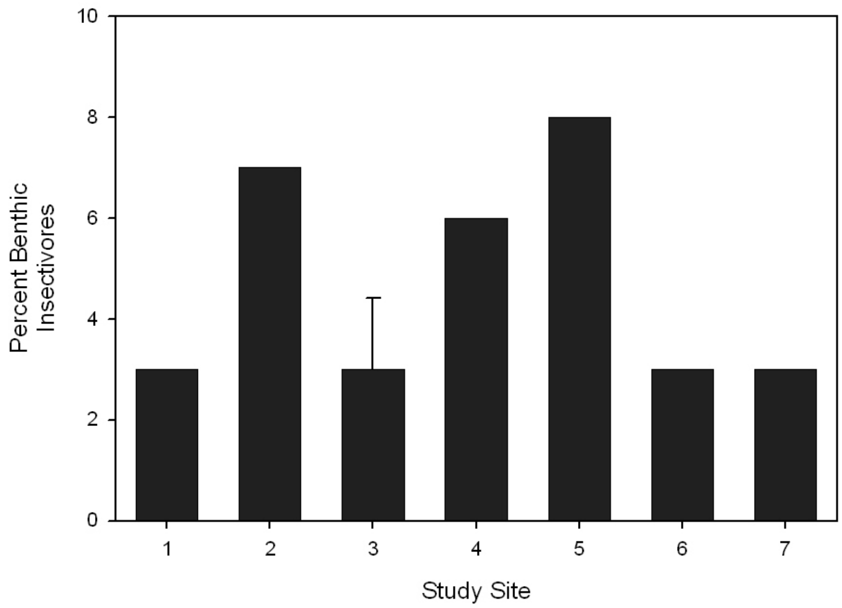

Figure 7. The number of benthic insectivore taxa found at sites in the Groundhouse River.

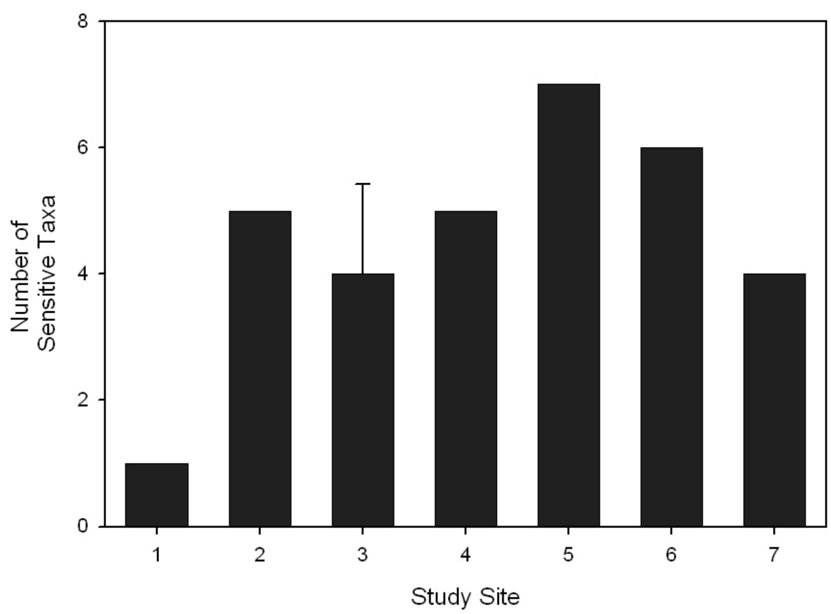

Figure 8. The number of sensitive fish found at sites in the Groundhouse River.

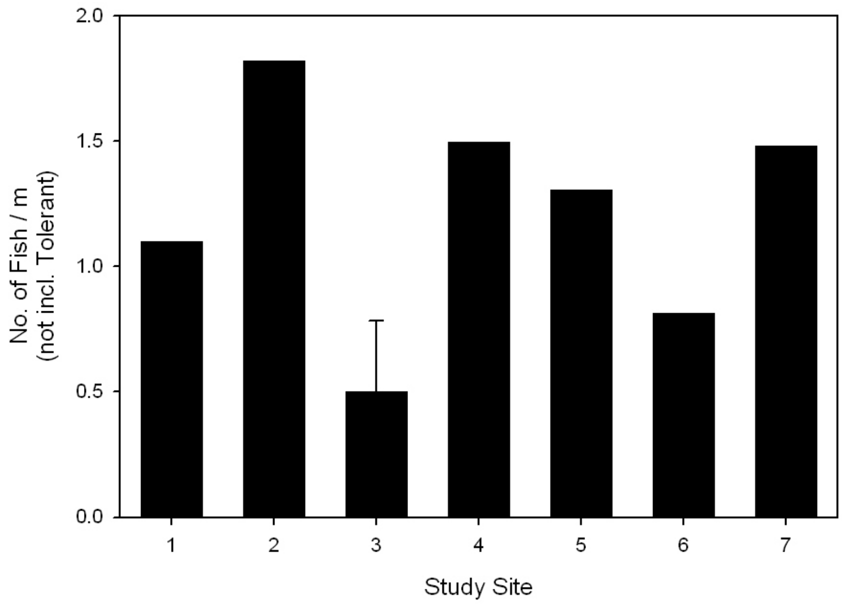

Figure 9. The number of fish per meter (not including tolerant taxa) found at sites in the Groundhouse River.

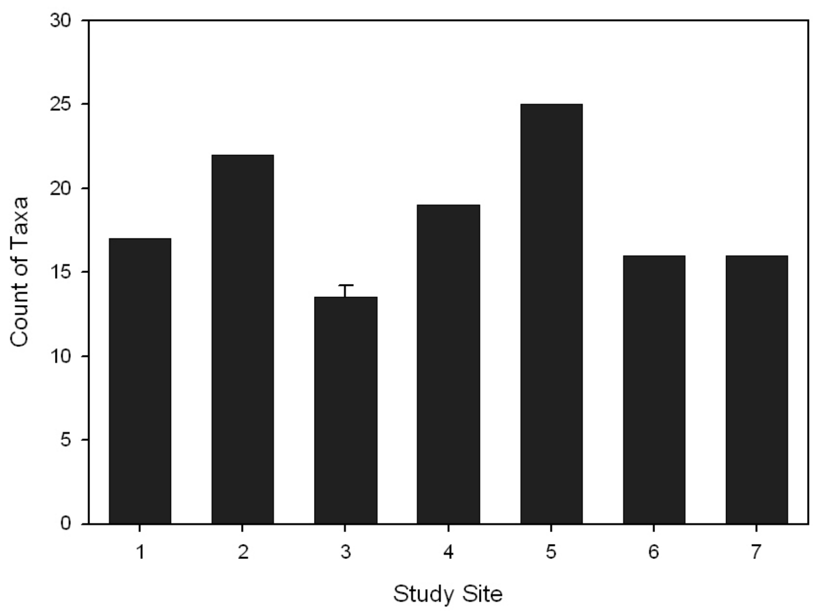

Figure 10. The count of taxa found at sites in the Groundhouse River.

3.0 CANDIDATE CAUSES

Based on an analysis of the data provided, as well as site visits and discussions with the MNPCA, three candidate causes in this screening-level assessment were considered for non-attainment at site 3. Conceptual models detailing the pathways involved for each of the candidate causes were likewise developed. The candidate causes are:

1. Loss of habitat associated with unstable or unsuitable geological substrates (Model 1, Figure 11),
2. Excessive nutrient loading causing the following sub-candidate causes:
    a. mortality associated with low dissolved oxygen (Model 2, Figure 13),
    b. altered food resource (Model 2, see Figure 14),
3. Chronic or acute toxicity from chemical compounds (Model 3, Figure 15).

A description of the potential effects of each candidate cause is described below.

Candidate Cause 1. Loss of Habitat Associated with Unstable or Unsuitable Geological Substrates

Loss of breeding, feeding, or refugia habitat associated with unstable or unsuitable geological substrates is a common disturbance in stream systems and can occur due to excess silt and sediments entering the stream, settling, and covering/filling cobbles and gravel substrates and interstitial spaces, decreasing pool depth, and potential burial of larger coarse woody debris. In addition, excessive sediments can affect stream aquatic use conditions by eliminating stable, coarse substrates that provide shelter during high flow events, thereby potentially affecting fry of larger fish, smaller fish, and the macroinvertebrate food resource. Sediment sources within the stream include materials eroded from banks and scoured off the stream bed. Potential exterior sources of silt and sediments include gravel and mining operations, farming activities, road ways and urban runoff, and the extensive dirt and gravel road system in the drainage area (see Figure 11).

Naturally occurring stream features and landscape characteristics may also affect stream sediment conditions, potentially altering the occurrence of suitable gravel substrates (Figure 12). Beaver dams and low gradients, may both decrease flow, causing particulates to settle (see Figure 12). Also, aquatic systems with naturally elevated particulate levels may be more susceptible to the effects of anthropogenic sediment loading.

