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Brown's Creek Impaired Biota TMDL – Appendix A: Stressor Identification

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EOR water ecology community

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Cover Images

Left Image: *Brown's Creek*

Right Image: *EOR staff performing stream cross section survey using high resolution DGPS*

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Brown’s Creek Stressor Identification

EXECUTIVE SUMMARY

Brown’s Creek (Washington County, MN) was listed as impaired by the Minnesota Pollution Control Agency in 2002 because of low indices of biological integrity (IBI) for fish and macroinvertebrates (Attachment B). Five stressors have been identified using the Causal Analysis/Diagnosis Decision Information System (CADDIS) of the United States Environmental Protection Agency (EPA) using data taken from 2000-2007. Most analyses in the stressor identification used the more extensive 2007 data to allow direct comparisons between a greater number of sites. Five key stressors were identified as contributing to the low IBI in Brown’s Creek. The identified stressors in order of strength of evidence are:

- Total suspended solids (TSS)
- Temperature
- Dissolved oxygen (DO)
- Copper
- Nitrate-Nitrite (NOx)

Temperature and DO levels at upstream sites (from 110th Street to Highway 15, Figure 1) were sufficient to cause physiological stress to coldwater fish assemblages and together explain much of the low IBI in these upper sites. Invertebrate community composition also indicates temperature is a stressor at upstream sites. TSS, copper, and NOx are the strongest stressors in the lower sites (Highway 15 to WOMP, Figure 1). Measured by site-specific TSS equivalents of the turbidity standard, the turbidity standard is exceeded by as much as two orders of magnitude. In downstream sites, copper concentrations exceeded maximum standards and chronic standards. NOx levels were higher than nitrite concentrations known to produce brown blood disease, lower productivity in trout, and other non-lethal impairments to trout growth and reproduction. Direct nitrite measurements were unreliable, but the total NOx levels were high enough to warrant attention.

These five stressors have multiple independent sources, but share a common relationship to landscape alteration. Surface water is significantly warmer than ground water, linking increases in surface water runoff to the temperature stressor. Changes in the watershed leading to increased runoff also increase the input of nutrients, suspended solids, and copper compounds into Brown’s Creek.

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ABBREVIATIONS

BCWD	Brown's Creek Watershed District
CADDIS	Causal Analysis/Diagnosis Decision Information System
DO	Dissolved oxygen
EPA	Environmental Protection Agency of the United States
IBI	Index of biological integrity
MPCA	Minnesota Pollution Control Agency
NHx	Ammonia and ammonium (undifferentiated)
NOx	Nitrate and nitrite (undifferentiated)
NTU	Nephelometric turbidity units
TAC	Technical advisory committee
TMDL	Total maximum daily load
TP	Total phosphorus
TSS	Total suspended solids
WCD	Washington Conservation District
WOMP	Watershed outlet monitoring program

INTRODUCTION

Brown's Creek was listed on the 303(d) list of impaired water bodies in 2002 for aquatic life impairment based on a low IBI for Class 2B[1] streams. Since this initial listing, the stream segments have changed, the classification of some of the segments was changed, and additional impairments were added. The current impairments cover the stream from 110th Street to the stream's confluence with the St. Croix River; this entire stretch is impaired for aquatic life for a Class 2A[2] stream. The upper portion (river ID 07030005-587: from 110th St. to Highway 15) is impaired due to a lack of a cold water fish assemblage and a low macroinvertebrate IBI (Table 1, a full account is given in Attachment B). The lower portion (river ID 07030005-520: from Highway 15 to the St. Croix River) is impaired due to a lack of a cold water fish assemblage (Figure 1). Biological data were taken from 1996 to 2008 at various locations by the MPCA, DNR, and others (Figure 2).

Table 1. Brown's Creek 303(d) listing

Reach	Description	Year Listed	River ID#	Affected use	Pollutant or stressor	TMDL Target start / completion date	CALM Category*
Brown's Creek	T30 R20W S18, west line to St Croix River	2008	07030005-520	Aquatic Life	Lack of a cold water assemblage	2007 / 2009	5C
Brown's Creek	T30 R21W S12, north line to T30 R21W S13, east line	2002	07030005-587	Aquatic life	Lack of a cold water assemblage	2006 / 2009	5A
Brown's Creek	T30 R21W S12, north line to T30 R21W S13, east line	2004	07030005-587	Aquatic life	Aquatic macroinvertebrate bioassessments	2006 / 2009	5A

*CALM (Consolidation Assessment and Listing Methodology):
5A – Impaired by multiple pollutants and no TMDL study plans are approved by EPA
5C – Impaired by one pollutant and no TMDL study plan is approved by EPA

Phase I of the stressor identification process was completed in June 2007 (Attachment A). During this phase of the project, water quality and biological monitoring, a geomorphic assessment, a groundwater assessment, and a water quality analysis were completed. The water quality analysis was based on all data collected through May 2007. The following factors were identified as potential stressors:

[1] Class 2B waters are protected so as to permit cool or warm water fisheries, associated aquatic life, and their habitats (MN Rule 7050.0222, Subp. 3 and 4).
[2] Class 2A waters are protected so as to permit cold water fisheries, associated aquatic life, and their habitats (MN Rule 7050.0222, Subp. 2).

- Sedimentation
- Low dissolved oxygen
- Nutrient enrichment
- Ammonia toxicity
- Copper toxicity
- High temperature

The stream classification changed during the course of Phase I, and therefore additional analysis was needed to examine the data relative to the current stream classification of Class 2A. Additional monitoring data were collected after the completion of Phase I at more sites to allow a more comprehensive stressor identification process that integrates all aspects of monitoring on Brown's Creek. This document contains the complete stressor identification for the impairments listed in Table 1.

Figure 1. Watershed District water quality monitoring locations on Brown's Creek.

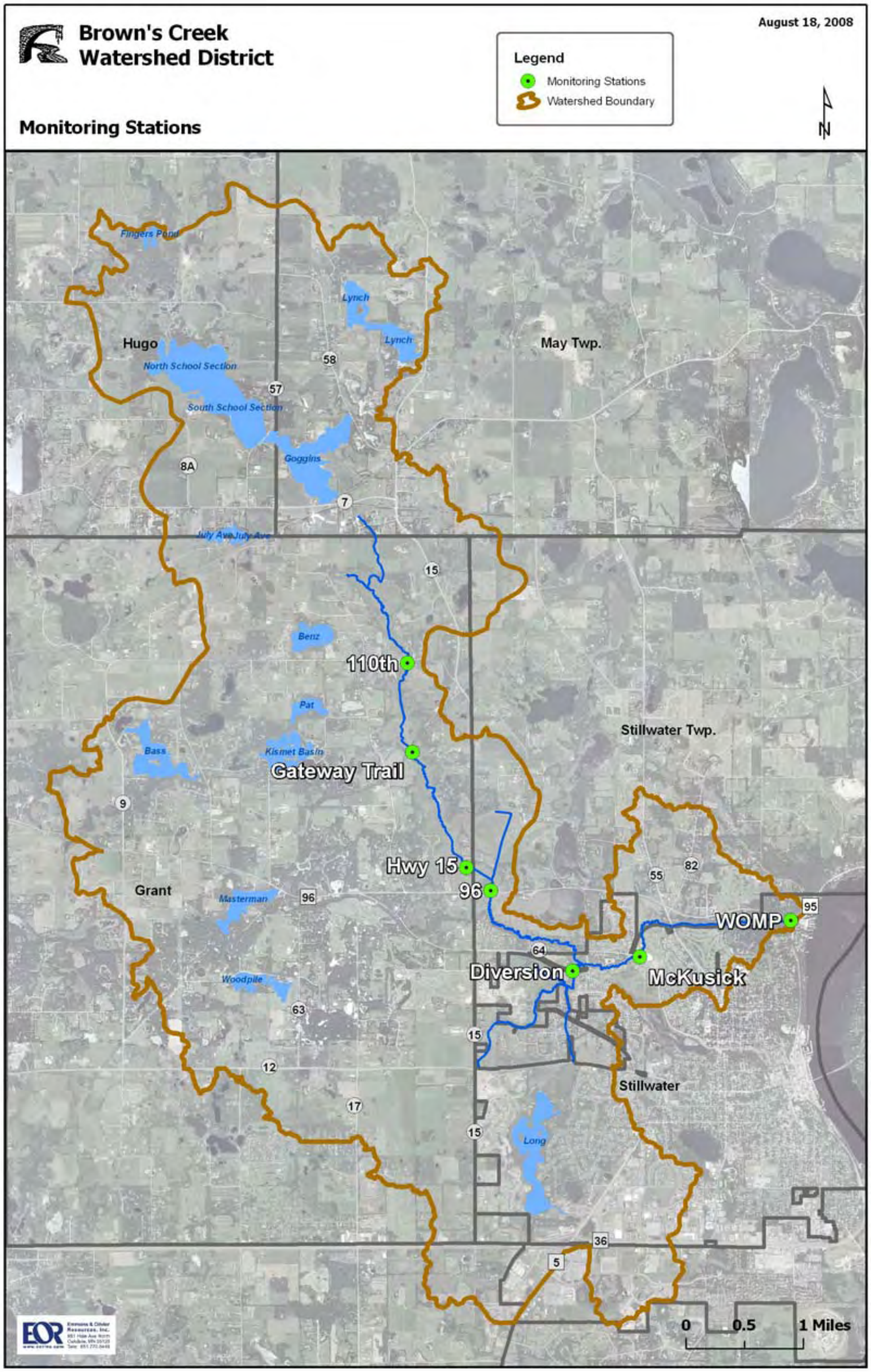
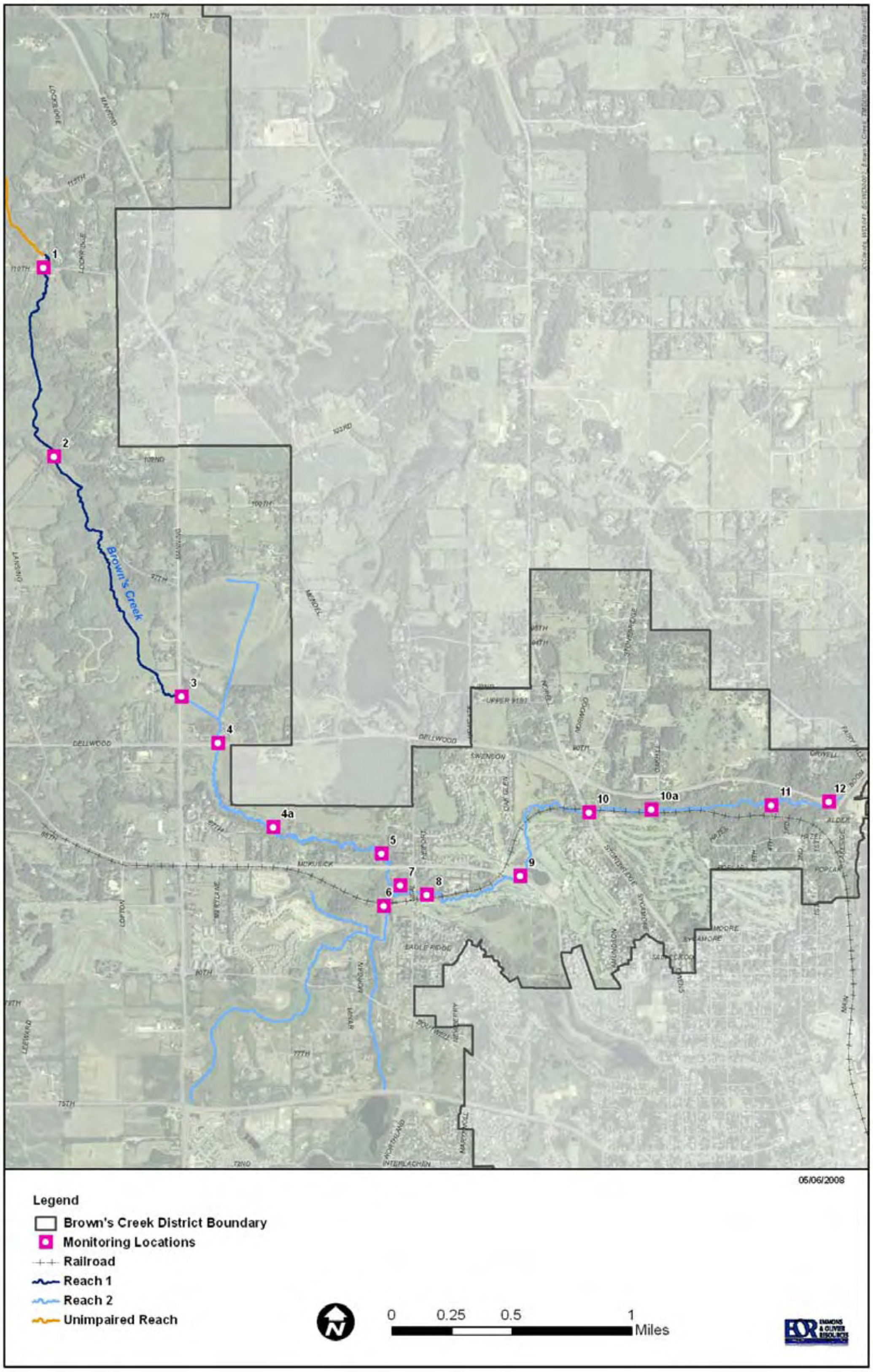


Figure 2. Biological monitoring stations on Brown's Creek.



DESCRIPTION OF IMPAIRMENT

A 2007 assessment of Brown's Creek by the MPCA listed biological impairments for both fish and invertebrates. The fish impairment was determined by the prevalence of highly tolerant warm water fish species, lack of intolerant species, and complete absence of cold water adapted species. Warm water and low dissolved oxygen tolerant species are present in high numbers, particularly the fathead minnow (*Pimephales promelas*) central mud minnow (*Umbra limi*), and creek chub (*Semotilus atromaculatus*). These species out-compete trout at warmer temperatures from 22 to 24 degrees Celsius and higher (Taniguchi et al., 1998). Cold water adapted species like the stocked brown trout (*Salmo trutta*) show up in surveys in very low numbers (1-20 individuals, maximum of 301 in 1998) or are completely absent despite sustained stocking efforts by the DNR.

Brown trout have been stocked yearly since 1958. Stocking is set between 800 and 1,000 individuals, sometimes including several size classes but generally limited to fingerlings. Fish surveys do not report many trout, sometimes fewer than 20 individuals, and the trout are primarily young of the year (indicating trout have not established a permanent population in Brown's Creek). Low temperatures from 1998 to 2004 co-occurred with improvements to the stream habitat, leading to higher trout populations in this period. Recent surveys show a decline again from 2004-2007. Long term data show that trout are not establishing well in Brown's Creek. Natural reproduction is confirmed sporadically (1966, 1976, 1989, 1998-2001) but not consistently enough to establish a permanent population. Native brook trout were not found in recent DNR surveys (2000, 2005). These trout issues, combined with the presence of warm water tolerant species and the lack of established cold water fish populations, are the basis for the fish impairment designation.

The invertebrate IBI score was below regional thresholds for impairment in the upper portion of Brown's Creek (110th Street to Highway 15, Figure 1). There are currently no specific cold water standards for invertebrates, but best professional judgment determined that there was a lack of a cold water assemblage corresponding to the fish impairment. The IBI lower than regional expectations and lack of expected coldwater species define the invertebrate impairment in the upstream reach of Brown's Creek. There is no invertebrate impairment from Highway 15 to the confluence with the St. Croix. A complete history of the assessment status by the MPCA is included in Attachment B.

APPROACH

Five water quality monitoring sites are primarily used in this stressor identification (Figure 1). From upstream to downstream, the sites are:

- 110th Street
- Gateway Trail
- Highway 15 (also known as County Road 15 or Manning Trail)
- McKusick
- WOMP

Highway 96 was not used in 2007 monitoring data but is referred to in some fish and invertebrate samples. Diversion is just upstream from the McKusick site, but does not connect back to Brown's Creek except at very high flows through a storm sewer. Data from Diversion are not addressed in the stressor identification unless relevant for analyzing effects of landscape use.

The 110th Street and Gateway Trail monitoring sites were added in 2007 to provide information on Brown's Creek upstream of the Highway 15 monitoring site. The stressor identification process uses all data available, so flow duration curves integrate several years of data (from 2000 to 2008 depending on availability). Site to site comparisons focus on the 2007 data because this is the only year all five monitoring sites were sampled.

The Causal Analysis / Diagnosis Decision Information System (CADDIS) was used to systematically review and evaluate all data. CADDIS is an online EPA application that guides the user through the stressor identification process, a method for identifying causes of impairments in impaired water bodies. CADDIS was used to evaluate, identify, and rank the stressors causing the biological impairments in Brown's Creek.

Flow and load duration curves were used to see under which flow regimes the standard exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis.

Load duration curves take the flow distribution information constructed for the stream and factor in pollutant loading to the analysis. The curve is developed by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The curve represents the pollutant load that can be in the stream at a particular flow without exceeding the standard for that pollutant. Monitored loads of a pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

CANDIDATE STRESSORS

Original list of candidate stressors

The first step in CADDIS is to list and evaluate the candidate causes of impairment. Common candidate stressors for the aquatic life impairments in stream systems are listed in Table 2.

Table 2. Broadest range of candidate stressors for Brown's Creek aquatic life impairments based on most likely stressors for similar aquatic systems defined by CADDIS.

Low dissolved oxygen	Algaecides
Hydrologic regime alteration	Lampricides
Nutrient regime alteration	Metals
Organic-matter regime alteration	Moluscicides
pH regime alteration	Organic solvents (e.g. benzene, phenol)
Salinity regime alteration	Other hydrocarbons (e.g. dioxins PCBs)
Bed sediment load changes including siltation	Endocrine disrupting chemicals
Suspended solids and/or turbidity alteration	Mixed, cumulative effect
Water temperature regime alteration	Interspecific competition
Habitat destruction	Small population (e.g. inbreeding, stochastic fluctuation, etc.)
Habitat fragmentation	Genetic alteration (e.g. hybridization)
Physical crushing and trampling	Overharvesting or legal, intentional collecting or killing
Toxic substances	Parasitism
Herbicides and fungicides	Predation
Halogens and halides (e.g. chloride, trihalomethanes)	Poaching, vandalism, harassment, or indiscriminate killing
Fish-killing agents (e.g. rotenone)	Unintentional capture or killing
Insecticides	Radiation exposure increase (e.g. increased UV radiation)

Sufficiency of evidence for potential stressors

CADDIS identifies different types of evidence to be used in the stressor identification, and a ranking is assigned to each type of evidence relative to the strength of the evidence (Table 3 and Table 4). The different categories of evidence have different weights, reflected by the range of possible values shown in Table 3. In this stage of the analysis, fish and macroinvertebrate stressors are considered together for the sake of simplicity, so the candidate stressors are evaluated against all biological impairments together. The biological impairments are treated individually again when candidate stressors are identified in later sections.

Table 3. Key to the values assigned evidence in the CADDIS stressor identification system of the US EPA.

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

Table 4. Possible values in the CADDIS stressor identification system of the US EPA. Different types of evidence carry different potentials for confirmation or elimination of candidate stressors.

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

Elimination of potential stressors

Potential stressors are grouped by similarity and strength of evidence. Table 5 lists all of the stressors that are ruled out as primary causes of the biological impairments in Brown's Creek. Many potential stressors can be eliminated simply because they or their effects are not present in Brown's Creek. Salinity, halogens, lampricides, piscicides, and moluscicides were not detected in Brown's Creek, and pH values fall within acceptable ranges. There is no evidence of crushing or trampling as a major problem in the stream (either by horses or ATVs) and there is little expectation that these will become problems. The Metropolitan Mosquito Control District treats the area for mosquitoes. Chemicals used in mosquito control do have some effect on non-target macroinvertebrates, but not in such a way that would select warm water species. The macroinvertebrate impairment in Brown's Creek shows a distinct pattern relating to temperature and dissolved oxygen, which is unlikely due to non-target effects of culicicides (insecticides that target mosquitoes).

Organic pollutants, hydrocarbons, endocrine disruptors, and most heavy metals were not detected in Brown's Creek at levels that would impact fish or invertebrates. Ecological impacts like parasitism, predation, and hybridization were not measured but are unlikely to cause the biological impairments. These factors are important in some systems, but no noticeable issues have arisen in Brown's Creek relating to them. Studies of streams near Brown's Creek show that growth rates of the non-native brown trout may be affected by inter-specific competition (Zimmerman et al., 2006; *ibid*. 2007a). There is no evidence, however, that competition is significant enough in Brown's Creek to cause the lack of a cold water fish assemblage. Competition due to stocked non-native trout is unlikely to impact the macroinvertebrate community (Zimmerman et al., 2007b).

Small population effects for fish are an unlikely source of problems for trout because the stream is stocked regularly. Brown's Creek also connects to the St. Croix River, so stocked non-native brown trout populations may not be entirely isolated. There are no known reports of tiger trout (brown-brook hybrids) from this area that are a sign of low populations of the non-natives and natives interbreeding. Most macroinvertebrates have a vagile life stage so small population effects are even less likely to be the source of the low indices of biological integrity for invertebrates in Brown's Creek.

Table 5. Sufficiency of evidence for stressors not identified to date as affecting Brown's Creek aquatic life impairments. Ranks follow the CADDIS system of the United States Environmental Protection Agency.

Types of Evidence	pH regime alteration	Salinity regime alteration	Physical crushing and trampling	Halogens and halides (e.g. chloride, trihalomethanes)	Fish-killing agents (e.g. rotenone)	Insecticide	Lampricide	Molus-cicide	Organic solvents (benzene, phenol)	Other hydro-carbons (dioxins, PCBs)
Evidence using data from Brown's Creek										
Spatial / temporal co-occurrence	---	---	NE	---	---	0	---	---	---	---
Evidence of exposure, biological mechanism	-	-	NE	-	-	-	-	-	-	-
Causal pathway	-	-	NE	-	-	+	-	-	-	-
Field evidence of stressor-response	-	-	NE	-	-	-	-	-	-	-
Field experiments / manipulation of exposure	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
Temporal sequence	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Verified or tested predictions	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
symptoms	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Evidence using data from other systems										
Mechanistically plausible cause	+	+	+	+	+	+	+	+	+	+
Stressor-response in other field studies	+	+	NA	+	+	+	+	+	+	+
Stressor-response in other lab studies	++	++	NA	++	++	++	++	++	++	++
Stressor-response in ecological models	++	+	NA	++	++	++	++	++	++	++
Manipulation experiments at other sites	++	+	NA	++	++	++	++	++	++	++
Analogous stressors	+	+	NA	+	+	+	+	+	+	+
Multiple lines of evidence										
Consistency of evidence	-	--	--	-	-	-	--	--	--	--
Explanatory power of evidence	-	-	-	-	-	-	-	-	-	-

Types of Evidence	Endocrine disrupting chemicals	Interspecific competition	Small population (inbreeding or stochastic mortality)	Genetic (e.g. hybridization)	Parasitism	Predation	Poaching	Over harvesting	Chloride	Lead	Nickel	Zinc	Cadmium	Chromium
Evidence using data from Brown's Creek														
Spatial / temporal co-occurrence	---	+	+	NE	NE	NE	-	-	--	--	--	--	--	--
Evidence of exposure, biological mechanism	-	0	0	NE	NE	NE	NE	NE	--	--	--	--	--	--
Causal pathway	-	0	0	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Field evidence of stressor-response	-	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
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	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Verified or tested predictions	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
symptoms	NE	NE	NE	NE	NE	NE	NE	NE	0	0	0	0	0	0
Evidence using data from other systems														
Mechanistically plausible cause	+	+	+	+	+	+	+	+	NA	NA	NA	NA	NA	NA
Stressor-response in other field studies	+	+	+	+	+	+	+	+	NA	NA	NA	NA	NA	NA
Stressor-response in other lab studies	++	++	++	++	++	++	++	++	NA	NA	NA	NA	NA	NA
Stressor-response in ecological models	++	++	++	++	++	++	++	++	NA	NA	NA	NA	NA	NA
Manipulation experiments at other sites	++	++	++	++	++	++	++	++	NA	NA	NA	NA	NA	NA
Analogous stressors	+	+	+	+	+	+	+	+	NA	NA	NA	NA	NA	NA
Multiple lines of evidence														
Consistency of evidence	--	-	-	NE	NE	NE	NE	NE	---	---	---	---	---	---
Explanatory power of evidence	NE	-	-	NE	NE	NE	NE	NE	-	-	-	-	-	-

Identification of stressors

Five main stressors and one stressor of potential concern had been previously identified for Brown's Creek (Attachment A, Status Report for Phase I of the Brown's Creek Biological TMDL), all of which were confirmed by this sufficiency of evidence analysis:

- Total suspended solids
- Temperature
- Dissolved oxygen
- Copper
- Nitrate-Nitrite
- Unionized ammonia (potentially)

Two secondary stressors, habitat destruction and habitat fragmentation, were added based on the sufficiency of evidence evaluation.

A summary of the sufficiency of evidence evaluation for these stressors is shown in Table 6. Stressors are listed from strongest evidence (left) to weakest (right). Stressor evaluations are treated individually in the causal pathway sections below, where supporting data and background research are discussed in detail.

In summary, total suspended solids were evaluated using site-specific relationships with turbidity. This correlation is explained in the section on TSS below. Levels of TSS violated the TSS equivalent of state standards for turbidity, and TSS has a direct impact on the biological integrity of Brown's Creek. Decreases in dissolved oxygen also violated standards for Class 2A cold water assemblages, and invertebrate community composition is diagnostic of low DO at some upstream sites. Temperatures were also higher than what professional judgment would expect in a Class 2A stream. The positive relationship between temperature and dissolved oxygen impairments, their compound effects on cold water biota, and their co-occurrence at specific sites show that these two factors are very important in Brown's Creek.

Copper toxicity is a significant biological impairment in the downstream reach of Brown's Creek, with one measurement in excess of final acute values. Nitrate + nitrite values were also very high in the downstream reach, exceeding guidelines for water quality.

Habitat fragmentation was not specifically studied in Brown's Creek. It is likely that some of the stressors are spatially differentiated enough to cause barriers to upstream migration (fish). Although direct physical alterations that fragment stream habitat are not present (e.g. dams), several stream crossings were identified as potential barriers to fish migration during low flow. Fragmentation is a serious concern as an effect of other stressors. For example, chemical fragmentation can occur from copper pulses or low dissolved oxygen. These pulses induce fish avoidance behavior, and effectively fragment accessible habitat.

Habitat loss could be a concern because of high input of suspended solids to Brown's Creek, as discussed above. Suspended solids can stay suspended and flow out to the St.

Croix River or they can be deposited in-stream. High TSS resulting in sedimentation can be a key mechanism of habitat loss as riffle areas are filled in and habitat structure is lost. Due to the high concentrations of suspended solids in Brown's Creek, sedimentation from high suspended solids is treated separately under suspended solids.

There is evidence of reduced habitat potential due to anthropogenic land use changes, including but not limited to channel manipulation. Historic channel ditching and alteration (prevalent upstream of Stonebridge Trail), coupled with watershed drainage and land cover alterations, have resulted in reaches with poor habitat potential. Tree removal has resulted in lower occurrences of instream woody debris and raised water temperatures. See *Attachment C: Geomorphic Analysis of Brown's Creek* for the stream classification and habitat observations.

Unionized ammonia is not identified as a primary stressor at this time, but levels detected suggest that monitoring should be continued for ammonia, particularly because the effects of ammonia on fish physiology and behavior compound with other stressors identified. When total ammonia is monitored, pH and temperature measurements should be taken concurrently to allow the estimation of unionized ammonia from total ammonia.

Table 6. Sufficiency of evidence for stressors identified as affecting Brown's Creek aquatic life impairments using the CADDIS system of the United States Environmental Protection Agency.

Types of Evidence	TSS	Temperature	DO	Copper	NOx	Habitat loss	Habitat fragmentation	Ammonia
Evidence using data from Brown's Creek								
Spatial / temporal co-occurrence	++	+	+	+	+	+	+	+
Evidence of exposure, biological mechanism	++	++	++	++	++	+	+	+
Causal pathway	+	++	++	++	++	+	+	+
Field evidence of stressor-response	++	++	++	++	NE	(see TSS)	NE	0
Field experiments / manipulation of exposure	NE	NA	NA	NE	NE	NE	NE	NE
Laboratory analysis of site media	NE	NA	NA	NE	NE	NE	NE	NE
Temporal sequence	+	+	NA	+	0	NE	NE	0
Verified or tested predictions	NE	NA	NA	NE	NE	NE	NE	NE
symptoms	NE	+	D	+	NE	NE	NE	NE
Evidence using data from other systems								
Mechanistically plausible cause	+	+	+	+	+	+	+	+
Stressor-response in other field studies	++	++	++	++	++	++	++	++
Stressor-response in other lab studies	++	++	++	++	++	++	++	++
Stressor-response in ecological models	+	+	+	NA	NE	++	++	NA
Manipulation experiments at other sites	+++	+++	+++	++	+	++	++	NA
Analogous stressors	++	NA	NA	++	+	+	+	+
Multiple lines of evidence								
Consistency of evidence	+++	+++	+++	+++	+++	+	+	0
Explanatory power of evidence	++	+	++	+	0	0	0	0

CAUSAL PATHWAY MODELING USING CADDIS

Identified stressors are treated individually in the following sections using the CADDIS stressor identification process, including models of causal pathways and detailed analysis of evidence. The models represent relevant ecosystem processes, causal pathways, and candidate sources. In the model diagrams, candidate sources and pathways supported by data are indicated by thicker arrows. Sources that can be ruled out by data are shaded, and pathways ruled out by data are hatched. All inferences are documented with references to specific data analysis and background literature. The sufficiency of evidence is assessed for each causal pathway for each stressor.

Total suspended solids

Total suspended solids and turbidity standards

Total suspended solids increase rapidly with landscape changes, particularly due to stormwater hydrology combined with increased impermeable surface area. Both surface water introduction of TSS and resuspension of stream bed sediments are increased by storm events, and TSS data can be highly variable. Perturbation of top-soils and vegetative cover also increases TSS. Turbidity, measured in NTUs (nephelometric turbidity units), is an index of total cloudiness of water including suspended sediments and solids, suspended organics, tannic acid and other discoloring natural chemicals, and algae. There are specific Class 2A water quality standards for turbidity set by the State of Minnesota, but no standards for TSS. There are more TSS data available than turbidity measurements in Brown's Creek, so site-specific correlations were made between turbidity and TSS to evaluate the turbidity in Brown's Creek relative to the standard. This method of developing TSS equivalents as a measure of turbidity is supported by other work (Earhart, 1984). Other research links TSS inputs to the destruction of trout habitat (Berkman et al., 1987; Argenta et al., 1999). Analyzing TSS also allows the use of flow duration curves that show relationships between stressor loads and flow.