In this screening level assessment, loss of habitat due to unstable or unsuitable geologic substrates was evaluated as a candidate cause for impairment at site 3 versus site 2 for several reasons (Table 4). Stream assessment at site 3 noted a low stream gradient, which would permit suspended sediments and floc to settle, filling interstitial spaces. The stream channel was incised, with high channel shear and weak point shear on the stream bed and banks. Highly incised channels do not have ready access to flood plains, thus water energies are not abated by floodplain vegetation and structure, but concentrated in the channel. In addition, fine silt is not deposited in the flood plain but remains within the channel. Weak point shear on stream bed and banks suggests that bed and bank materials are easily eroded by low water energies, and greatly eroded by high energies

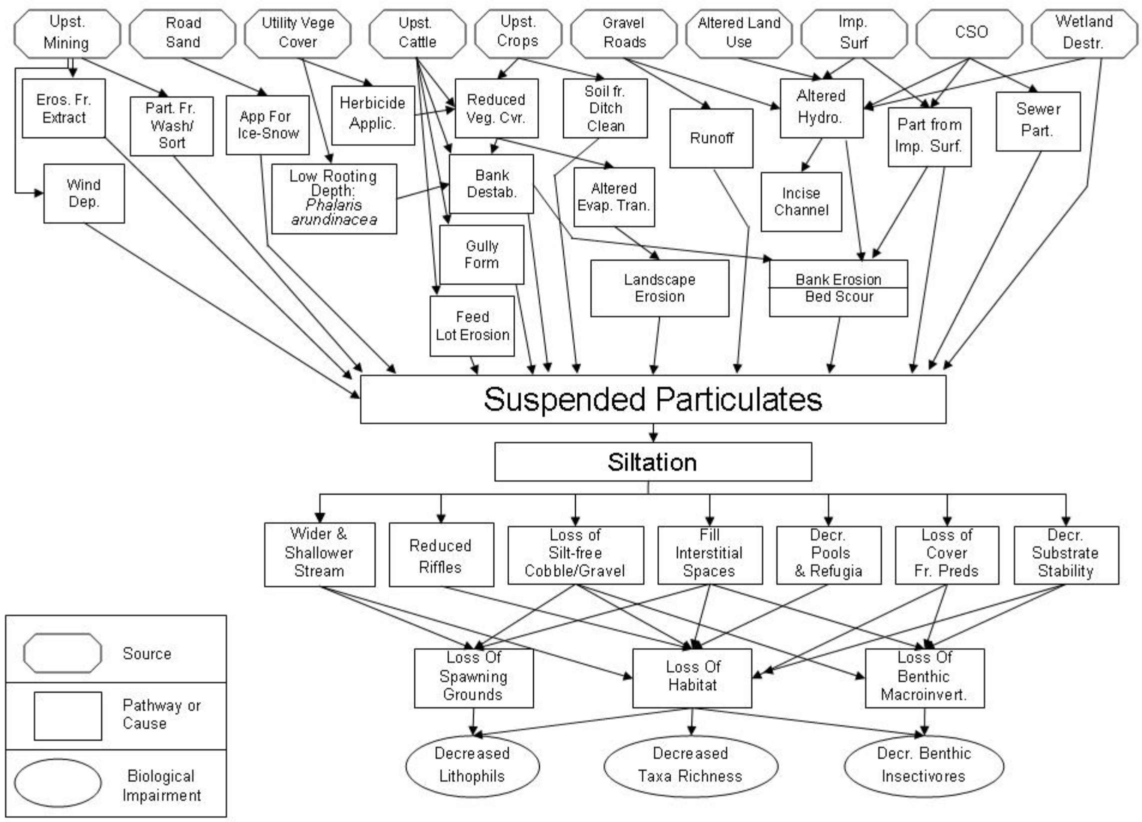

Figure 11. Model 1: Conceptual Model of Candidate Cause 1, Loss of Habitat Associated with Unstable or Unsuitable Geological Substrates.

Table 4. Selected physical parameters for analyses of differences between sites 2 and 3 applicable to model 1.

Parameter	Site 2	Site 3 (Standard Deviation)
D50 (mm)	22	1[a]
% Fines	17.3	58.7 (17.7)
Depth of Fines (cm)	5.60	7.99 (0.86)
% Embed.	39.0	51.2 (8.8)
% Boulder	3.5	0 (0)
% Coarse Substrate	82.7	40.4 (16.3)
% Cover	10.8	8.65 (1.90)
% Riffles	14.5	6.7 (2.9)
Gradient (m/km)	1.89	0.8 (0.00)
Bed Shear (KPa)	2000	400 [a]
Bank Shear (KPa)	470	150 [a]
Incised Channel?	No	Yes
TSS	2.40	1.85 (0.78)

[a] Data collected in 2003

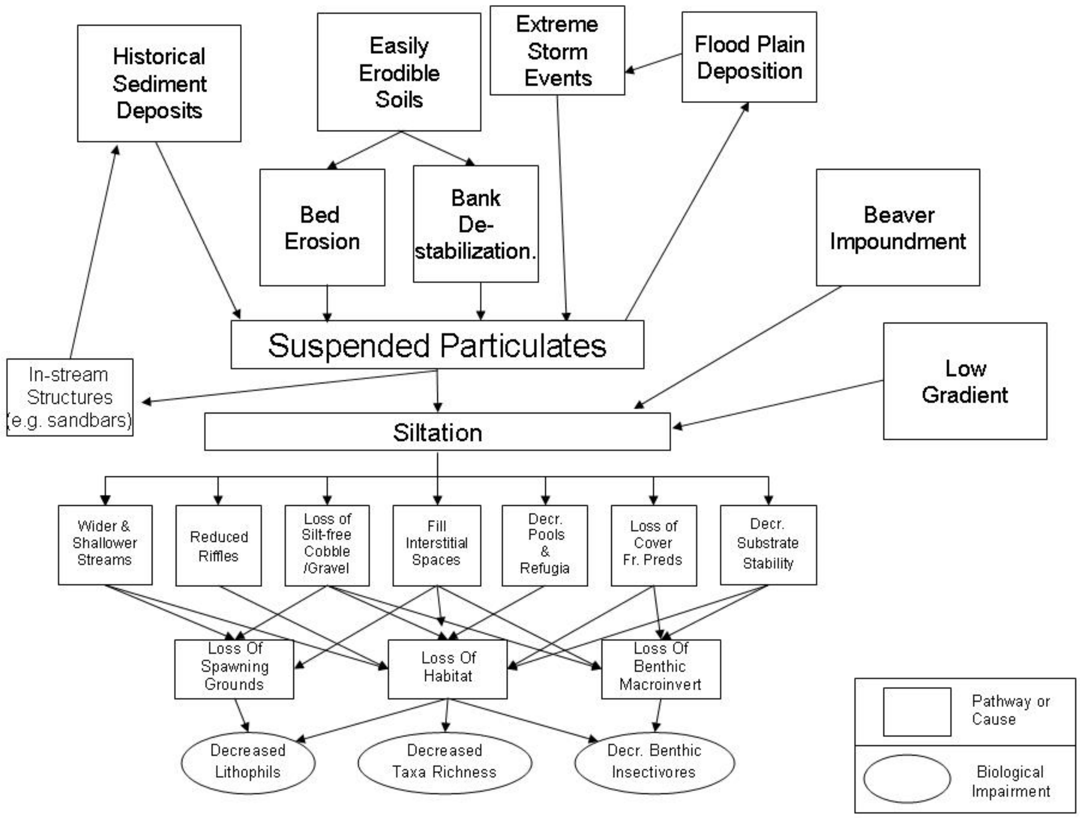

Figure 12. Natural features and characteristics of stream systems related to sedimentation. Those systems already predisposed to sedimentation may be additionally vulnerable to anthropogenic inputs.

(Paul and Meyer 2001). The bed substrate at site 3 was composed of a high percentage of fine materials, low percentage of coarse substrate or cobbles, and a high percentage of embedded substrate. There was also a low percentage of simple and lithophilic spawning taxa sampled.

Candidate Cause 2. Low Dissolved Oxygen or Altered Food Source Associated with Excessive Nutrient Loading

Subcause 2.1: Excessive Nutrient Loading and Low Dissolved Oxygen. Low dissolved oxygen can occur due to excessive algal growth resulting from nutrient addition (Figure 13). Increased nutrient (e.g., nitrogen, phosphorus) loading from point sources such as AFOS and POTW, CSOs, or treatment bypassing, and myriad non-point sources, can increase periphyton community metabolism and hence respiration, causing dissolved oxygen levels to decrease. Additionally, decomposition of excessive algae also consumes oxygen from the water column. Precipitous drops in dissolved oxygen can cause fish kills (Myers and Barclay 1990), and habitat shifts or emigration in both fish (i.e., migration from low dissolved oxygen area) and macroinvertebrates (i.e., increased drift, flight, or avoidance). That is especially true for organisms that are not physiologically tolerant of hypoxic conditions. Other factors can affect dissolved oxygen

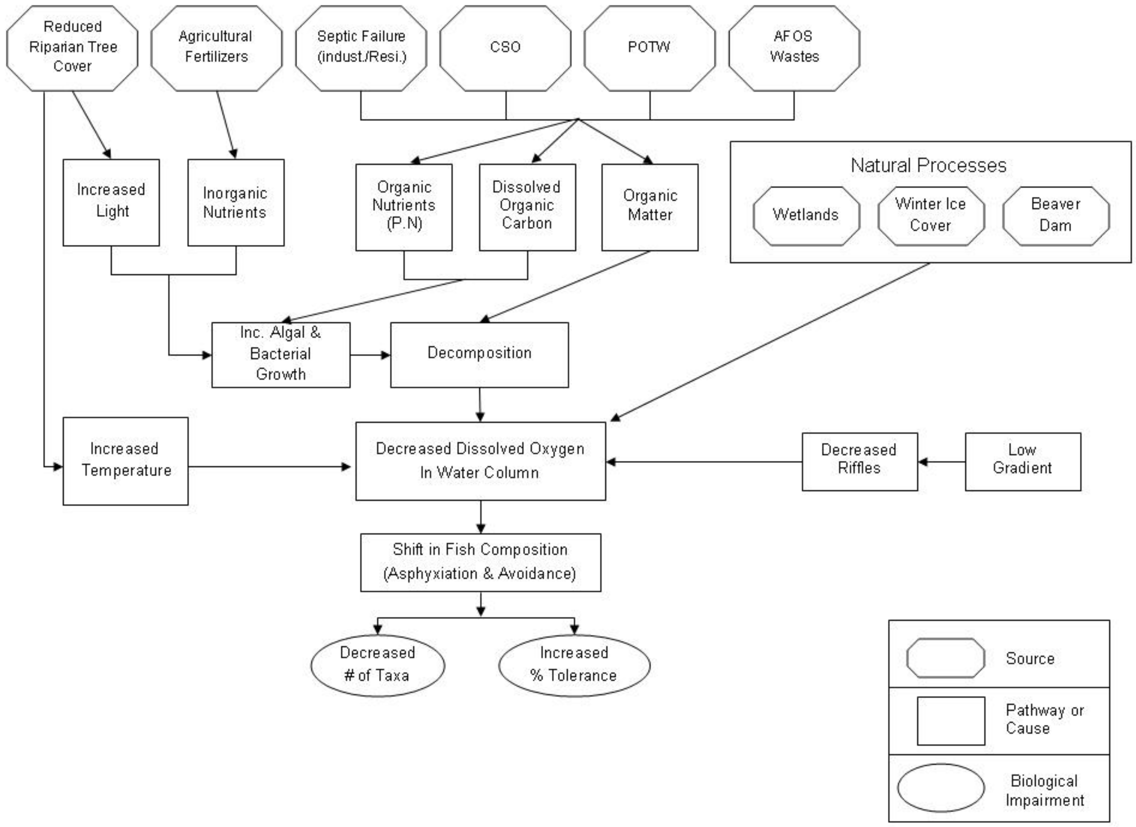

Figure 13. Conceptual model of candidate cause 2.1, decreased dissolved oxygen associated with nutrient loading.