Site-specific relationships between TSS and turbidity were used; the turbidity standard was transformed to TSS concentration equivalents for each site (Table 7). The only site where this relationship was not statistically significant was WOMP (watershed outlet monitoring program site, the farthest downstream), so the nearest site (McKusick) was used to estimate the standard. All analyses referred to below use these site-specific relationships.

Table 7. Relationship between total suspended solids and turbidity to allow comparison of TSS with turbidity standards. R-squared values for the correlations are shown below TSS equivalents (mg/l) to Class 2A and 2B turbidity standards. All relationships are statistically significant ($p < 0.001$). Three extremely high outliers were not analyzed for McKusick.

Statistic	Site					
	110th St.	Gateway	Hwy 15	Diversion	McKusick	WOMP
TSS equivalent (mg/l) of 10 NTU (Class 2A standard)	71.65	18.35	28.47	No data	23.23	74.93
TSS equivalent (mg/l) of 25 NTU (Class 2B standard)	160.4	45.90	71.91	No data	63.28	176.6
r-squared	0.948	0.591	0.664		0.758	0.495

Causes and effects of high total suspended solids in streams

Previous TMDL studies have identified increases in TSS as a key factor in biological impairments (e.g., Garcia River Sediment TMDL, US EPA region IX, 1998). Increases in suspended solids can have major impacts on stream biota (Berkman et al., 1987; Wang et al., 2003a and 2003c). TSS can increase in streams due to bank destabilization (e.g. from removal of upland or riparian vegetation), stormwater input, certain agricultural practices, and other landscape alterations that increase impervious surfaces. Measuring the amount of impervious surfaces alone is often sufficient for predicting the health of trout streams in Minnesota and Wisconsin (Wang et al., 2003a). Internally, increases in TSS can produce more scouring, introducing additional suspended solids. The sites impacted and the extent of damage depend on stream magnitude, gradient, and whether the site is erosional or depositional.

Newcombe et al. (1996) review of the impacts of TSS on fish. TMDL studies involving excess sediment are reviewed in Yagow (2007). Two primary pathways link TSS to biological impairments: the direct impact of suspended solids on biota and the indirect impact of suspended solids on sedimentation and changes in substrate and habitat.

Suspended materials directly impact growth and reproduction in fish by decreasing success of visual predation (e.g. Sutherland, 2001). Suspended solids can directly impact gill function (Brown et al., 1994). Fish eggs are also directly impacted by high sedimentation. The siltation of sediment drastically impacts species dependent on riffle habitats (Berkman et al., 1987). Sediments can also decrease micro-climate oxygen levels resulting in reduced body weight (and consequently survival) of fry at hatch (Argenta et al., 1999).

Secondly, suspended solids can drop out of suspension and cause sedimentation. As sedimentation increases, it fills in riffle areas resulting in a more homogenous stream bed. Changes in habitat reduce kind and density of the most preferable macroinvertebrate prey. Sedimentation also covers redd (egg laying areas), reducing reproductive success. Invertebrates are similarly impacted (Zweig, 2001). Increases in sedimentation remove habitat structure, damage gills, and can impact feeding (in this case not necessarily visual predators, but filter feeders like many Trichoptera).

Data evaluation for total suspended solids and turbidity in Brown's Creek

Mean TSS at each site over all available years is shown in Figure 3. The TSS equivalents of the turbidity standards for both Class 2A and 2B waters were calculated for each site (Table 7). The standard shown in Figure 3 uses a combined TSS standard calculation to allow site to site comparisons, all other analyses use site-specific TSS-turbidity relationships. This summary indicates very high concentrations and variability of TSS at the 110th St. and Diversion sites. Fewer data points at these sites and the loose sediment (which gives high readings if disturbed) contribute to the high variability. This indicates that high amount of fine sediments may itself be an issue at these sites. The McKusick and WOMP sites show consistently high TSS, with levels at WOMP higher than the standards for Class 2B waters. This illustrates the seriousness of the problem at the downstream reaches relative to the desired cold water assemblages of fish and macroinvertebrates expected in Class 2A waters.

The load duration curves (Figure 4 through Figure 7) use the site-specific relationships between TSS and turbidity (Table 7) to present the TSS equivalents of the turbidity standards for both Class 2A and 2B waters. Results from the most upstream site (110^{th} St., Figure 4) are ambiguous in that there were two exceedances under dry conditions, but no clear pattern. High suspended solids can occur under dry conditions due to runoff from irrigation or disturbances from cattle or ATVs in the stream. The infrequency of points in excess of the standard shows that high TSS is unlikely to be a major problem in these upstream sites, but low sample size and high variation makes it difficult to warrant a strong conclusion.

The lower sites show a more typical pattern of high TSS at periods of high flow (Figure 5 through Figure 7). The level and frequency of points above the turbidity standards are very high, particularly at McKusick. The occurrence at high flow is an indication that the source of TSS could be a combination of runoff (high TSS at high flows during storms) and in-stream erosion (in both high flows and residual scouring at low flows).

Figure 3. Mean total suspended solids from monitoring data (2000-2007). TSS equivalents for turbidity of Class 2A waters (10 NTU) and 2B waters (25 NTU) are shown using turbidity/TSS correlations using data from all sites combined.

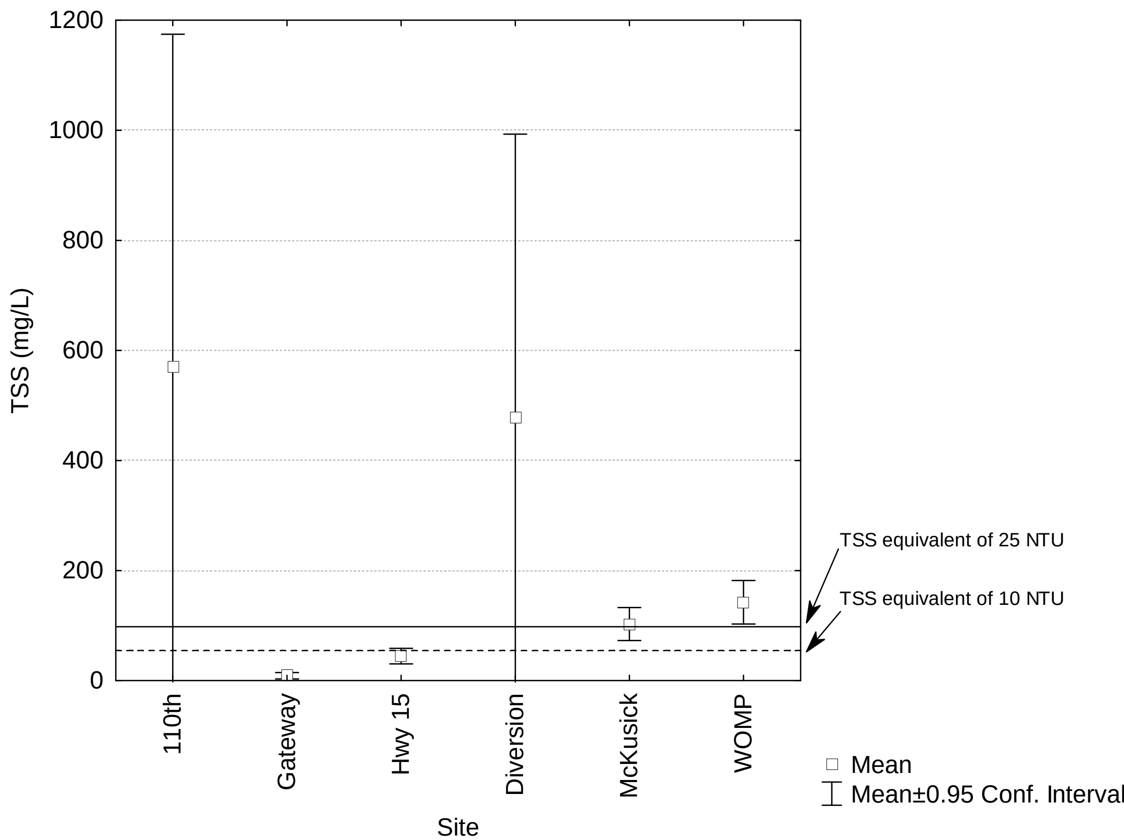


Figure 4. Load duration curves for TSS monitoring data, 2007, at 110th St., using the TSS equivalents of turbidity standards (10 NTU for Class 2A water and 25 NTU for 2B water).

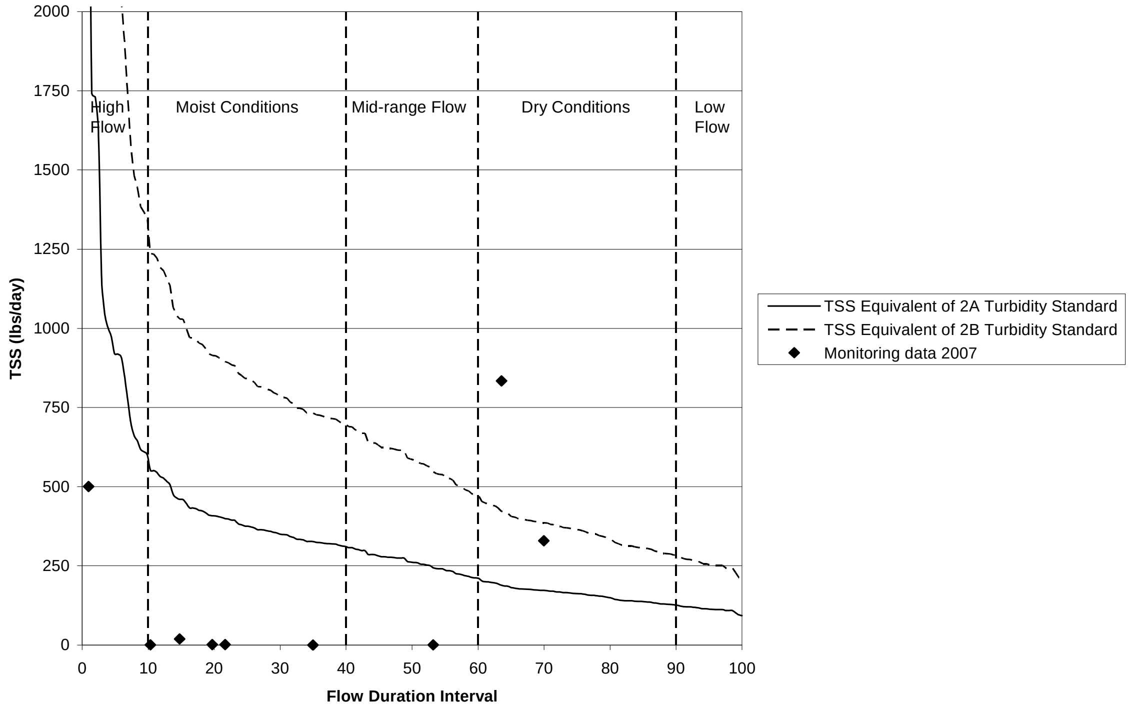


Figure 5. Load duration curves for TSS monitoring data, 2007, at Highway 15, using the TSS equivalents of turbidity standards (10 NTU for Class 2A water and 25 NTU for 2B water).

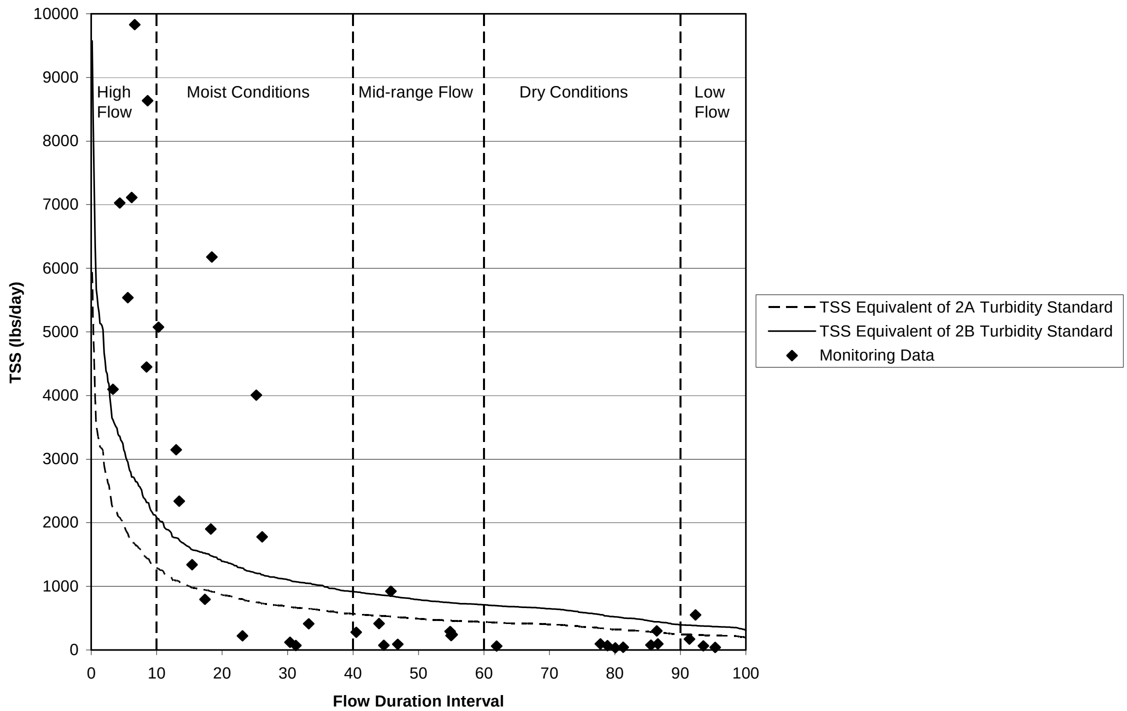


Figure 6. Load duration curves for TSS monitoring data, 2000-2007, at McKusick, using the TSS equivalents of turbidity standards (10 NTU for Class 2A water and 25 NTU for 2B water).

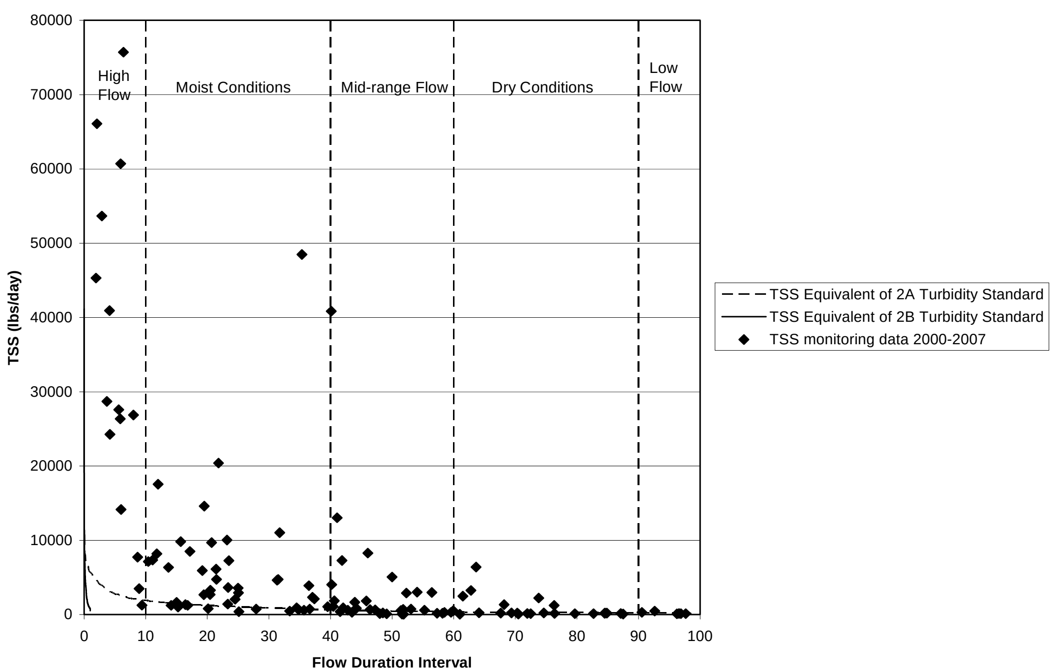
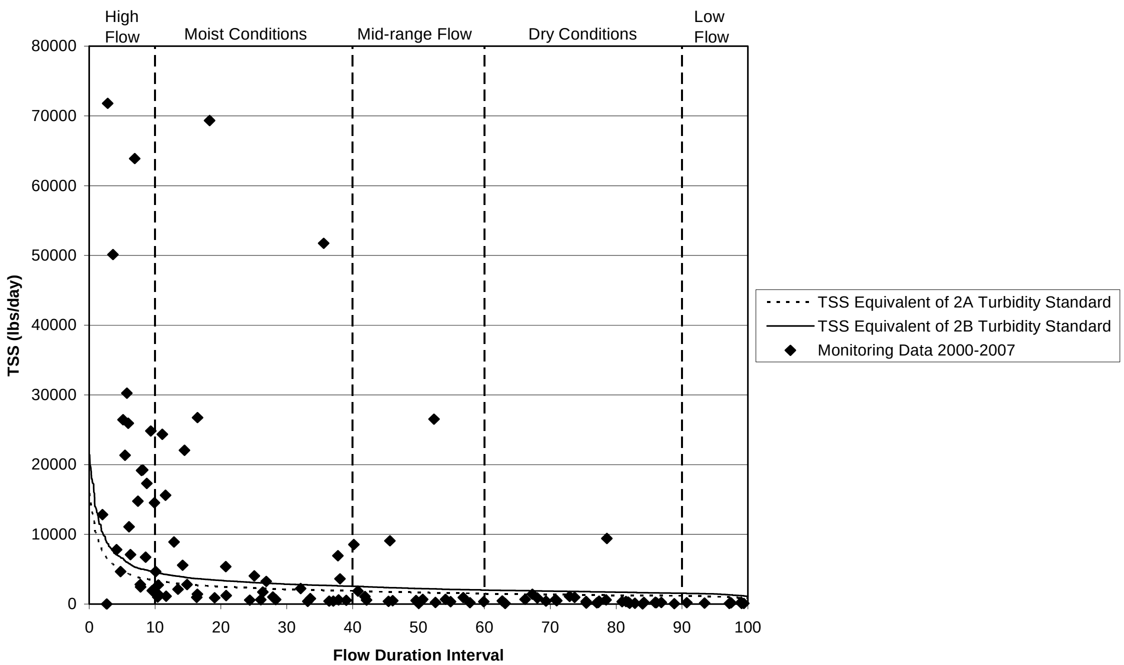


Figure 7. Load duration curves for TSS monitoring data, 2000- 2007, at WOMP, using the TSS equivalents of turbidity standards (10 NTU for Class 2A water and 25 NTU for 2B water).



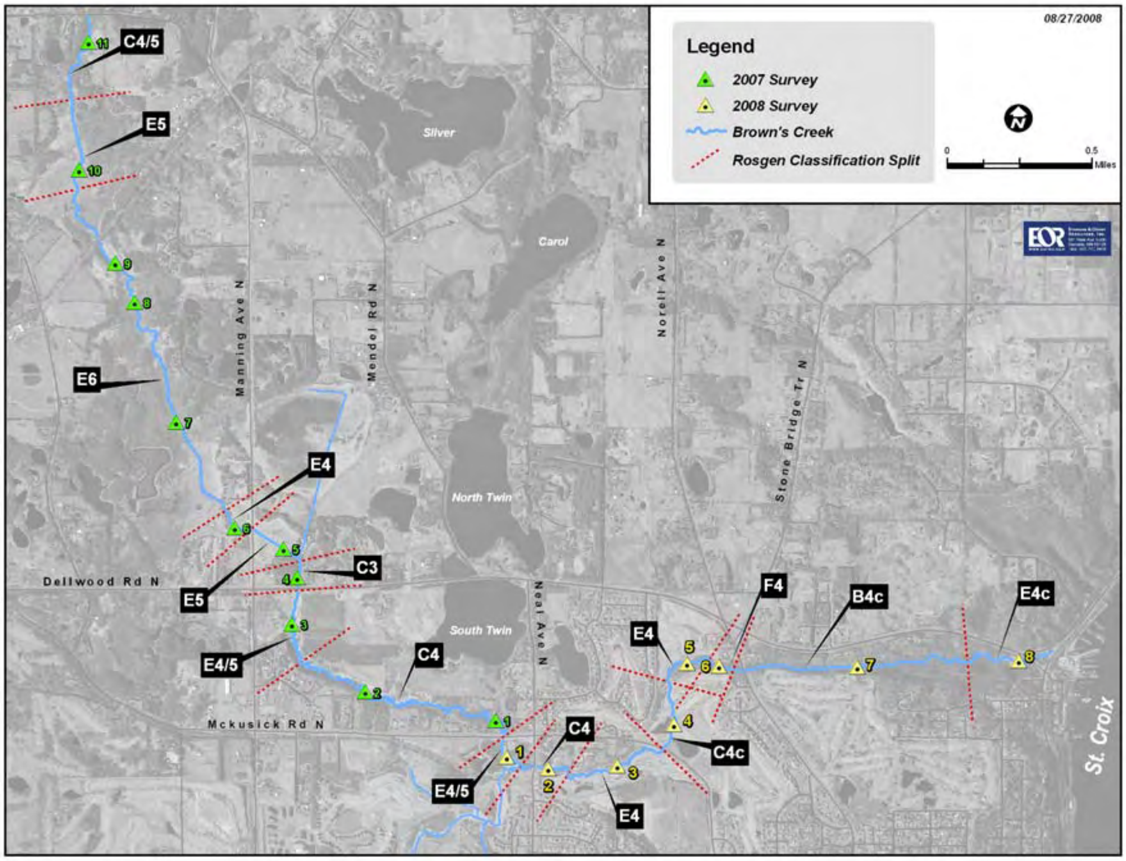
Models of sources and causal pathways for total suspended solids in Brown's Creek
The causal pathways between potential sources of high TSS and mechanisms causing impairment are modeled in Figure 10. Pathways that are dashed are ruled out by data from Brown's Creek, while pathways with thicker arrows are confirmed by available data. The potential sources of the high TSS in Brown's Creek were evaluated by re-running the CADDIS stressor identification process at a high resolution (Table 9).

A few sources of TSS can be eliminated with the available data combined with landscape analysis (spatial distribution of land use in the sub-watersheds). The channel in Brown's Creek has been altered by development and roads in some places, but the majority of the stream has not been significantly channelized. Historic ditching is present but does not currently appear to be a major influence on stream hydrology. The geomporphic analysis (Figure 8) and observations by MPCA and Washington County staff do not indicate major bank destabilization. Decreased bank stability may be a problem at very localized sites but is not considered a primary source of TSS. This is not to say that changes in bank vegetation or reduced buffer zones are not a contributing factor to the impact that surface runoff has on Brown's Creek, but only that bank erosion is not a major or immediate source of suspended solids. Details of the geomorphic stream survey are in Attachment C.

Table 8. Summary of geomorphic analysis. Sites are listed from upstream to downstream.

Site name	Site classification	Rosgen Level II classification	Bank stability	Notes
#11 (2007)	375 river feet downstream of 110th St.	C4	significant instabilities	culvert high enough to be fish barrier
#10 (2007)	1850 river feet upstream of Gateway	E5	very stable	significant groundwater
#9 (2007)	890 river feet downstream of Gateway	E6	generally stable	
#8 (2007)	1670 river feet downstream of Gateway	E6	generally stable	active beaver dam
#7 (2007)	2725 river feet upstream of Highway 15	E6	generally stable	strong groundwater contribution
#6 (2007)	300 river feet upstream of Highway 15	E4	generally stable	
#5 (2007)	500 river feet downstream of Highway 15	E5	generally stable	historic ditching
#4 (2007)	300 river feet upstream of Highway 96	C3	highly manufactured buffer	cross section and profile rip-rapped.
#3 (2007)	400 river feet downstream of Highway 96	E4/5	generally stable	steep gradient
#2 (2007)	2600 river feet downstream of Highway 96	C4	generally stable	strong groundwater contribution
#1 (2007)	500 river feet upstream of McKusick road.	C4	generally stable	strong groundwater contribution, deepest pool found in Brown's Creek (3.75 feet)
#2 (2008)	185 river feet downstream from Neal Ave.	C4	erosion on upstream portions	
#3 (2008)	Oak Glen Golf Course	E4	stable	restored portion
#4 (2008)	265 river feet upstream of Zephyr Railroad bridge (Oak Glen Golf Course)	C4c-	generally stable	turf all the way down to banks
#5 (2008)	510 river feet downstream of Zephyr Railroad bridge	E4	generally stable	back to typical riparian vegetation, some thermal protection
#6 (2008)	300 river feet upstream of Highway 5 (Norell)	F4	root depth inadequately protecting banks	ample thermal protection
#7 (2008)	1500 river feet downstream from Highway 5 (Norell)	B4c	high erosion potential	heavy groundwater discharge
#8 (2008)	320 river feet upstream of Highway 5	E4	bank under-cutting due to shallow root depths	floodplain reach

Figure 8. Geomorphic analysis of Brown's Creek.



TSS increases rapidly in the downstream sites as the landscape transitions to suburban or urban. Landscape use in the area does not indicate heavy irrigation even in agricultural areas, and agricultural irrigation is ruled out as a source. A significant portion of some of the lower sub-watersheds is composed of golf courses and larger footprint homes, so irrigation is likely to have some impact in these areas by increased runoff over impervious surfaces

The load duration curves (Figure 4 through Figure 7) show highest TSS at high flows, particularly at the downstream sites. The high TSS during high flows indicates suspended solids entering the creek during high precipitation events. Surface water carrying TSS relates to patterns of altered landscape hydrology, particularly increased impervious surfaces. These sources are a highly visible component of the landscape in the sub-watersheds around the sites impacted by TSS. In recent years (2006-7), large tracts of land have been cleared for development at the southwest corner of Highway 15 and Highway 96.

Impervious surface cover of 6-11% or higher has been found to be the most significant factor correlating with degraded trout streams in Minnesota and Wisconsin (Wang et al., 2003a). The levels of impervious surfaces in the Brown's Creek watershed average near

30% in most of the sub-watersheds, which indicates an important component of the land use that is likely a strong component of high TSS (specific subwatershed imperviousness will be calculated as part of the TMDL). Identifying more specific elements of the pathway to the impairment requires further analysis. The available data combined with the amount of quality scientific research published about the relationship between these landscape effects, TSS, and biological impairments all support TSS as a primary stressor for fish in the lower reach of Brown's Creek.

TSS also impacts invertebrates. To date, only the upper reach is listed as impaired for invertebrates. TSS is not likely to be causing severe changes to habitat and substrates that would impact the benthic community in the upper reach. Invertebrate data show a high EPT, an index of taxa generally sensitive to changes in habitat from sedimentation (Table 11 in the DO section below). Detailed invertebrate studies of the biological impairment are less clear about the mechanisms leading to biological change. A low EPT at the WOMP site could indicate some sedimentation is changing habitat (Table 11), but it is not conclusive with regards to positively identifying or eliminating the pathway by which TSS is most impacting the biota. Data from the MPCA on embededness, a measure of how much habitat is covered in fine sediment, does not show a dramatic problem in the lower reaches where TSS is the highest.

Fish egg survival and habitat (riffle) loss can be a major impact from sedimentation, preventing trout establishment. However, the embededness data suggest that the TSS is staying suspended and flowing into the St. Croix River. Figure 9 shows that the percent of fine sediment is highest upstream, not below. If TSS were increasing sedimentation, the opposite pattern would be expected, since sedimentation is higher where percent fines are higher. Similarly, embededness (the amount of substrate material that is buried in sediment) decreases downstream, again the opposite pattern of high sedimentation rates. TSS impact on fish is most likely due to lowered rates of predation and direct damage to gills. More detailed analysis of the fish populations would clarify these points, because sedimentation (measured as increases in percent fines) is evident at the lower reaches (comparing Highway 15 to Mckusick in Figure 9). A relatively high number of sensitive invertebrate taxa, the EPT (Table 11 in the following DO section), at the McKusick site supports the inference that sedimentation is not the major pathway of TSS impacting the biota, but this high EPT value is not supported by other invertebrate work (Table 11). A longitudinal study of sedimentation would tease out these issues.

For the purposes of identifying pathways in the model of TSS (Figure 10), the data to date support the inference that most of the TSS is remaining in suspension, so the mechanisms relating to biological impairment are more strongly related to that pathway. These data do not eliminate the possibility that sedimentation is having some impact.

Figure 9. Data from MPCA streambed analysis, 1996-2007. Percent fines versus percent rock is shown for three sites (averaged over two sampling visits). Average embededdness over two sampling dates is compared over the same three sites.