concentrations in the water. Decreased canopy cover, often associated with development (agricultural and urban), can increase water temperatures, which subsequently decreases the solubility of oxygen in water and also increases microbial respiration (Allan 1995). As oxygen diffusion rates are generally highest in agitated waters, such as those flowing over riffles, changes to stream morphology that affect the abundance of riffles (e.g., channelization, increases in water depth, changes in surface area) also may affect dissolved oxygen concentrations.

Subcause 2.2: Excessive Nutrient Loading and Altered Food Resource. Excessive nutrient loading, in addition to potentially causing precipitous drops in water column dissolved oxygen, can also affect stream organism composition through changes in food (macroinvertebrate) resources (Figure 14). Generalists, with a broad diet, are typically more tolerant of perturbations (Barbour et al. 1996). Some macroinvertebrate trophic guilds fare poorly after excessive nutrient loading, even with adequate oxygen, as excessive algal growth can decrease visibility (affecting visual-oriented predators, such as odonates), habitat complexity (e.g., fill interstitial spaces or cover cobbles), and respiratory effectiveness. Changes in macroinvertebrate abundances can affect fish through prey availability.

These candidate causes were examined for site 3 due to the potential for CSO (or treatment bypassing), POTW, and agrochemical loading of stream nutrients and organic matter, as well as the low abundance of rocks in the substrate and riffles (Table 5).

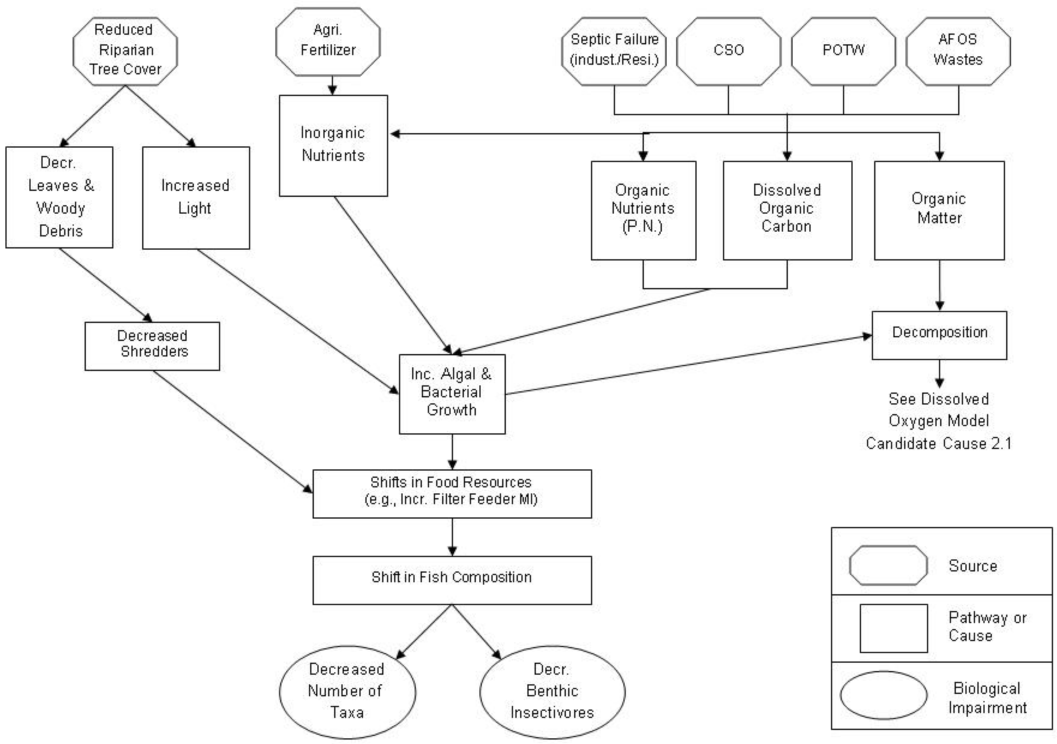

Figure 14. Model 2: conceptual model of candidate cause 2.2, altered food resources associated with excessive nutrient loading.

Table 5. Selected physical and chemical parameters for screening analyses of differences between sites 2 and 3 applicable to model 2.

Parameter	Site 2	Site 3 (Standard Deviation)
Dissolved Oxygen (mg/L)	8.40	8.73 (0.11)
P (mg/L)	0.08	0.08 (0.02)
NO_2+NO_3 (mg/L, Nitrogen)	0.05	0.07 (0.00)
% Riffles	14.5	6.7 (2.9)
% Cover	10.8	8.65 (1.90)
Temperature (^oC)	26.80	21.40 (0.01)
Algal Growth	Not Sampled	Visible only at POTW outflow [a]

[a] Field observations on 10/14/03

Candidate Cause 3: Chronic or Acute Toxicity

POTW and CSOs are frequently cited as sources of potentially toxic substances, including refractory organics (i.e., household products or industrial wastes), heavy metals, detergents, greases, and oils (Holzer and Krebs 1998, Eganhouse and Sherblom 2001). Additionally, ammonia (NH_3), which can be toxic to aquatic organisms, can also occur in streams from several sources including direct waste discharge, agricultural operations such as AFOS, aerial deposition, and natural decay processes (Holzer and Krebs 1998).

The candidate cause (Figure 15) was evaluated because of the spatial proximity of the POTW to site 3, as well as the potential for a CSO to be located upstream of site 3. Additional potential sources include agricultural operations (i.e., pesticide, herbicides, other biocides), and domestic lawn and garden chemicals, as well as petroleum distillates, toxic metals, and other compounds associated with roadway traffic (e.g., zinc, lead, chromium, copper, cadmium; Paul and Meyer 2001), and the maintenance of the right-of-way located immediately upstream of site 3.

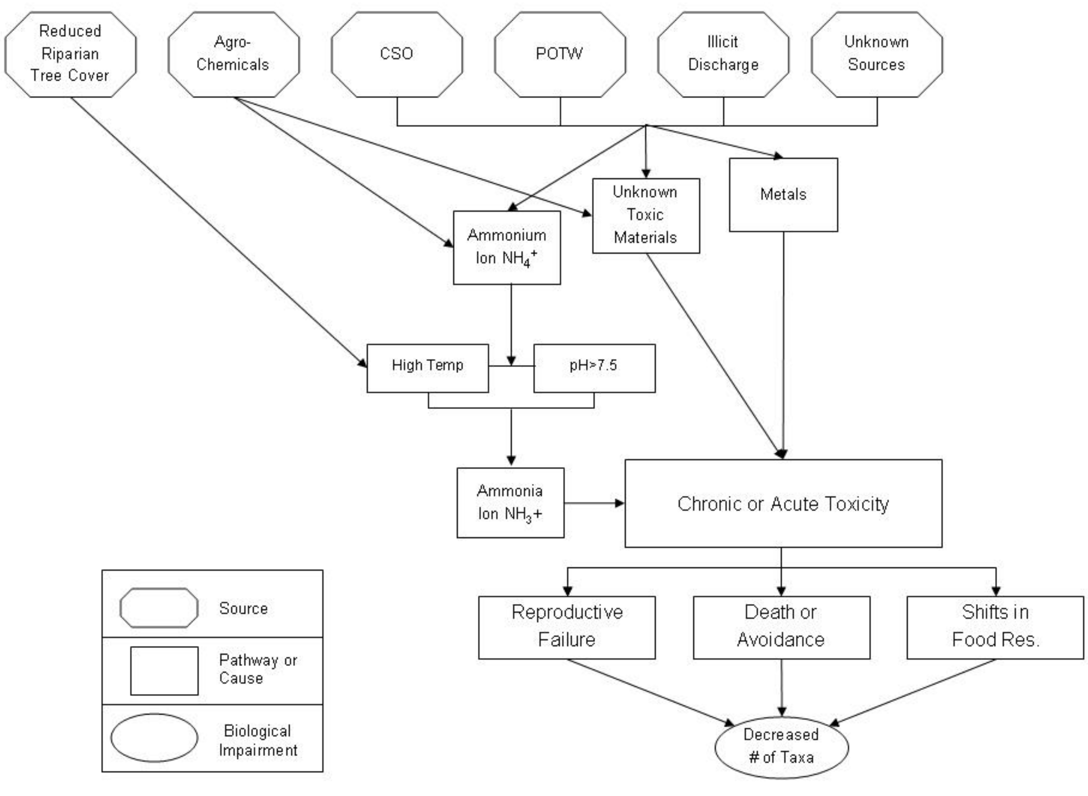

Figure 15. Model 3: Conceptual model of candidate cause 3, chronic or acute toxicity.