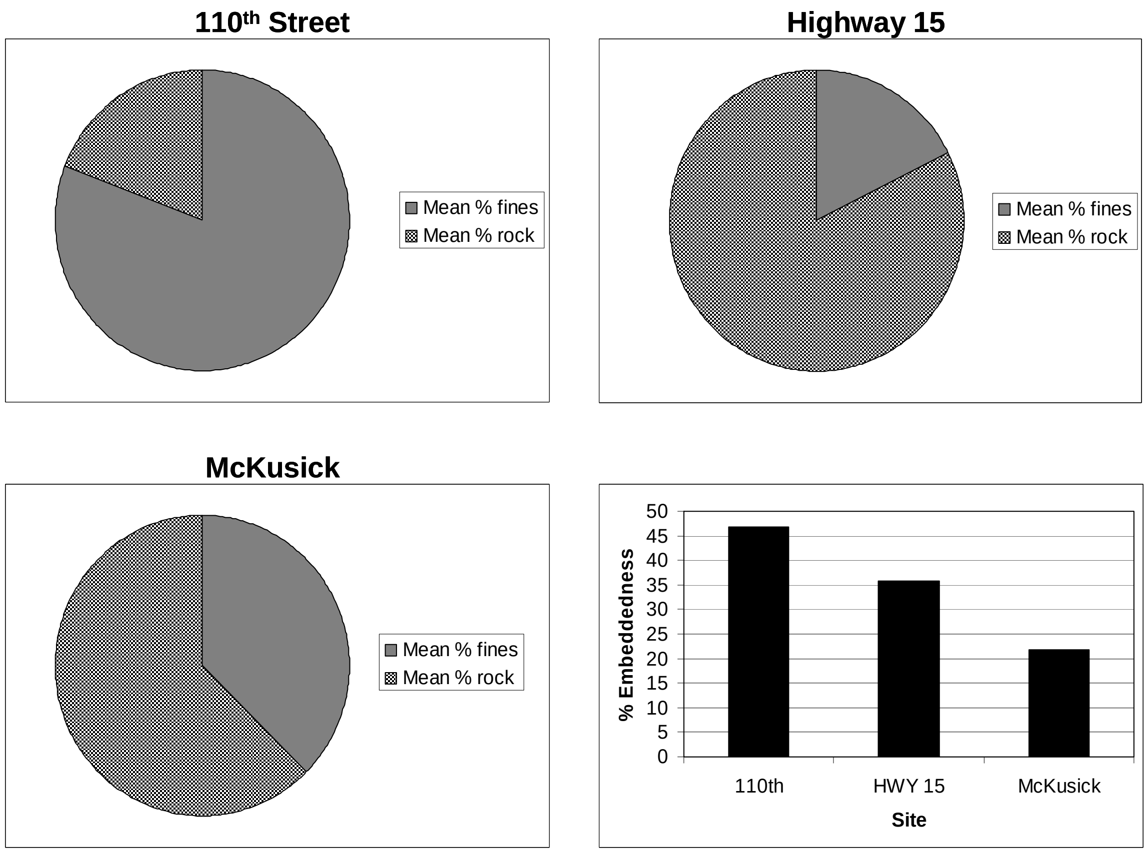


Figure 10. Model of causal pathways for total suspended solids in Brown's Creek.

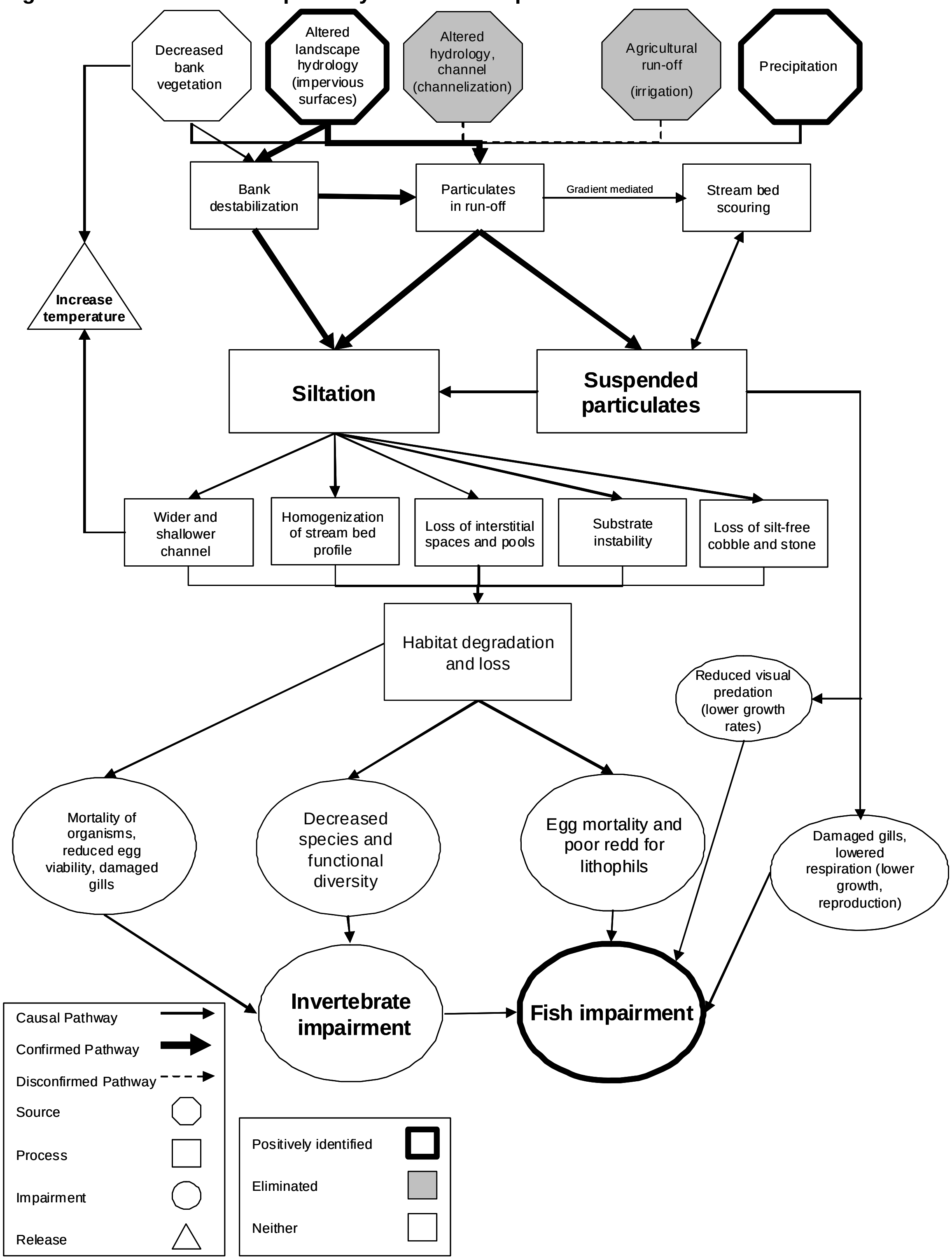


Table 9. Sufficiency of evidence table for sources of total suspended solids in Brown's Creek.

Types of Evidence, TSS	Decreased Bank Vegetation	Altered landscape hydrology (e.g. impervious surfaces)	Altered channel hydrology (channelization)	Anthropogenic runoff (irrigation)
Evidence using data from Brown's Creek				
Spatial / temporal co-occurrence	+	+	0	+
Evidence of exposure, biological mechanism	0	++	0	0
Causal pathway	+	++	-	+
Field evidence of stressor-response	NA	NA	NA	NA
Field experiments / manipulation of exposure	NA	NA	NA	NA
Laboratory analysis of site media	NA	NA	NA	NA
Temporal sequence	NA	NA	NA	NA
Verified or tested predictions	NA	NA	NA	NA
symptoms	+	+	+	+
Evidence using data from other systems				
Mechanistically plausible cause	+	+	+	+
Stressor-response in other field studies	++	++	++	++
Stressor-response in other lab studies	NA	NA	NA	NA
Stressor-response in ecological models	+	+	+	+
Manipulation experiments at other sites	+++	+++	+++	+++
Analogous stressors	++	++	++	++
Multiple lines of evidence				
Consistency of evidence	+	+++	0	+
Explanatory power of evidence	++	++	0	0

Conclusion: total suspended solids as a biological stressor in Brown's Creek

TSS concentrations are high in Brown's Creek. TSS can have direct and indirect effects on stream biota (from interference with gill function to loss of habitat). TSS is identified as a primary stressor causing the biological impairments for fish at the downstream sites in Brown's Creek (McKusick and WOMP). At high flows, TSS is a problem for fish and invertebrates at all sites in the lower reach, from Highway 15 to WOMP. Increases in impervious surfaces leading to higher runoff carrying suspended solids have been found to be the primary determinant of trout stream (Class 2A) health in Minnesota and Wisconsin streams (Wang et al., 2003a). There is no state standard for TSS, but each site on Brown's Creek showed very tight correlations between TSS and turbidity with the exception of WOMP. Site specific equations were generated to compare total suspended solids to turbidity standards, showing all sites at times violate standards for Class 2A streams. Downstream sites show violations at high flow levels. Upper sites are variable, with some sites (110th St.) producing a few high points at low flows, and others (Highway 15) producing violations at high flows only. This suggests a variety of sources of TSS at the upstream sites. Downstream sites (especially McKusick and WOMP) show much higher levels of TSS at all flows.

The strength of evidence, magnitude of the impact, comparison with research on similar streams, and the multiple effects on biota (fish and invertebrates) indicate TSS is a primary stressor in Brown's Creek. The most likely sources of TSS in Brown's Creek are landscape alterations in the watershed including high percentage of impervious surfaces and decreased bank vegetation.

Dissolved oxygen

Dissolved oxygen standard

The EPA guidance document for setting DO standards (Quality Criteria for Water, 1986) recognizes the daily and seasonal variation in DO, incorporating several major studies of fish and invertebrate responses to low DO in recommending 1-day minimums, 7-day means, and 30-day means. Criteria are also set differently for different classes of water (based on biota and human use). The Minnesota DO standard for Class 2A waters states that a daily minimum of 7.0 mg/l DO must be met during 50% of 7Q10 flow conditions (MN Rule 7050.0222, Subp. 2). The 7Q10 flow is the lowest stream flow over 7 consecutive days that, on a statistical basis, can be expected to occur once every 10 years. In terms of flow duration curves, for Brown's Creek the 7Q10 point is 99.808%, using regressions from previous studies (Flynn, 2003).

Effects of low dissolved oxygen in streams

The concentration of dissolved oxygen (DO) in water is directly related to invertebrate and fish survival, growth, and reproduction. Low dissolved oxygen is often the source of or a major contribution to biological impairments (e.g. Beaver River Watershed TMDL, Utah Department of Environmental Quality-Division of Water Quality; Mathews et al., 1997; Dissolved Oxygen TMDL Protocol and Submittal Requirements (MPCA) 2008).

The amount of dissolved oxygen in water is physically related to air pressure and water temperature (warmer water holds less dissolved gasses). Oxygen is dissolved into and released from water by diffusion and atmospheric pressure, produced by aquatic plants and algae, and physically introduced via mechanical aeration by waves, wind, riffles, and other agitation of the water surface. Oxygen is removed from the water primarily by decomposition, respiration, and increases in temperature. Anthropogenic impacts like sewage inputs, removal of riparian vegetation that increases temperature, and increased nutrients in runoff can dramatically lower dissolved oxygen. Increases in nutrients can shift streams from heterotrophic to autotrophic production, but increases in decomposition out-weigh additions of DO by photosynthesis in most circumstances, resulting in a net loss of oxygen (Peterson et al., 1985). Allochthonous nutrients increase decomposition rates but also change the trophic structure from the bottom-up, alter internal nutrient cycling, and increase immobilization of nitrogen and carbon which in turn increase chemical and biological use of oxygen (Elwood et al., 1981).

Low DO characterizes natural areas with high rates of decomposition, slower and warmer waters, and low rates of mechanical aeration, including wetlands and backwaters of many streams. In many trout streams, the distribution of springs is important since cooler water holds more DO and cold areas offer refugia from low DO at high summer temperatures (Baldwin et al., 2002). Consequently, stream geomorphology and the distribution of wetlands, backwaters, springs, riffles, and other physical features are important for understanding changes in DO. Finally, photosynthesis produces DO at irregular rates (usually high during the light phase, lower during the dark phase). Diel fluctuations compound with other factors, making continuous DO monitoring data extremely valuable.

Data evaluation of dissolved oxygen in Brown's Creek

Dissolved oxygen data were taken in Brown's Creek at most sites using 15-minute frequency data loggers set up to record values in the ice-free season. These data were evaluated against standards and against particular physiological requirements of trout that characterize the cold water fish assemblage. The 7Q10 criteria are based on monitoring point source loads, a conservative measure to guarantee mixing. A DO level of 7.0 mg/l was used as a guideline for non-point source assessment of Brown's Creek. Levels of 7.0 and 5.0 mg/l are used below to evaluate frequency and duration of low DO relative to tolerances of the biota. DO levels below 7.0 mg/l can change fish behavior, increase physiological stress, and inhibit normal functions. DO levels below 5.0 mg/l cause more severe physiological stress, egg mortality, avoidance behavior, and other problems. MPCA guidelines use these two levels to evaluate Class 2A and 2B streams. Although the standard is evaluated using the 7Q10 criteria, Class 2A streams are often expected to consistently have DO levels above 7.0 mg/l and Class 2B DO levels are expected to be consistently above 5.0 mg/l. The MPCA standards based on 7Q10 levels in Brown's Creek correspond to the 99-100% range of the flow duration intervals.

Dr. Len Ferrington, Jr. (University of Minnesota) studied species-specific responses to dissolved oxygen and temperature. This kind of study provides insight into the biological system and preliminary results are incorporated below. Final results and analysis are contained in *Attachment E: Bioassessment of Macroinvertebrates at Five Sites on Brown's Creek Near Stillwater, Minnesota*.

Natural and anthropogenic fluctuation in DO levels make continuous monitoring data necessary. Water quality measurements taken in the field at the time of sampling for other measurements are compared to continuous data (2007) in Table 10. Percent of measurements above 7.0 mg/l DO from 2007 water quality sampling on Brown's Creek listed by site (upstream to downstream) were compared to percent of measurements from 15- minute frequency monitoring (from 2000 to 2007). Values in bold are levels of particular concern to biota. Values in bold indicate sites that are below 7.0 mg/l DO nearly half the time or more. These sites also have DO levels below 7.0 mg/l at 7Q10 flows more than half the time.

The total number of samples taken for each site in the first column varied between 10 and 27 samples. The impression these data give is that the impairment is limited to 110^{th} St. The 15-minute frequency continuous data collection is based on several thousand data points for each site. The increase in detail produces a better picture of the role DO plays in Brown's Creek.

Table 10. Percent of measurements above 7.0 mg/l DO from 2007 water quality sampling data on Brown's Creek listed by site (upstream to downstream) compared to percent of measurements from 15-minute frequency monitoring data (from 2000 to 2007). Values in bold indicate sites that are below 7.0 mg/l DO less than or nearly half the time.

Site on Brown's Creek	% 2007 water quality measurements above 7.0 mg/l DO	% of 15 minute frequency data logger periods above 7.0 mg/l DO
110th St.	**55.6**	**35.9**
Gateway	83.3	**50.4**
Highway 15	74.2	**58.1**
McKusick	91.7	93.5
WOMP	90.0	no data

The 15-minute data from 2007 showing the DO values taken by continuous loggers is plotted for each site in Figure 11. The upstream sites fall below the 7.0 mg/l value throughout 2007, while the high gradient, riffle-dominated McKusick site stays well above the standards. The WOMP site was not monitored continuously for DO.

Biological responses to low DO depend on frequency and duration of exposure. Most organisms can avoid areas of low DO to some extent or simply weather the low DO conditions. Under these conditions, feeding, growth, and reproduction are suppressed but permanent physiological stress does not occur. Periods of low DO that are more frequent or last longer have more severe effects, including mortality of eggs and adults. Sub-lethal effects are important to keep in mind as a fish stressor because low DO lowers appetite (Bernier et al., 2005), changes predator avoidance behavior in fry (Roussel, 2007), and has other impacts resulting in reduced fish population size, health, and reproduction. Site to site differences in frequency and duration of low DO relate strongly to the fish and invertebrate impairments of the upstream sites on Brown's Creek.

Exposure to very low DO (5.0 mg/l or below) at the uppermost site is quite frequent. Figure 12 shows periods of low DO in black over the 2007 monitoring season. The dense stripes indicate high frequency of low DO, while white areas indicate DO above 5.0 mg/l. The banding effect is from diel variation in DO.