4.0 ANALYSIS OF THE EVIDENCE

In this screening-level SI analysis, evidence of causation is formed through the construction of logical associations using empirical data collected in 1996, 1998, and 2003 (Table 6). Each of the three candidate causes are initially examined for the logical pathways associated with temporal co-occurrence, spatial co-occurrence, biological gradient, complete exposure pathway, and experiment (U.S. EPA 2000a). In addition, seven additional associations, based on other situations or knowledge of biological, physical, or chemical mechanisms, are explored: mechanistic plausibility, stressor-response plausibility, consistency of association, analogy, specificity of cause, experiments from similar situations, and predictive performance. An examination of the associations listed above is contingent upon available data, which often precludes assessments using all twelve associations (only four were used in this assessment). Furthermore, temporal uncertainty of the data necessitated the use of the SI process as a screening level tool for assessment. Conclusions and recommendations in this report are based on the available data; as additional data and analysis are required for a complete SI assessment (see section 7.0).

Table 6. Analysis of evidence for the Groundhouse River based on limited observations.

Spatial Co-occurrence		**Conc. or level at upstream site 2**	**Conc. or level at downstream site 3 (Standard Deviation)**	**Consistent with pathway?**[b]
Candidate Cause	**Parameter**			
1. Loss of Habitat Associated with Unstable or Unsuitable Geologic Substrates	D50 (mm)	22	1[a]	Yes
	% Fines	17.3	58.7 (17.7)	Yes
	Depth of Fines (cm)	5.60	7.99 (0.86)	Yes
	% Embed.	39.0	51.2 (8.8)	Yes
	% Boulder	3.5	0 (0)	Yes
	% Coarse Substrate	82.7	40.4 (16.3)	Yes
	% Cover	10.8	8.65 (1.90)	Yes
2.1. Excess Nutrients and Low Dissolved Oxygen	Dissolved Oxygen(mg/L)	8.40	8.73 (0.11)	No
2.2. Excess Nutrients and Altered Food Resources	Algae Present?	Unknown	Only at POTW Outflow [a]	Unknown
3. Chronic or Acute Toxicity	NH_4 (mg/L)	0.03	0.04 (0.01)	Yes
	Calculated un-ionized NH_3 (ug/L)[c]	0.45	1.03	Yes

Table 6. (Continued).

Complete Exposure Pathway		Concentration or level at upstream site 2	Conc. or level at downstream site 3 (Standard Deviation)	Consistent with pathway?[b]
Candidate Cause	**Parameter**			
1. Loss of Habitat Associated with Unstable or Unsuitable Geologic Substrates	% Riffles	14.5	6.7 (2.9)	Yes
	Gradient (m/km)	1.89	0.8 (0.00)	Yes
	Bed Shear (KPa)	2000	400 [a]	Yes
	Bank Shear (KPa)	470	150 [a]	Yes
	Collapsed Banks?	No	Yes	Yes
	Bank Erosion (m/m)	1.00 / 5	0.08 / 5	If source from site No, if upstream source, Yes
2.1. Excess Nutrients and Low Dissolved Oxygen	D.O. (mg/L)	8.40	8.73 (0.11)	No
	P (mg/L)	0.08	0.08 (0.02)	No
	NO_2+NO_3+N (mg/L)	0.05	0.07 (0.00)	Yes
	Gradient (m/km)	1.89	0.8 (0.00)	Yes
	% Riffles	14.5	6.7 (2.9)	Yes
	TSS (mg/L)	2.40	1.85 (0.78)	No
	Temp. (^{o}C)	26.80	21.40 (0.01)	No
2.2. Excess Nutrients and Altered Food Resources	Turbidity (NTU)	2.90	3.42 (1.72)	Yes
	Algal Growth	Unknown	Present only at POTW outflow [a]	No
	P (mg/L)	0.08	0.08 (0.02)	No
	NO_2+NO_3-N (mg/L)	0.05	0.07 (0.00)	Yes
	TSS (mg/L)	2.40	1.85 (0.78)	No
	D.O. (mg/L)	8.40	8.73 (0.11)	No
3. Chronic or Acute Toxicity	Insufficient Data Available			

[a] Data collected in 2003; site 2 was sampled in 1996

[b] Is the difference in the parameter between sites 2 and 3 consistent with greater strength of the exposure pathway at site 3?

[c] Calculated following Minnesota Rule 7050.0222 (Specific Standards of Quality and Purity for Class 2 Waters of the State; Aquatic Life and Recreation)

Spatial Co-occurrence

Co-occurrence associations were examined by comparing measured values between site 3 and the upstream site 2 for each candidate cause. Data available for the examination of spatial co-occurrence came from 1996 (site 2), and 1998 and 2003 (site 3). While the data were collected following established guidance (i.e., Simonson et al. 1994, Niemela and Feist 2000), parameters were also collected after several years had passed. The data are nevertheless useful in the screening-level stressor identification process (U.S. EPA 2000a), as additional data needs may be identified. Values for measured parameters associated with candidate causes are compared between sites 2 and 3 in Tables 6. Co-occurrence was used in the strength of evidence tables.

Complete Source to Exposure Pathway

Complete exposure pathway is the logical and existent physical path a stressor takes from the source to the community or organisms of interest. Evidence concerning the occurrence or level of intermediate steps in the conceptual models is analyzed to determine whether it supports the occurrence of an exposure pathway within that model. Parameters that provide such evidence are listed in Table 6, their occurrences or levels are listed, and their implications for the completeness of the exposure pathways are defined.

Plausible Mechanism

This step determines whether a plausible mechanism associates the effects with the candidate causes. In this case, all associations are mechanistically plausible, although large temporal differences exist among the data set.

Plausible Stressor Response

A stressor-response association is plausible if the level of a stressor associated with the effects to be explained are sufficient to cause the effects, given stressor-response relationships derived from laboratory tests, field tests, or regional synoptic data. For example, if the concentrations of ammonia observed at site 3 were sufficient to kill larval fish in laboratory toxicity tests, then the stressor-response association is plausible for the effects on fish abundance. Criteria values are designed to be safe levels for exposure of organisms to a chemical or other agent. Therefore, if a criterion is appropriate for a site, failure to exceed the criterion suggests that the agent is not the cause. This is helpful in screening analyses like this one in that it provides evidence against consideration of the agent as a candidate cause in subsequent data collection and causal analyses.

The stressor-response association was explored for sediments, dissolved oxygen, nutrients, and toxic compounds (Table 7). Criteria data from Caux et al. (1997) and Knopp (1993) were developed for salmonid streams of the mountain west and Canada, as no available data were found for streams of the mid-west. Several parameters exceeded the recommended criteria or reference conditions (U.S. EPA 2000b) at both sites 2 and 3, including phosphorus concentrations, % fines, D50, and total suspended sediments. Recommended criteria were not exceeded for dissolved oxygen levels, nitrogen (as nitrate/nitrite), calculated un-ionized ammonia (Emerson et al. 1975), chronic un-ionized ammonia (U.S. EPA 1999) and turbidity. The analyses shown in Table 7 were used in the strength of evidence tables.

Table 7. Recommended parameter criteria potentially applicable to the Groundhouse River and values for sites 2 and 3.

Parameter and Potential Effect	Criteria	Site 2	Exceeds Criteria? (Extent)	Site 3 Mean (Stand Deviation)	Exceeds Criteria? (Extent)
Dissolved Oxygen (mg/L, asphyxiation)[1]	<5.0	8.40	No	8.73 (0.11)	No
Phosphorus (mg/L, nutrient loading)[2]	>0.03	0.08	Yes (0.05)	0.08 (0.02)	Yes (0.05)
NO_2+NO_3 Nitrogen (mg/L, nutrient loading)[2]	>0.13	0.05	No	0.07 (0.00)	No
Un-ionized Ammonia (calculated, ug/L, toxic)[3]	>40	0.45	No	1.03	No
Ammonia (from N), Calculated Chronic Exposure (mg/L, toxic)[4]	Site 2: 1.98–2.26 Site 3: 1.96–2.23	0.03	No	0.04	No
% Fines (<2mm, habitat loss)[5]	<10%	17.3%	Yes (7.3%)	58.7 (17.7)	Yes (48.7%)
D50 (mm, habitat loss)[6]	>37	22	Yes (15)	1	Yes (36)
TSS (mg/L, habitat loss, nutrient loading)[5]	>1.7	2.40	Yes (0.70)	1.85 (0.78)	Yes (0.15)
Turbidity (NTU, nutrient loading, habitat loss)[2,7]	>25	2.90	No	3.42 (1.72)	No

1: MN State Code 7050.0222 (Specific Standards of Quality and Purity for Class 2 Waters of the State)
2: Exceeds regional reference conditions as defined by U.S. EPA (2000b)
3: Minnesota Guidance document and Emerson et al. (1975)
4: U.S. EPA (1999)
5: Caux et al. (1997)
6: Knopp (1993)
7: Assuming background conditions < 25 mg/L

5.0 CHARACTERIZING CAUSES

Elimination

A candidate cause may be eliminated if there is sufficient scientific evidence to warrant its exclusion. As this study was a screening-level analysis, no causes were eliminated due to lack of sufficient data, such as continuous measurements for certain pathways.

Diagnosis

Diagnosis comes from the examination of exposed organisms and includes symptomology, measures of internal exposure (i.e., concentrations in organs), or measurements of intermediate processes. Effective diagnoses are species-specific, with only one potential candidate causal mechanism responsible for the given set of symptoms. Insufficient evidence was available to fully explore this pathway as this study was a screening-level analysis.

Strength of Evidence

Strength of evidence tables (SOE Tables) utilize all appropriate data collected from sites within the study area, as well as other relevant data, to best determine the cause of the impairment(s). Evidence for the candidate causes of impairment at site 3 are presented in both model and strength of evidence (SOE) table format. Each line of evidence for each candidate cause was analyzed and scored based on the format developed by Suter et al. (2002) with minor modifications (Cormier *in preparation*). A summary of the SOE tables is presented in Table 8.

Substantial uncertainty exists in the strength of evidence table due to the synoptic nature of the grab samples and the lag time between sampling events at site 2 and site 3. Many parameters change by the second, minute, or hour, if not seasonally, and almost certainly yearly depending on temperature and flow. It is unlikely that parameters measured in

Table 8. Summary of strength of evidence tables for all candidate causes.

Parameter	Candidate Cause 1 (Sediments)	Candidate Cause 2.1. (Low DO)	Candidate Cause 2.2. (Altered Food Resource)	Candidate Cause 3 (Acute or Chronic Toxicity)[a]
Spatial Co-Occurrence	+	0	---	+
Complete Exposure	0	0	+	NE[a]
Plausible Mechanism	+	+	+	+
Plausible Stressor Resp.	+	-	0	NE
Consistency of Evidence	+	-	-	NE
Coherence of Evidence	+	0	0	0

[a] Unmeasured chemicals not considered
[b] NE = No Evidence

1996 would still be directly relevant for comparisons in 2003; they might be useful in establishing trends or historical conditions. Thus direct comparisons between sites 2 and 3 are inherently uncertain. However, this SI process was done as a screening assessment of the available data, with an emphasis on organizing the data to identify data needs and providing an example of the SI process. Thus, the SOE table was completed acknowledging the lack of timely data for comparisons, but generally considering conditions to be comparable (see section 7.0).

Candidate Cause 1. Loss of Habitat Due to Unstable or Unsuitable Geologic Substrates: SOE Table 1, Model 1

The evidence for spatial co-occurrence was compatible with this candidate cause and was scored a (+) in Table 8. When compared with site 2, site 3 had a lower median particle size diameter (D50), a greater percentage and depth of fines (<2.0mm), a greater percent embeddedness, lower percent boulders, coarse gravel, and cover. Site 3 had a greater percent of fine materials (60%), than site 2 (15% fines), and exceeded the recommended fine sediment maximums for water quality criteria (<10 % fine sediment maximums, Caux et al. 1997, U.S. EPA 1998) for salmonids (although site 2 also exceeded the criterion, albeit not as greatly). In addition, the minimal D50 value of 1mm for site 3 was much lower than the recommended minimum of 37mm (Knopp 1993).

The complete exposure pathway contained evidence that was ambiguous for one or more steps, and was scored a (0) in SOE summary Table 8. Site 3 was characterized as a low gradient stream bed with fewer riffles and lower bed and bank shear strength, all three of which can contribute to unstable and unsuitable substrates. In addition, collapsed and undercut banks were evident at site 3. These parameters were scored a (+) in SOE Table 1 as evidence that some steps were present. However, less bank erosion was measured at site 3 than at site 2. This inconsistency may be a function of the steeply incised channel at site 3. Conversely, the higher bank erosion at site 2 may support candidate cause 1, if the unstable substrates at site 3 originated from site 2 and settled out downstream. Higher TSS were also measured at site 2. These parameters were scored a (-) in SOE Table 1, as the source of sediments was uncertain. The final score for complete exposure pathway was (0) in Table 8 based on the ambiguity of the analyses.

Plausible mechanisms and plausible stressor response were identified from the literature for loss of habitat due to unstable geological substrates. A score of (+) was given for candidate cause 1 (SOE Table 1, summary Table 8) as a plausible mechanism exists and there is evidence of that mechanism at the site (i.e., unconsolidated and excessive sediments can affect benthic assemblages, and ample evidence exists of unconsolidated and excessive sediments at site 3). A score of (+, quantitatively consistent) was given for plausible stressor response, as values at site 3 for fine sediments and D50 scores both clearly exceeded targets from the literature, as well as values for site 2 (which also exceeds literature targets, though not as greatly). A score of (+++) was not used because species-specific stressor response curves were not available.

A score of (+, mostly consistent) was given for both consistency of evidence and coherence of evidence, (SOE Table 1, summary Table 8). With the exception of additional bank erosion and TSS at site 2, all other scores for candidate cause 1 were consistent (consistency of evidence score). The inconsistent score for site 3 (bank erosion) could be explained by the credible mechanism of incised banks, thus a score of (+) was entered for coherence of evidence.

Screening Level Summary: It is likely that the embedded and unstable nature of the substrate at site 3 may be responsible, at least in part, for the low scores evidenced by the biota (see summary Table 8).

Candidate Cause 2.1. Excessive Nutrient Loading, Leading to Low Dissolved Oxygen: SOE Table 2, Model 2

A spatial co-occurrence score of (0, SOE Table 2, summary Table 8) was given for low dissolved oxygen (candidate cause 2.1). Higher dissolved oxygen values were obtained at site 3 than at site 2, however, many factors (including a 7 year span between measurements) can affect dissolved oxygen sampling, such as time of day, temperature, and where in the water column the sample was taken. These factors affect the precision of the dissolved oxygen concentration readings. As these factors differ between sites 2 and 3, confidence in the representativeness of the single measurement at the sites is low, and a (0) score for ambiguous results was given.

For cause 2.1, a complete exposure pathway score for an ambiguous pathway (0, SOE Table 2, summary Table 8) was given. Site 3 was characterized by a lower gradient and lower abundance of riffles. Dissolved oxygen measurements were confounded by differences in sampling conditions, which causes the higher dissolved oxygen value measured at site 3 to be viewed cautiously. Higher temperatures and total suspended solids were characteristic of site 2, which is inconsistent with lower dissolved oxygen pathways at site 3. In addition, nutrients (N) were higher at site 3 than at site 2, which would provide the pathway for excessive algal growth and thus lower dissolved oxygen.

A plausible mechanism score of compatible (+, SOE Table 2, summary Table 8) was given for candidate cause 2.1 as a plausible mechanism exists but there is no evidence that the mechanism took place at the site. Most coolwater stream organisms require dissolved oxygen concentrations of at least 5.0 mg/L (U.S. EPA 1986).

A plausible stressor response score of incompatible (-) was given for candidate cause 2.1 (SOE Table 2, summary Table 8). The recommended minimum criterion for dissolved oxygen concentration for non-impaired lotic systems is 5 mg/L (Minnesota Rule 7050.0222). The average values for both sites 2 and 3 are above 8.0 mg/L, although the data were not taken when dissolved oxygen concentrations were known to be at their lowest (i.e., early morning), nor in the same season or year. However, it seems unlikely that dissolved oxygen levels at either site 1 or site 2 falls below 5.0 mg/L for extended periods of time.

As inconsistencies exist within the strength of evidence tables, a consistency of evidence score of (-) was given in SOE Table 2 and summary Table 8 for candidate cause 2.1. A coherence of evidence score of (0, uncertain) was given for candidate cause 2.1. As the dissolved oxygen readings were not taken when they would be lowest in the water column, nor continuously (thus missing any potential episodic events), nor in the same season of the same year, the coherence of the evidence is uncertain.

Screening-Level Summary: The candidate cause of compositional alterations associated with nutrient loading is unlikely. Insufficient evidence exists to implicate low dissolved oxygen as a stressor (see summary Table 8).

<u>Candidate Cause 2.2. Excessive Nutrient Loading, Leading to Altered Food Resources: SOE Table 3, Model 2</u>

An incompatible (---) score was given to spatial co-occurrence association for candidate cause 2.2, altered food resource (SOE Table 3, summary Table 8). Increased algal growth was evident at site 3, but only downstream from the sampling area and near the POTW outflow. Leaf packs, which provide allochthonous inputs to the stream organisms, were abundant at site 3. Thus, in comparison with site 2, the candidate cause does not occur where the effect (biological impairment) occurs.

The complete exposure pathway for candidate cause 2.2 was scored a (+), partial evidence, in summary Table 8. Partial evidence (+, SOE Table 3) exists as N was slightly higher at site 3 than at site 2. However, TSS was higher at site 2 than at site 3.

Plausible mechanism scores of (+, SOE Table 3, summary Table 8) was given for candidate cause 2.2, as organic enrichment and altered food source changes stream invertebrate composition and trophic interactions (Hilsenhoff 1987, Shieh et al. 2002).

An uncertain plausible stressor response score of (0) was also given for candidate cause 2.2 (SOE Table 3, summary Table 8). Phosphorus values were similar between sites 2 and 3, but site 3 had higher nitrogen levels. It is unclear if the magnitude of change is sufficient to alter food resources. TSS values, however, were lower at site 3 than at site 2, which does not support candidate cause 2.2.

An inconsistent score (-) was given for the consistency of evidence consideration (SOE Table 3, summary Table 8). Algal growth was not evident at site 3, and the allochthonous inputs appear sufficient to support the benthic invertebrate food web, which includes many fish species.

A coherence of evidence scores of (0) were given to candidate cause 2.2, as no known explanation exists to describe the inconsistencies in the evidence.

Screening-Level Summary: The candidate cause of compositional alterations due to a changing food source associated with excessive nutrient loading is unlikely (See summary Table 8).

Candidate Cause 3. Chronic or Acute Toxicity From Chemical Compounds. SOE Table 3, Model 3

A spatial co-occurrence score of (+) was given for candidate cause 3 (SOE Table 4, summary Table 8). A single parameter was measured that is potentially applicable to spatial co-occurrence for candidate cause 3: ammonium. However, the toxicity of ammonium is low. Ammonia, which forms from ammonium under the proper circumstances, is more toxic. Following Minnesota Rule 7050.0222 and Emerson et al. (1975), ammonia values were calculated (Table 7) using temperature, pH, and ammonium concentration. The abundance of un-ionized toxic ammonia was calculated to be higher at site 3 than at site 2, but not above the recommended criteria for either site 2 or 3. Chronic values were also calculated following U.S. EPA (1999). As in the Emerson calculation of fractional un-ionized ammonia, calculated chronic values were well below threshold limits, although other authors have found deleterious effects for fish at concentrations as low as 0.0017 ug/L (Rice and Bailey 1980).