Frequency charts of fifteen minute periods with low DO show the environment the fish and invertebrates are exposed to. These charts link water quality standards with the physiological environment of the biota by showing how often stressfully low oxygen conditions occur. The 2007 frequency data for Brown's Creek show a pattern expected from a Class 2B stream, not a Class 2A stream. The frequency of very low DO is likely enough to repel fish, driving them to lower sections of Brown's Creek (Dean et al., 1999). The same frequency plot for the 110th St. site using the Class 2A standard of 7.0 mg/l is shown in Figure 13. Similar plots characterize the frequency of low DO at the Gateway site (Figure 14 and Figure 15), Highway 15 (Figure 16 and Figure 17) and McKusick (Figure 18). Continuous DO data were not taken at the WOMP site. A high frequency of sub-standard DO events characterizes the upper sites. The frequency of DO below 5.0 mg/l at the upper sites indicates the seriousness of low dissolved oxygen as a stressor in Brown's Creek. The periods below 5.0 mg/l DO at the Gateway site is likely due to natural causes (the site is a protected wetland area with slow moving water and plenty of organic material). Even the well-aerated McKusick site has DO levels below 7.0 mg/l at some points.

Another important dimension to the relationship between low DO and stream biota is consecutive time below DO standards. There are no EPA or MPCA standards based on direct biological exposure in terms of consecutive hours, but fish hatcheries use this kind of information to avoid serious mortality or low growth rates due to low DO. As a rough guideline, 12 hours of exposure to DO below 7.0 mg/l reduces growth and reproduction while inducing a variety of behavioral changes including avoidance, 'hunker-down' behaviors, or increased surfacing (Matthews et al., 1997; Dean et al., 1999; Wherly et al., 2007). Exposure over 48 hours significantly increases mortality, and the upper y-axis limit of Figure 19 through Figure 25 at 168 hours (1 week) below DO standards is enough to extirpate all but specially adapted biota (Wherly et al., 2007). The upstream two sites (110th St. and Gateway) are regularly impacted by low DO (Figure 19 through Figure 22). McKusick is an area of steep gradients and characterized by riffles typical of prime trout habitat and high DO from mechanical aeration. Nonetheless, there are several points in 2007 when DO was below standards for close to 24 hours, and one where DO was below standard for 64 consecutive hours (Figure 25). These periods are not frequent enough to be physiologically dangerous to fish, but certainly enough to produce avoidance behavior and increase egg mortality.

There was no relationship between flow and DO concentrations (r^2 values range from 0.0119 to 0.1655 for DO-flow relationships at each site). Flow duration curves show that there is roughly the same number of points below DO standards at high, medium, and low flows (Figure 26 and Figure 27).

Nutrients in runoff can be a significant source of eutrophication (and low DO) in lakes, and this effect is also known in streams. In standing water, nutrients are modeled as cycles; this same model applied to flowing water results in a "spiral" type model (e.g. Newbold 1992). Nutrients cycle continuously down the system (rather than only flowing like particles in a pipe). Nutrients have a direct relationship with lower DO in streams both by chemically binding with oxygen (see Nitrogen, below) and increasing decomposition.

A study of wadeable streams in Wisconsin showed a correlation between low fish IBI and increases in phosphorus load (Robertson et al., 2006). The mechanisms are difficult to untangle, but the relationship between phosphorus and a lower fish IBI may be due to eutrophication processes. Some phosphorus is natural but most comes from runoff originated in agricultural or suburban fertilizer use. Increases in landscape alterations that increase flow and heavier use of fertilizers have increased phosphorus in the St. Croix Valley and are linked to many detrimental changes. There is currently no state standard for phosphorus levels in streams. The phosphorus regime in Brown's Creek is still informative, however, and helps identify some of the processes under human control leading to low DO. The MPCA has ecoregion specific guidelines for phosphorus defined for minimally impacted streams indicated on the graphs below (Figure 28 through Figure 30; McCollor et al., 1993). The 75th percentile of data (1970 through 1992, annual) in the north central hardwood forests ecoregion (0.15 mg/l TP) was used as a guideline to evaluate phosphorus concentrations. The available data suggest that phosphorus is being loaded at relatively high rates into the stream, particularly at mid to higher flows at all sites.

Finally, invertebrate data are extremely useful for identifying oxygen impairments. Species distributions of invertebrates can show impairments because different organisms have different tolerances to low DO. Invertebrate larvae are less mobile than fish, so groups like chironomids do not migrate much and are exposed to a site's environment continuously until the adults emerge. In addition, the phenology of chironomid emergence can be used to measure when and where DO levels are low (see also temperature, below). Dr. Len Ferrington, Jr. (University of Minnesota) is in the process of completing a full analysis of the invertebrate communities and patterns of chironomid emergence.

Preliminary data show that a low number of Diptera species (including chironomids) are found at the upper two sites, a sign of low DO (Table 11). The Brillouin's Diversity Index is a factorial calculation of diversity that indexes community health such that numbers close to or below 1.5 indicate biological stress, and values from 1.5 to 2.0 indicate possible stress and the need for more investigation. The upstream sampling site (site 1 in Table 11) is below 1.5, a sign of biological stress. The two upstream sites showing high percent Diptera also cluster together on similarity analysis (multi-dimensional scaling) suggesting that the entire community structure is impacted at these sites.

The invertebrate effects confirm that the frequency and duration of low DO at the upper sites on Brown's Creek are biologically significant. Levels of DO go below not only the 7.0 mg/l standard for Class 2A waters but also often fall below the 5.0 mg/l standard for Class 2B waters. Invertebrate community analysis and the lack of cold water fish assemblage at these sites show that low levels of DO have a significant impact on the biological impairment. The only other common stressor at these sites is high temperature.

Table 11. Preliminary analysis of invertebrate communities in Brown's Creek, 2008, by Len Ferrington, Jr combined with a summary of MPCA invertebrate monitoring data from 1996 and 2006 (rows in italics). The percent EPT and Diptera values are based on abundances, while EPT and Dipteran taxa are based only on numbers of taxa present. Taxa richness for the Ferrington data is cumulative.

Site	Taxa richness	Brillouin's diversity index (nats)	EPT	% EPT	Dipteran taxa	% Diptera
Site 1 (downstream of 110th St.)	29	1.499	4	0.6	19	35.6
110th St.	*34*		*7*	*25.3*	*21*	*59.8*
Site 3 (upstream of Hwy 15)	36	2.423	7	15.2	19	35.5
Site 4 (upstream of Hwy 96)	45	2.094	9	23.5	25	17.5
Site 10 (Stone Bridge)	49	2.527	11	41.5	23	26.2
McKusick	*58*		*21*	*39.8*	*27*	*25.2*
Site 12 (WOMP)	46	1.932	7	58.4	27	30.0

Figure 11. Dissolved oxygen monitoring data by site on Brown's Creek, 2007.

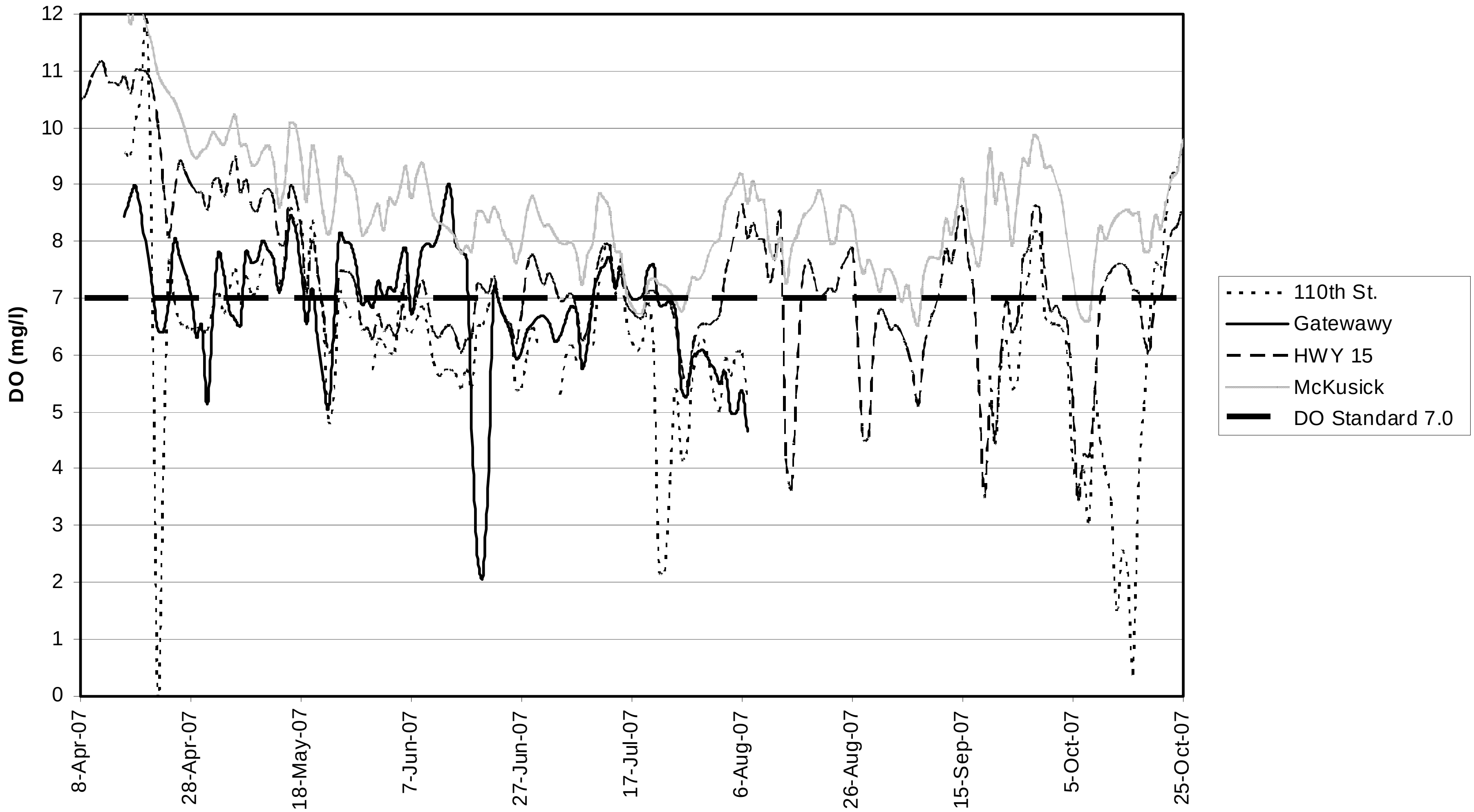


Figure 12. Frequency of 15 minute periods below DO levels of 5.0 mg/l, 110th St., Brown's Creek. Data not available from 7 August to 20 September 2007.

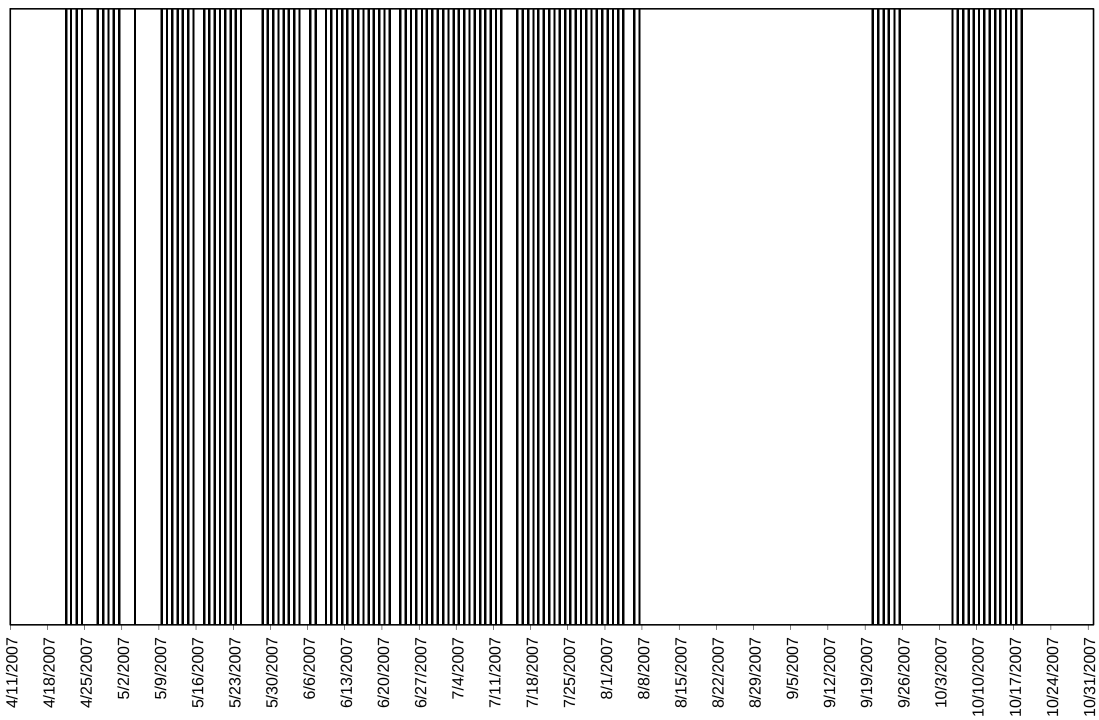


Figure 13. Frequency of 15 minute periods below DO levels of 7.0 mg/l, 110th St., Brown's Creek. Data not available from 7 August to 20 September 2007.

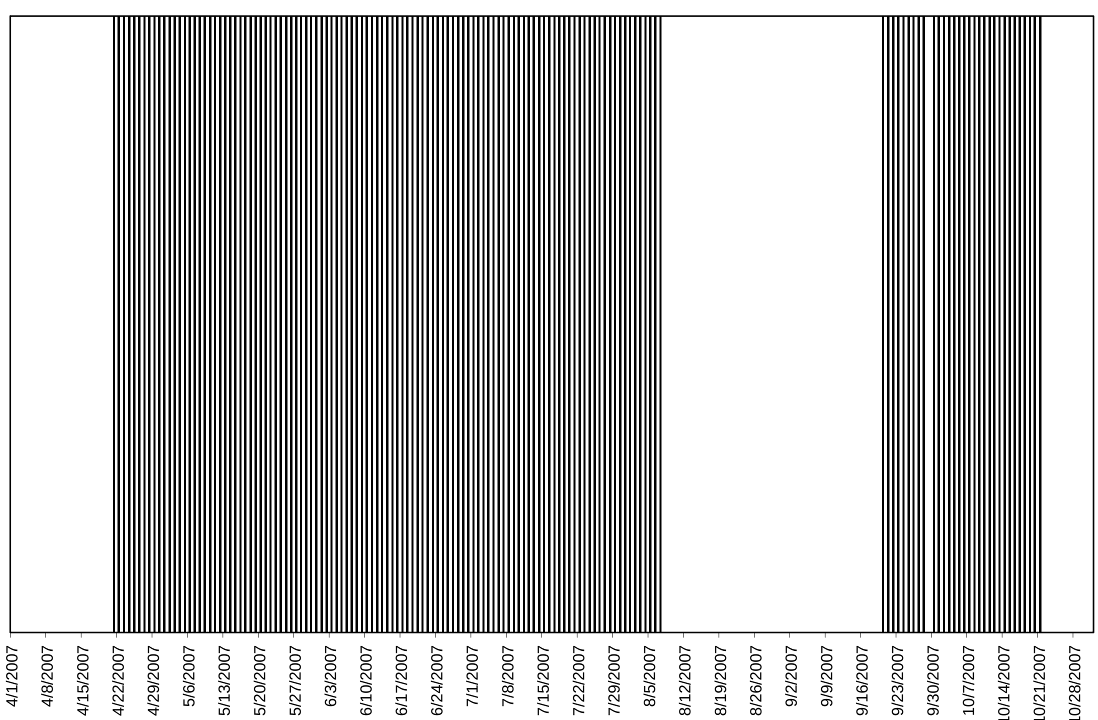


Figure 14. Frequency of 15 minute periods below DO levels of 5.0 mg/l, Gateway, Brown's Creek.