Scoring for a complete exposure pathway for toxicity is not possible, as no directly toxic constituents were measured. A value of no evidence (NE) was given in SOE Table 4 and summary Table 8. (Note: Complete information on gravel operations is still being developed. These operations could include temporary asphalt making. This occasionally involves a water discharge from scrubbers. Permittees are supposed to annually report activities at each site.)

A plausible mechanism exists for chronic or acute toxicity of fish to various constituents of runoff, wastewater, or other anthropogenic modifications of stream water characteristics (Paul and Meyer 2001). A score of (+) was given for candidate cause 3 (SOE Table 4, summary Table 8) as a plausible mechanism exists but no evidence exists that the mechanism took place.

Insufficient evidence exists to score the plausible stressor response for candidate cause 3 (SOE Table 4, summary Table 8). Although site 3 is higher in toxic ammonia than site 2, the levels are two orders of magnitude below toxic concentrations, and it is unlikely that the difference between calculated ammonia values at site 2 and site 3 are sufficient to cause the impairment at site 3.

Consistency of evidence was scored (NE) for candidate cause 3 (SOE Table 4, summary Table 8). NH_3 values collected were below toxic criteria, but data on other toxicants were not collected.

No known explanation can be made for inconsistencies in the dataset, thus a score of (0) was given for coherence of evidence score (SOE Table 4, summary Table 8).

Screening-Level Summary: Metals and other toxic compounds remain a potential cause for impairment at site 3 of the Groundhouse River due to the plausible mechanisms associated with POTW and urban drainage areas. However, data do not support ammonia as a potential toxicant. Additional information on potential sources of toxic compounds, namely the frequency and happenstance of releases, ought to be investigated.

6.0 IDENTIFY PROBABLE CAUSE(S)

Based on the strength of evidence tables the most likely cause of impairment at site 3 is related to candidate cause 1, unconsolidated and unstable sediments, although substantial caveats remain based on the synoptic nature of the data and the temporal lag between sampling events. A summary of the results of the strength of evidence tests for all candidate causes is presented in Table 8, and conceptual models identifying incomplete pathways for candidate causes 2.1, 2.2, and 3 are presented in Figures 16, 17, and 18, respectively. Weak bed and bank shear strength suggest that flowing waters (including storm flow) may cause bank collapse, which would increase the depth and abundance of fine materials in the water, as well as cover gravel and cobble substrates. Suspended particles and bed load carried along by the stream might also be deposited in and around site 3, as the stream gradient decreases from 1.8m/km at site 2 to 0.8m/km at site 3. These would also cover substrates and result in a higher abundance of embedded cobbles. The decrease in simple and lithophilic spawning taxa and benthic insectivores may follow as a result of the increased fine and coarse particulates at site 3.

Given these associations with sediment measurements and biological endpoints and the very fine particle size at the site (<1mm), excess fine sediment is the most likely cause at the site. The full mechanism is not completely clear, but may involve reduced numbers of invertebrate prey. Other mechanisms may include loss of pools, loss of interstitial habitat, and unstable substrates and the reader may choose to examine other causal pathways depicted in the conceptual model for excess sediment. The gradient at the site is less than 0.8m/km and the numbers of riffles is less than half that of the nearest upstream site. This suggests that this portion of the river may be a depositional zone and may be limited in its stream potential. However, the proposed sampling at the upstream locations, if the gradients are comparable, may help to establish a realistic potential for biological condition at site 3 (see section 7.0).

7.0 UNCERTAINTY AND CAUSAL CONSIDERATIONS

Synoptic data collection, especially water chemistry data, is problematic due to variation from uncontrollable sources of error. For instance, concentrations of chemical constituents in the water column will vary depending on the flow volume, which is a function of rain fall. Community composition over time likewise changes dynamically through immigration and emigration, drift, and breeding cycles. In most cases the highest accuracy can be obtained through repeated monitoring. Data that is collected multiple times over varying times of day and seasons are more representative of actual stream conditions than single samples, and are encouraged. Data collected in this screening-level causal analysis spanned several years (1996-2003), and data for site 3 was averaged from sampling completed in 1998 and 2003. While certain parameters were comparable to established standards (i.e., DO levels < 5.0 mg/L; D50 > 37), direct comparisons between sites 2 and 3 were questionable due to the large temporal difference between sampling events. Thus, additional confidence in the causal assessment process for the Groundhouse River could be obtained through additional sampling efforts and a reiteration of the SI process. Such efforts may include sampling sites 2 and 3 on successive days with similar weather conditions (to account for daily, yearly, and seasonal variation between sites) and including macroinvertebrates in the data collection and analysis.

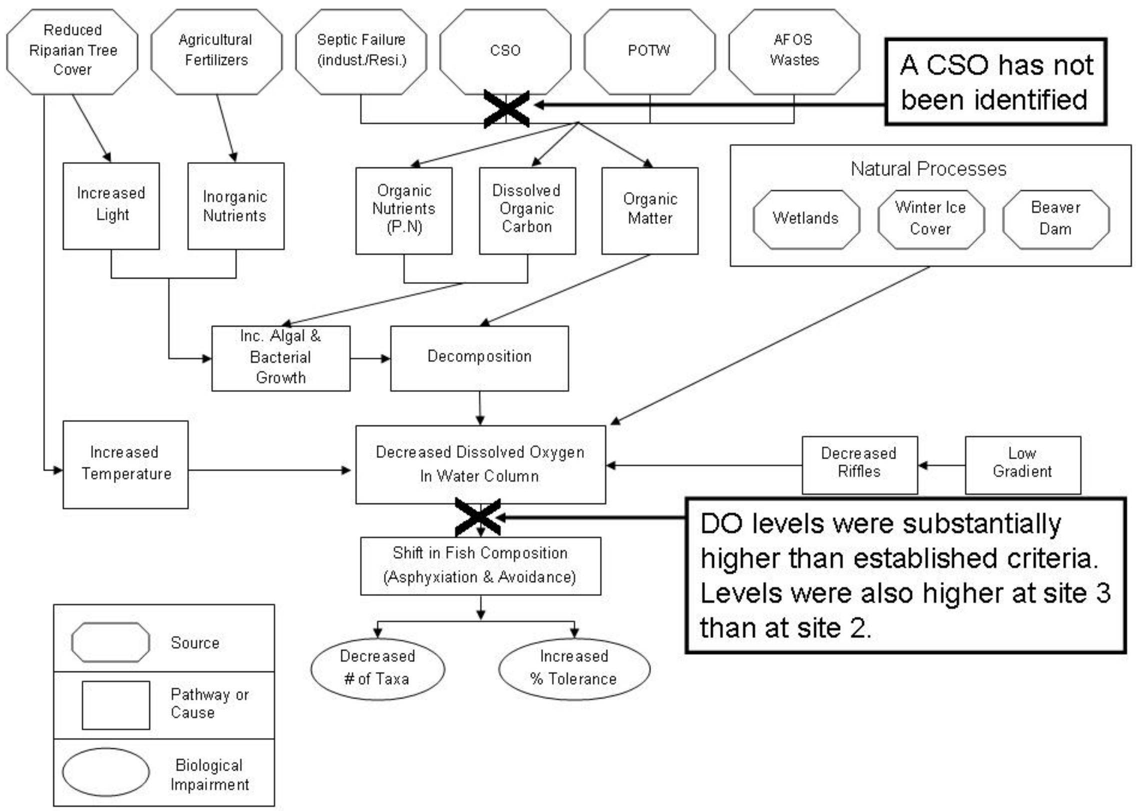

Figure 16. Conceptual model of candidate cause 2.1 showing evidence contrary to candidate cause.

Data on water chemistry parameters at both sites, such as metals and other toxicants, could determine the chronic (or acute) levels affecting stream organisms at both sites (described below). Additionally, determining minimum dissolved oxygen levels through 24hr monitoring could provide necessary evidence for causal associations.

Toxic compounds remain a possible candidate cause of impairment at site 3, however only ammonia was measured as a candidate fish toxicant. Several considerations regarding toxic conditions need to be addressed. The existence of a combined sewer overflow (CSO) has been suggested but none have been found after an extensive investigation; hence the CSO is an unlikely source of toxicants. Assays for other toxicants would help to identify causal mechanisms of perturbation at site 3, as well as aid in the mitigation of the problem through potentially permitting the stressor source to be identified (e.g., a previously unknown point source).

A power company right-of-way cleared of trees and planted with reed canary grass *(Phalaris arundinacea)* is located immediately upstream of site 3. It is likely that the location is periodically managed to retard the growth of trees (which can interfere with power transmission wires). This could include periodic herbicide application. Information on the management practices for this area may provide insight into potential perturbations causing impairment at site 3.

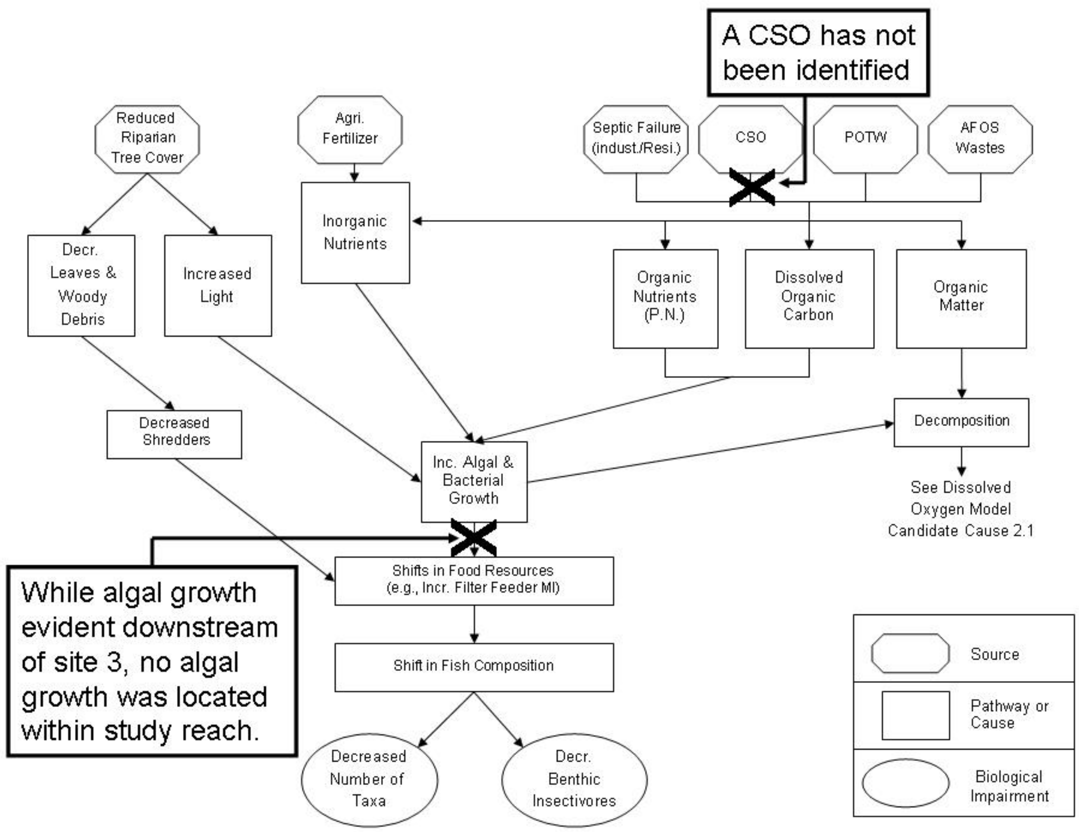

Figure 17. Conceptual model of candidate cause 2.2 showing evidence contrary to candidate cause.

Additional Causal Considerations

This report focused on the proximal causes (i.e., excessive siltation, nutrient enrichment, toxic loading) of biological impairment in the Groundhouse River. A common intermediary factor influencing these proximal causes may be altered hydrology, perhaps as a result of increased impervious surface or cropland tiling, both of which affect aspects of the physical and chemical nature of the river.

Impervious surface concentration dramatically affects the hydrology of receiving waters through increases in the energy, frequency, and chemical constituents of rainwater runoff. Likewise tiling affects stream conditions through increased volume and "stream flashiness," or the rapid attainment of peak discharge rates, as well as potentially altering the chemical concentration of stream column constituents. Aspects of chemical change associated with rainfall and toxic compounds have previously been addressed, as have some changes potentially wrought by increased flow associated with increased impervious area (i.e., increased bank erosion). Understanding the role altered hydrology plays in the Groundhouse River watershed may help optimize and sustain solutions for the river.

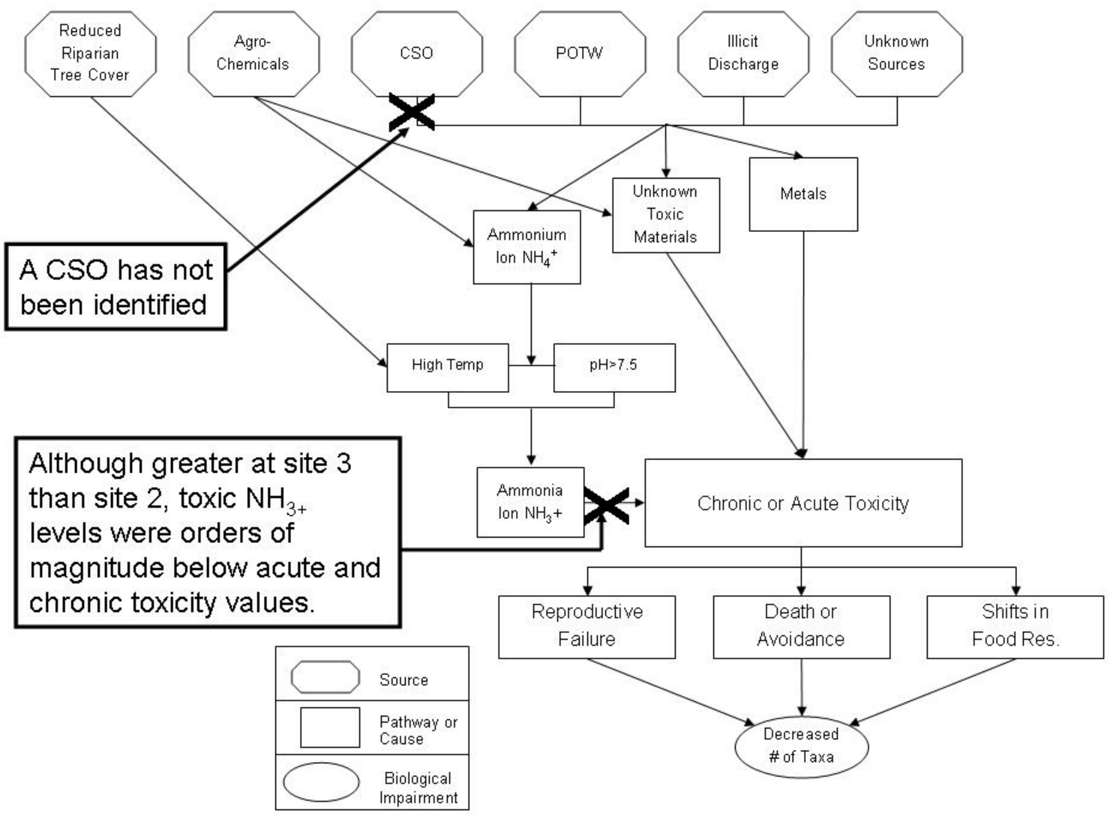

Figure 18. Conceptual model of candidate cause 3 showing evidence contrary to candidate cause.

Suggestions for Addressing Uncertainty

Although the environmental data available for the Groundhouse River suggest that the habitat is less suitable for a diverse and abundant fishery, there is substantial uncertainty due to the temporal limitations of the data set. Additional sampling and a reiteration of the SI process is warranted.

One of the ways to reduce this uncertainty is to more tightly define the location of the most severe impairment in the watershed found near site 3. This may also help to eliminate or reduce the number of potential causal pathways or sources. In all cases, interpretation of the results should consider all potential lines of evidence and the possibility that there are additional causes for the observed conditions. Additionally, sampling should be completed in such a manner as to be comparable to previous sampling events in this report (see Niemela and Feist 2000), and the inclusion of macroinvertebrates (and subsequent SI analysis) may increase the information content of the data set.

To determine if the road or culvert (Highway 23) is contributing to the impairment, sampling should be done about 50 m downstream from the road crossing:

- If the impairment **does not persist**, then the culvert should be considered as a factor altering the sediment supply in the stream.
- If the impairment **persists** and then improves gradually downstream, then the culvert may not be affecting the sediment supply and deposition.

Another important sampling site should be located about 50 m upstream from the location of the power line:

- If the impairment is **not apparent** upstream from the power line, then the study can focus on those stressors that may be associated with the area along the power line. Based on this scenario, another sample should be taken about mid-reach under the power-line.
    - If the impairment is **not present**, then the impairment is highly localized just below the POTW, and is tightly bounded indeed
    - If the impairment seen at site 3 **is also present** mid-reach of the power line area, then this strengthens the causal pathway associated with the power line.
- If the impairment **is still apparent** upstream from the power line, then the power line and all stressors attributed to it can be eliminated, however upstream sources must be considered.

Another site located upstream from Ogilvie preferably within the stream reach possessing intact forested riparian zones would help to determine the potential impacts of land uses and sources from Ogilvie:

- If the impairment **is not apparent** and similar to site 3, then sources and causal pathways associated with Ogilvie and nearby areas must be considered more carefully.
- If the impairment **is apparent** and similar to site 2, then the causal pathways attributed to stressors associated with Ogilvie can be eliminated.

Sampling as described above will help to establish associations of co-occurrence of the effect with potential sources or stressors and will likely to narrow the list of candidate causes, especially those associated with chronic point and non-point sources. Although episodic events may not be captured, characterizing the extent of the impairment can help to focus the search for episodic causes. That is, if there is a clear demarcation of unimpaired and impaired stream reaches and there is no apparent difference in stream water quality, water quantity, or in-stream habitat, then an intermittent toxic event, although not previously considered likely, must be considered more carefully.

This proposed sampling plan does not directly address the potential causes for impairment in the rest of the watershed. Tables could be constructed that compare the stressor levels from the uppermost to the lower sections of the watershed. Of these candidate causes, temperature, habitat diversity, sediment, channel modification, hydrology and other causes need to be measured concurrently with biological endpoints similar to those depicted in Tables 6. These values can be compared to biological conditions in the basin.

SOE Table 1. Strength of Evidence Table for Candidate Cause 1, Loss of Habitat Associated with Unstable or Unsuitable Geologic Substrate.

Candidate Cause #1: Loss of Habitat Associated with Unstable or Unsuitable Geological Substrates			
	Evidence	**Evidence**	**Score**
Case-Specific Considerations			
Spatial Co-Occurrence	Compared with upstream site: Lower D50, greater % and depth of fines, greater % embeddedness, less % boulders, less % coarse material, less % cover	Compatible	+
Complete Exposure Pathway	Compared with upstream site: Fewer riffles, lower gradient, lower bed shear strength, lower bank shear strength, collapsed banks evident; lower D50, greater depth and percent fines, greater embeddedness, and fewer boulders and coarse gravel	Compatible	+
	Compared with upstream site: Lower measured bank erosion and TSS at site 3 than at site 2	Source Uncertain	-
Considerations Based on Other Situations or Biological Knowledge			
Plausible Mechanism	**Reproduction:** Caux et al. (1997) and Rowe et al. (2003) noted changes in salmonid community composition associated with increased turbidity, such as cascading trophic effects affecting fish community composition, high mortality of eggs from decreased gas exchange, and physiological and behavioral changes in juvenile and adult fish. A high percentage of fine sediments is also inversely related to the size (and ultimately survival) of embryos and fry (U.S. EPA 1998). **Prey Availability:** Fine sediments also disrupted trophic interactions, due to smothering, scour, and lack of habitat (Caux et al. 1997). Highly embedded substrates, low abundance of boulders and gravel affect fish through decreased intergravel flow (decreasing prey abundance) and decreased cover (Rowe et al. 2003).	Plausible	+

SOE Table 1. (Continued).