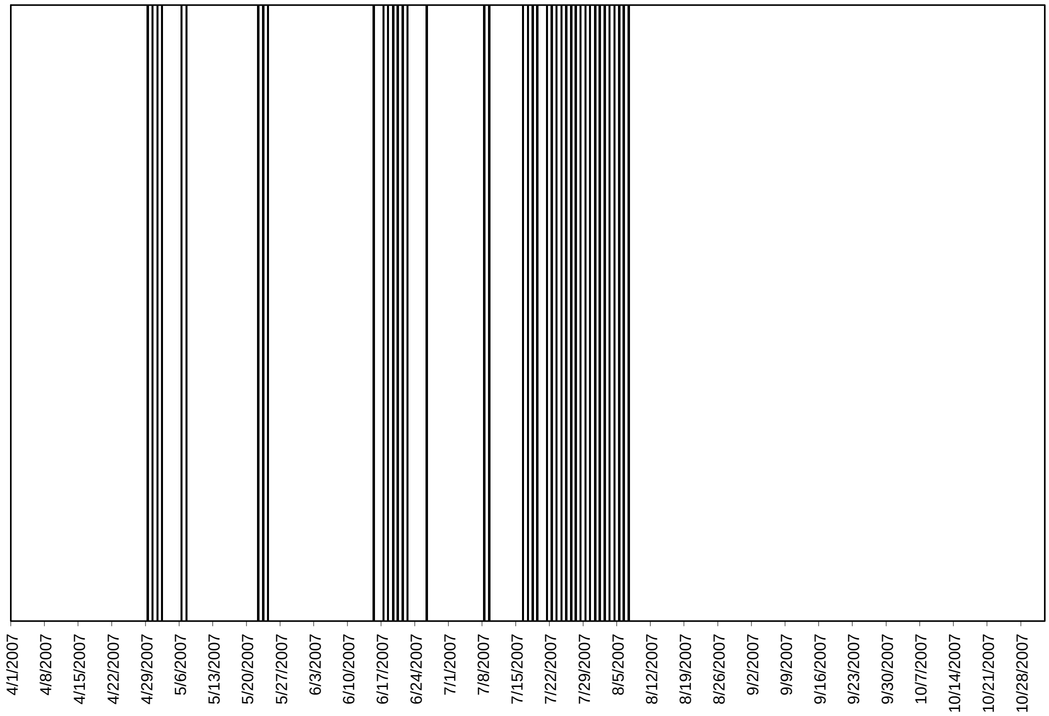


Figure 15. Frequency of 15 minute periods below DO levels of 7.0 mg/l, Gateway, Brown's Creek.

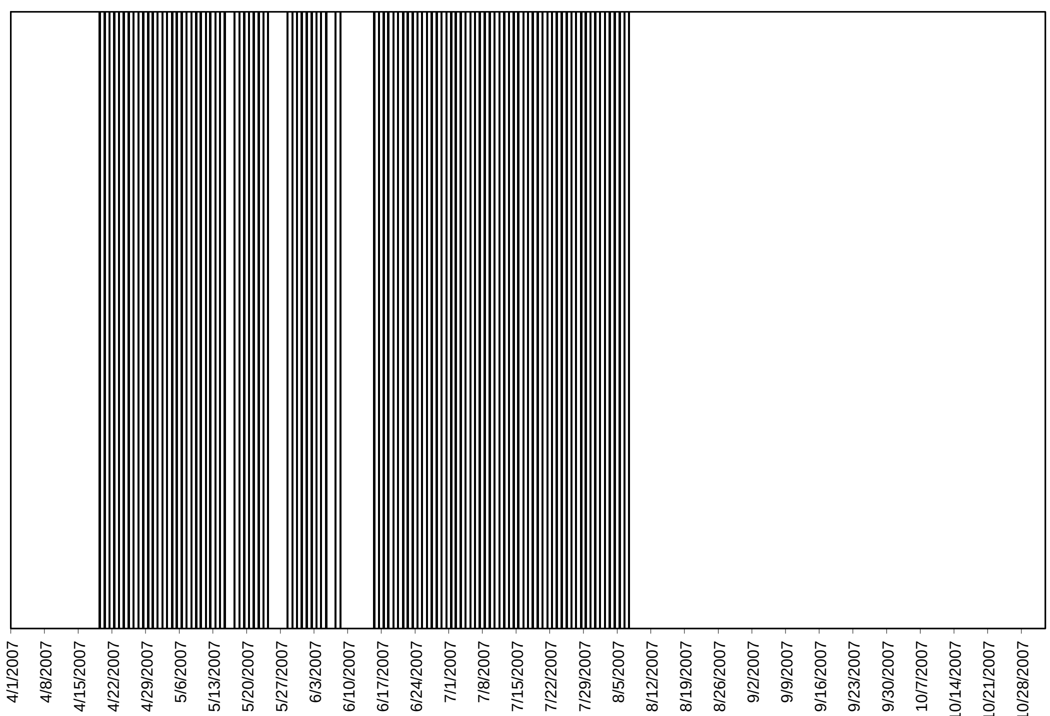


Figure 16. Frequency of 15 minute periods below DO levels of 5.0 mg/l, Highway 15, Brown's Creek.

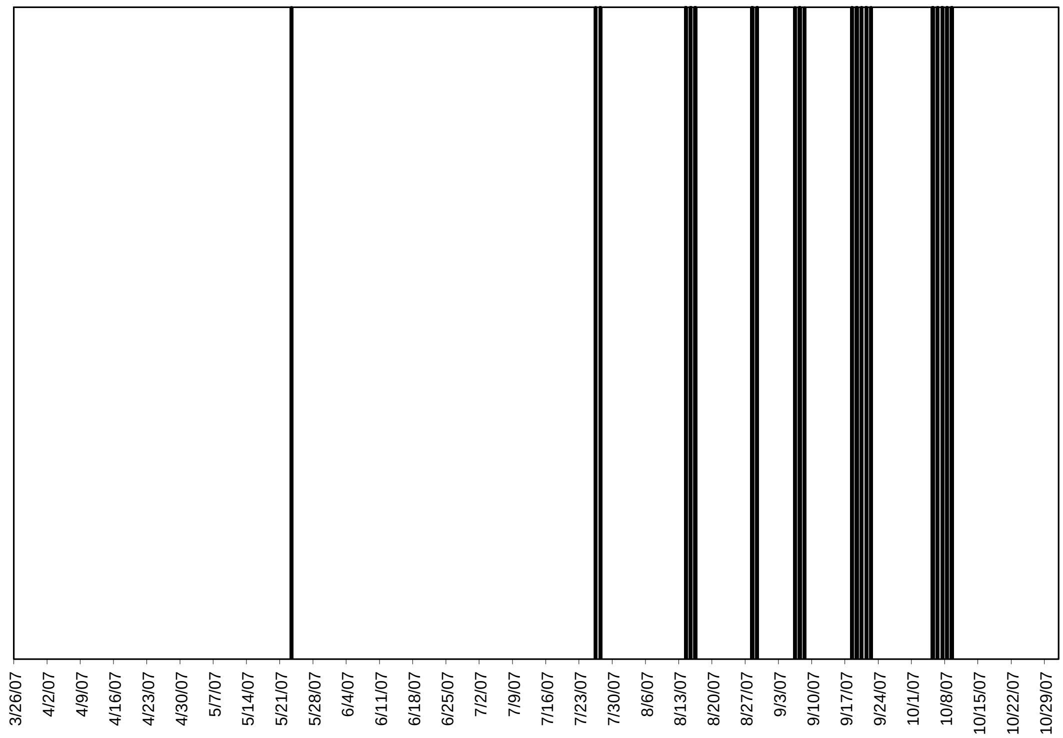


Figure 17. Frequency of 15 minute periods below DO levels of 7.0 mg/l, Highway 15, Brown's Creek.

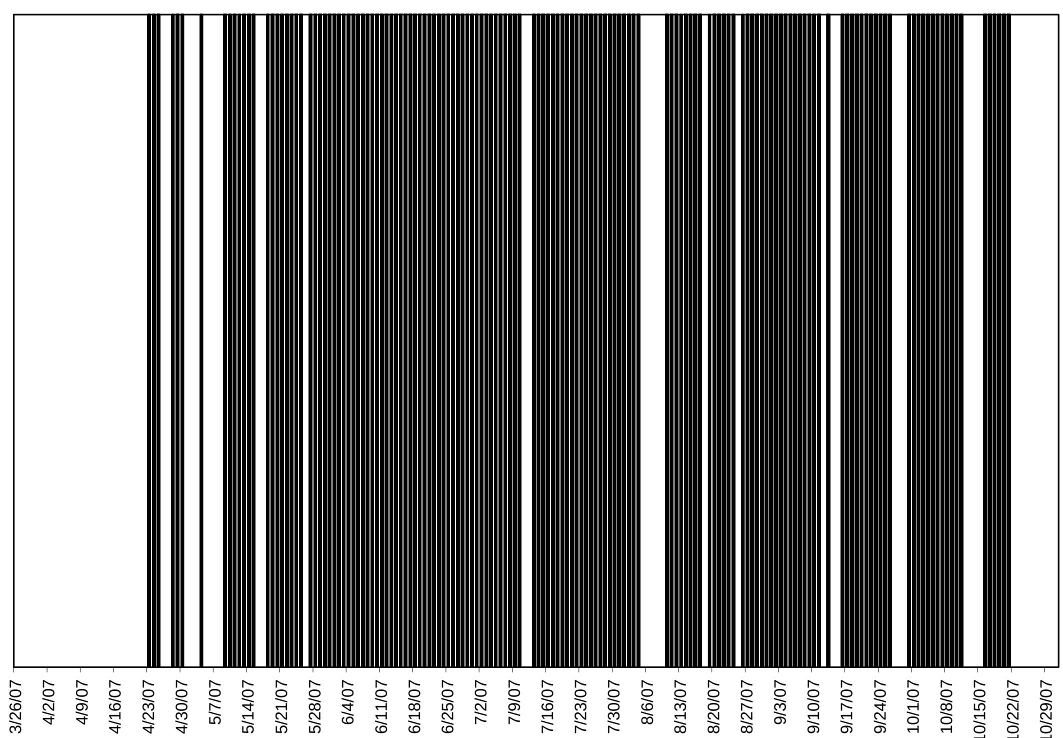


Figure 18. Frequency of 15 minute periods below DO levels of 7.0 mg/l, McKusick, Brown's Creek.

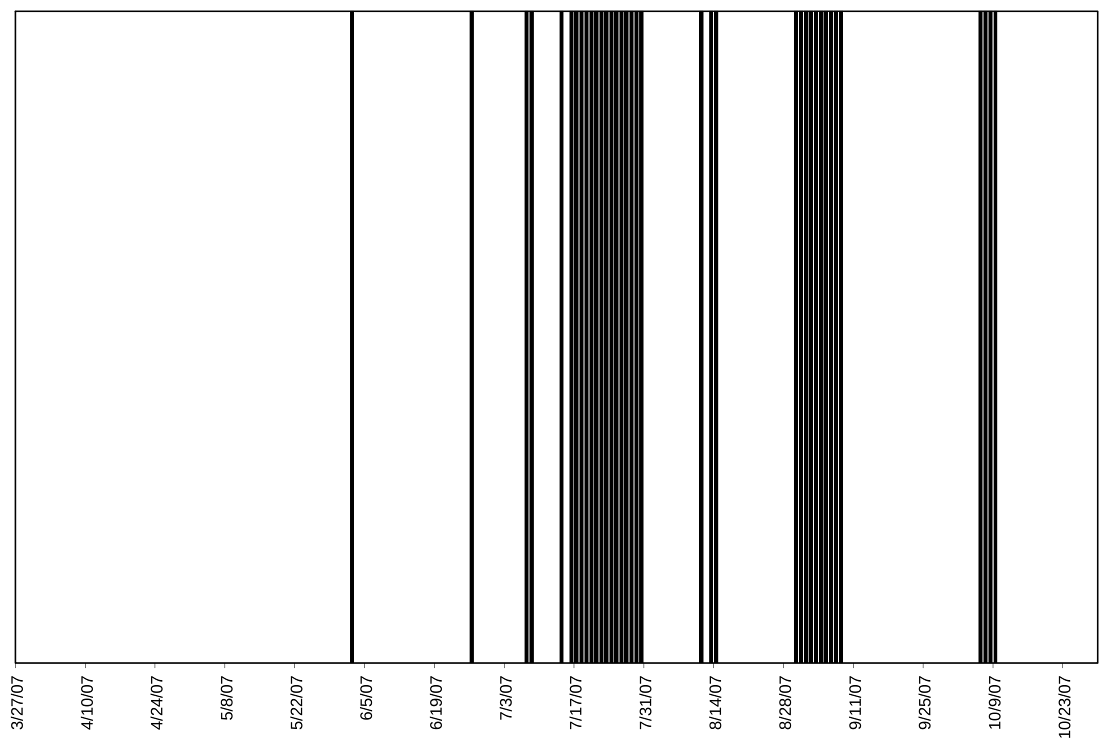


Figure 19. Consecutive hours below DO of 5.0 mg/l at 110th St., 2007 monitoring data, Brown's Creek. Data not available from 7 August to 20 September 2007.