Candidate Cause #1: Loss of Habitat Associated with Unstable or Unsuitable Geological Substrates			
	Evidence	**Evidence**	**Score**
Considerations Based on Other Situations or Biological Knowledge			
Plausible Stressor-Response	Caux et al. (1997) recommend substrate not exceed 10% fine material (<2 mm) for Canadian salmonids. U.S. EPA (1998) set in-stream numeric criteria for percent fines (<6.5 mm) of <30% for viable salmonid fry emergence. The D50 (Knopp 1993) values of at least =37 mm and ideally =69 mm are ideal targets for mean particle size diameter for western mountain streams. Site 3 had almost 60% fines (vs. 15% for site 2), greater than 50% embedded substrates, and a D50 value of 1 mm.	Consistent for count of taxa	+
Considerations Based on Multiple Lines of Evidence			
Consistency of Evidence	Scores for candidate cause are nearly all consistent.	Mostly Consistent	+
Coherence of Evidence	Low bank erosion at site 3 may be a function of a low gradient and wider and more accessible floodplain, thus lower banks. Source of silt may be upstream.	Credible Explanation	+

SOE Table 2. Strength of Evidence Table for Candidate Cause 2.1, Excessive Nutrient Loading Resulting in Low Dissolved Oxygen.

Candidate Cause #2.1: Excessive Nutrient Loading Resulting in Low Dissolved Oxygen			
	Evidence	**Evidence**	**Score**
Case-Specific Considerations			
Spatial Co-Occurrence	Low dissolved oxygen not observed at sites. Infrequent nature and time of sampling weaken value of data.	Ambiguous	0
Complete Exposure Pathway	**Physical:** Abundance of riffles higher at site 2 than at site 3, which would generally increase the oxygen diffusion rates. Lower gradient at site 3 than at site 2, which would decrease the likelihood of riffles and similarly decrease potential oxygen diffusion sites. Temperature higher at site 2 than at site 3, and oxygen solubility decreases with increasing temperature. Low (<5.0 mg/L) dissolved oxygen not observed at either site.	Partial Evidence	+
	Chemical: Higher TSS were found at site 2 than 3. Organic enrichment and/or algal growth not evident. Slightly higher nutrient levels (N) were sampled from site 3 than site 2.	Ambiguous	0
Considerations Based on Other Situations or Biological Knowledge			
Plausible Mechanism	Adequate dissolved oxygen is required for gas exchange and ultimately cellular respiration of fish and other aquatic organisms.	Plausible	+
Plausible Stressor-Response	Both site 2 and site 3 had D.O. readings substantially higher than 5.0 mg/L criteria (U.S. EPA 1986). Dissolved oxygen not observed below 8.0 mg/L.	Incompatible	-
Considerations Based on Multiple Lines of Evidence			
Consistency of Evidence	Inconsistencies in evidence.	Inconsistencies	-
Coherence of Evidence	Possible episodic events. Early morning dissolved oxygen levels not measured; may be low.	Uncertain	0

SOE Table 3. Strength of Evidence Table for Candidate Cause 2.2, Community Shifts Due to Altered Food Resources.

Candidate Cause #2.2: Community Shifts Due to Altered Food Resources			
	Evidence	**Evidence**	**Score**
Case-Specific Considerations			
Spatial Co-Occurrence	Increased algal growth at site 3, but only at the POTW outfall downstream of impairment. Leaf packs evident at site 3. Site 2 was not examined in full for either algae or leaf packs. Uncertainty exists in measurements and spatial relationship.	Incompatible	---
Complete Exposure Pathway	Turbidity higher at site 3 than site 2. Slightly higher nutrient levels for N were sampled from site 3 than site 2. Decreased benthic insectivores and number of taxa at site 3.	Partial Evidence	+
Considerations Based on Other Situations or Biological Knowledge			
Plausible Mechanism	Organic enrichment and altered food source changes stream invertebrate composition and trophic interactions (Hilsenhoff 1987, Shieh et al. 2002).	Plausible	+
Plausible Stressor-Response	Nutrient values similar between sites 2 and 3; site 3 had slightly higher N levels. It is unclear if the magnitude of change is sufficient enough to alter food resources. TSS values, however, were lower at site 3 than at site 2.	Uncertain	0
Considerations Based on Multiple Lines of Evidence			
Consistency of Evidence	Algal growth not observed; allochthonous input seems sufficient for benthic invertebrates, the prey of many fish species.	Inconsistent	-
Coherence of Evidence	No known explanation.	No Known Explanation	0

SOE Table 4. Strength of Evidence Table for Candidate Cause 3, Chronic or Acute Toxicity from Chemical Compounds.

Candidate Cause #3: Chronic or Acute Toxicity From Chemical Compounds			
	Evidence	**Evidence**	**Score**
Case-Specific Considerations			
Spatial Co-Occurrence	Ammonium (NH_4) can convert to the more toxic ammonia (NH_3) at high pH, usually above 7.5. Values for pH at site 3 were higher than at site 2, and averaged above 7.5.	Compatible	+
	No data on other toxic compounds were collected, it is not possible to evaluate this pathway.	NE	NE
Complete Exposure Pathway	No evidence of for a complete exposure pathway collected. Temporary asphalt making at gravel pits could occur periodically. Such operations may discharge scrubber water from air pollution control equipment.	NE	NE
Considerations Based on Other Situations or Biological Knowledge			
Plausible Mechanism	Metals, organic compounds, and ammonia may be toxic at both acute and chronic doses, and may enter water column from POTW, CSOs, and other sources. Stressors may also markedly affect trophic interactions through toxic interactions with producers or primary consumers.	Plausible	+
Plausible Stressor-Response	Ammonia sampling is infrequent and would not capture acute episodic events. The small increase in NH_3 at site 3 compared to site 2 seems insufficient to cause decline in fish at site 3 and is 2 orders of magnitude lower than toxic values (Table 7).	Inconsistent	-
	Other toxicants not sampled.	NE	NE
Considerations Based on Multiple Lines of Evidence			
Consistency of Evidence	Inconsistencies in evidence for NH_3 (lower than toxic criteria).	Inconsistent	-
	No other toxicants were sampled.	NE	NE
Coherence of Evidence	No known explanation for inconsistencies.	No Known Explanation	-

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APPENDIX A. Images of the Groundhouse River

Figure A1. Site 3 impaired reach (from upstream downstream). Large, coarse, woody debris and leaf packs are evident, as are collapsed trees and exposed roots.

Figure A2. Upstream of site 3 impaired reach. Power transmission right-of-way is evident in the upper left corner.

Figure A3. Lower portion of site 3 impaired reach. Excessive sediments have formed a sandbar on left that was being eroded as picture was taken (white arrow).

Figure A4. Downstream of site 3. A sandbar associated with excessive sediments and bridge pylons (MN23). Actively eroding banks insufficiently supported by reed canary grass are highlighted with white arrows.

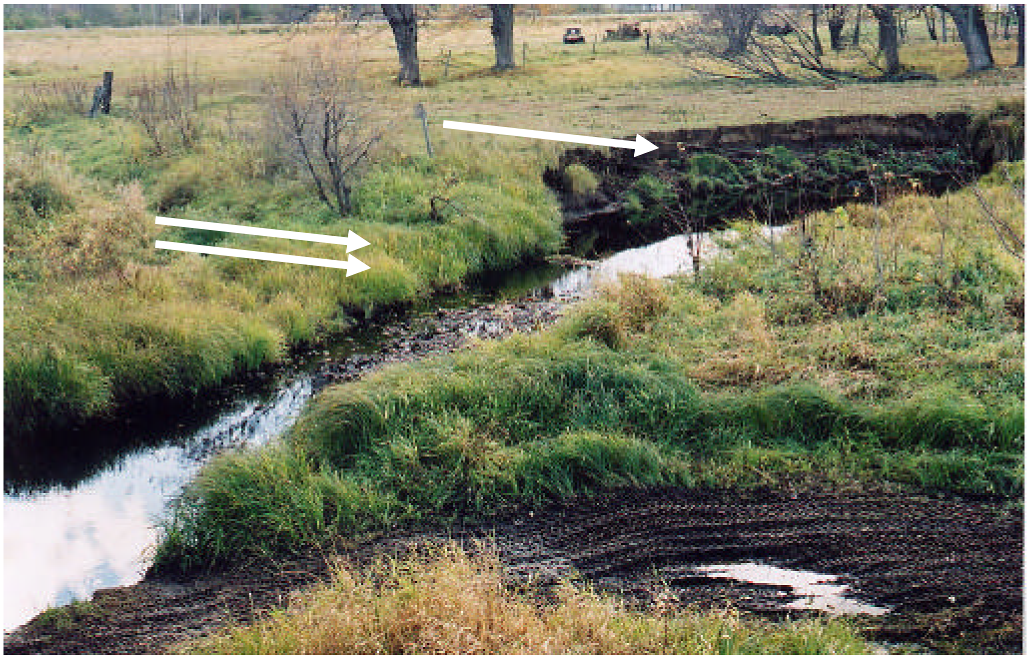

Figure A5. Approximately 0.8 km upstream from site 3. Severely incised and collapsed banks in active pasture (white arrow). Portions of the bank fenced from cattle (double arrows) appear stable. Tractor or ATV trails through stream are evident in bottom of picture.

Figure A6. POTW effluent entering the Groundhouse River downstream of site 3. Grey water plume highlighted with an arrow and a dashed line.