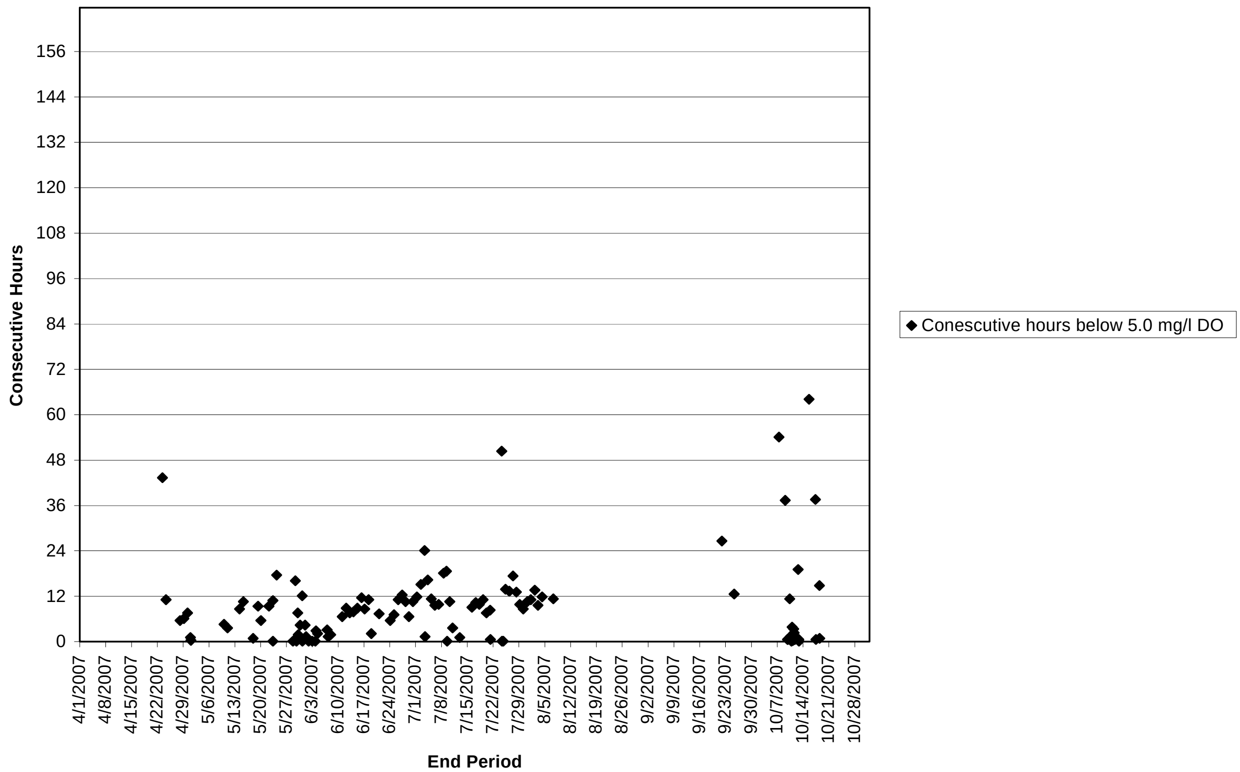


Figure 20. Consecutive hours below DO of 7.0 mg/l at 110th St., 2007 monitoring data, Brown's Creek. Data not available from 7 August to 20 September 2007.

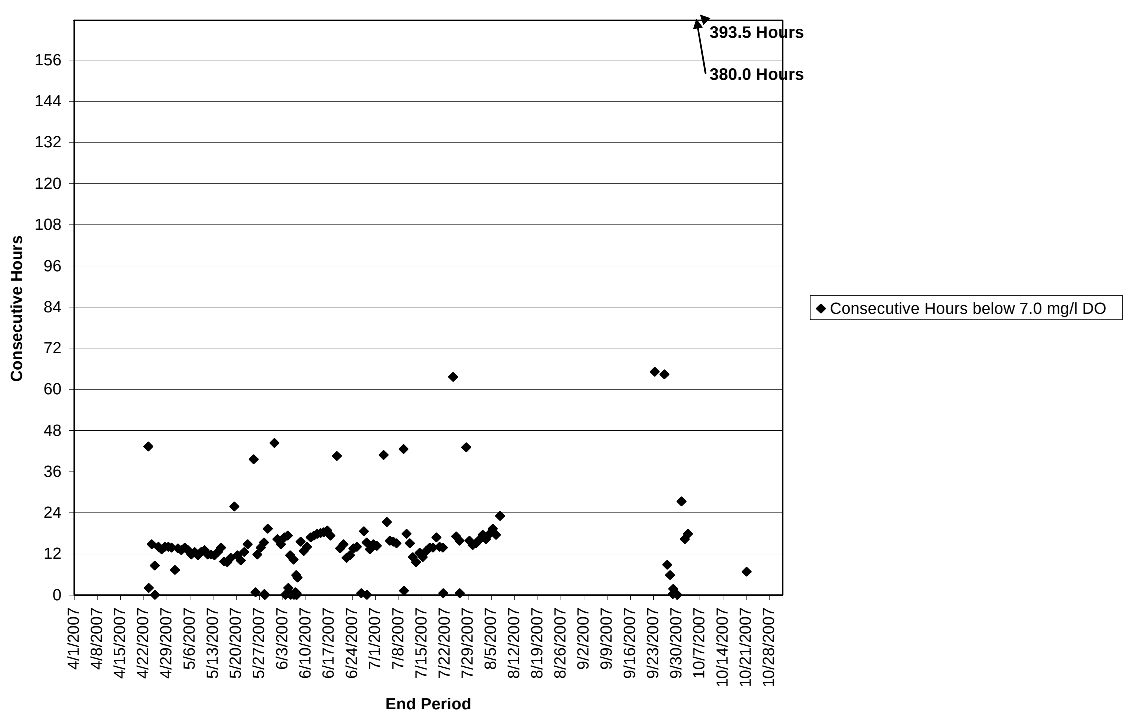


Figure 21. Consecutive hours below DO of 5.0 mg/l at Gateway, 2007 monitoring data, Brown's Creek.

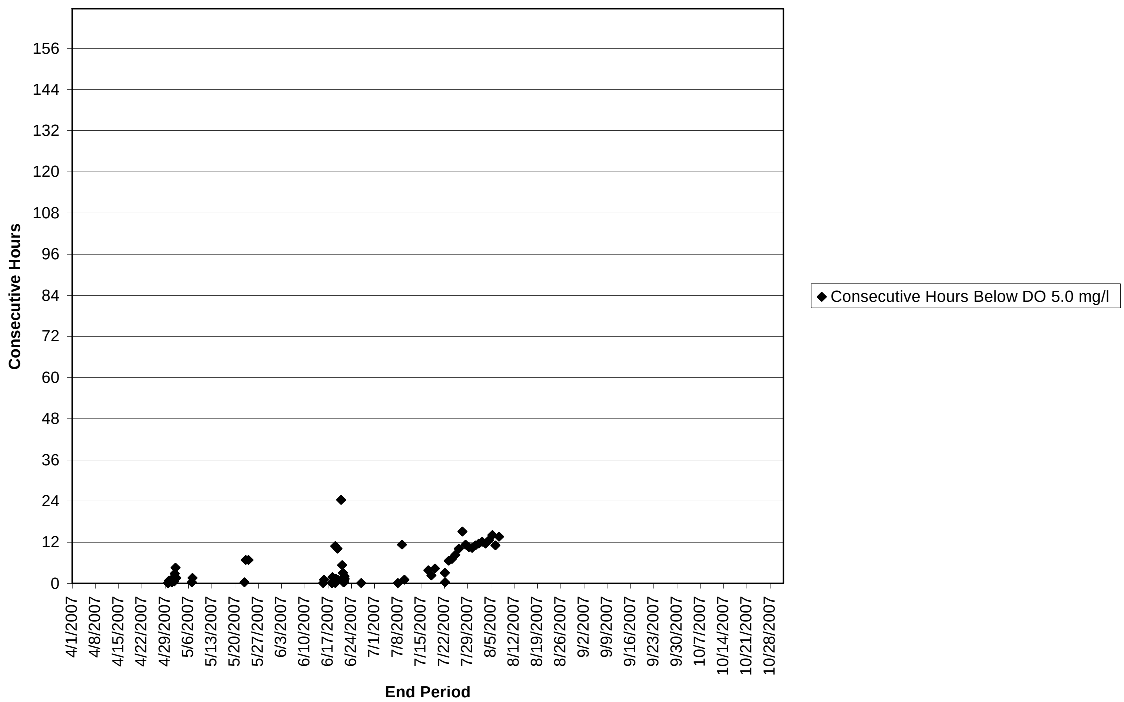


Figure 22. Consecutive hours below DO of 7.0 mg/l at Gateway, 2007 monitoring data, Brown's Creek.

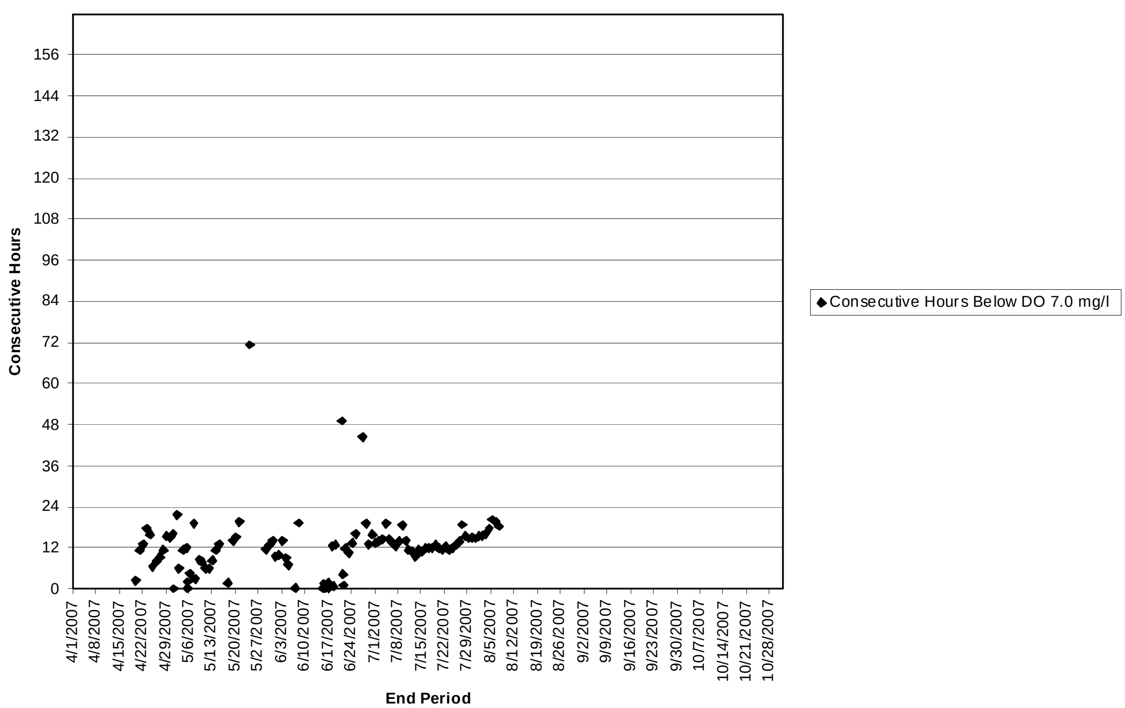


Figure 23. Consecutive hours below DO of 5.0 mg/l at Highway 15, 2007 monitoring data, Brown's Creek.

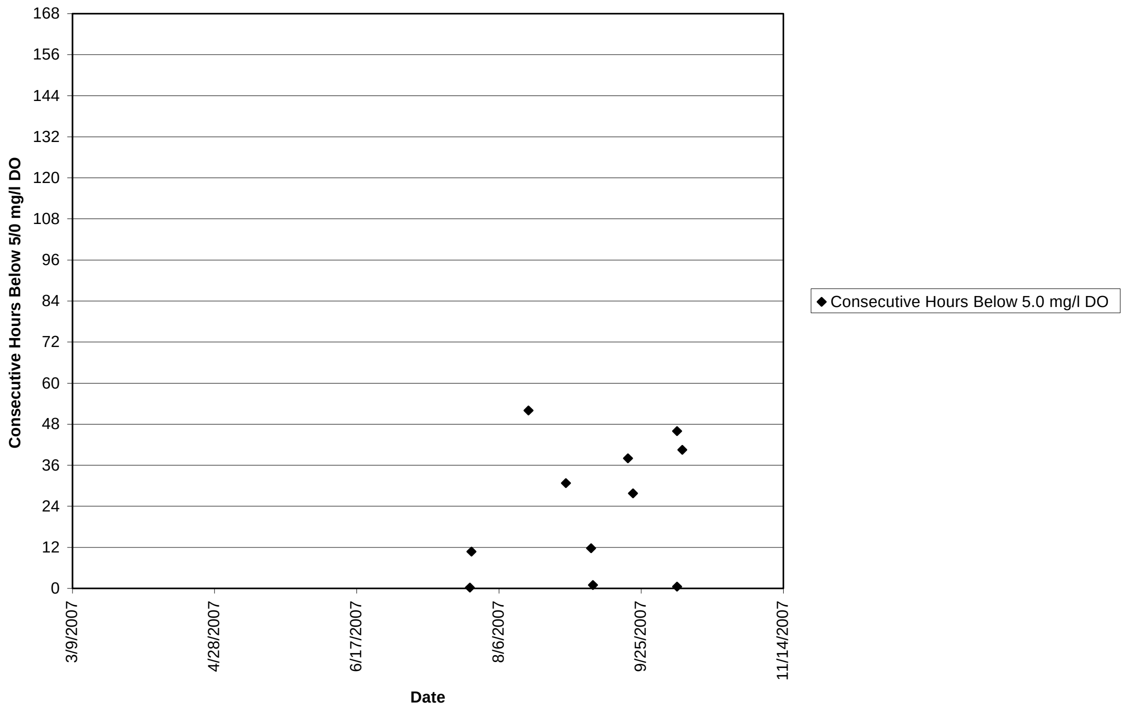


Figure 24. Consecutive hours below DO of 7.0 mg/l at Highway 15, 2007 monitoring data, Brown's Creek.

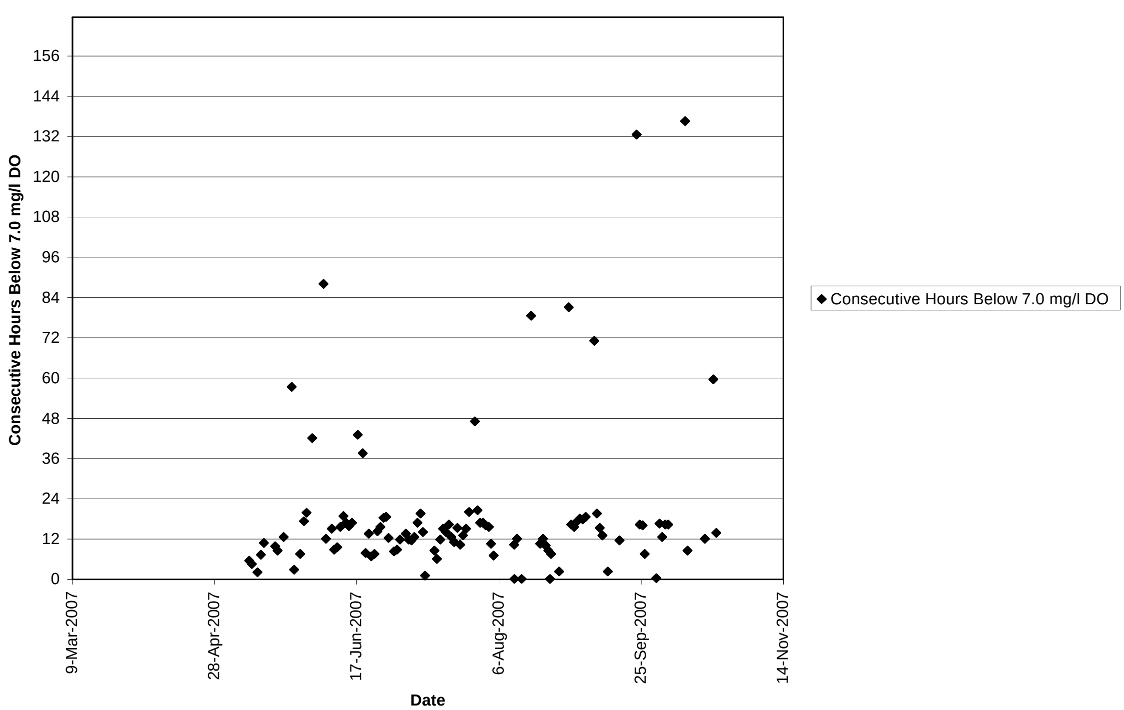


Figure 25. Consecutive hours below DO of 7.0 mg/l at McKusick, 2007 monitoring data, Brown's Creek

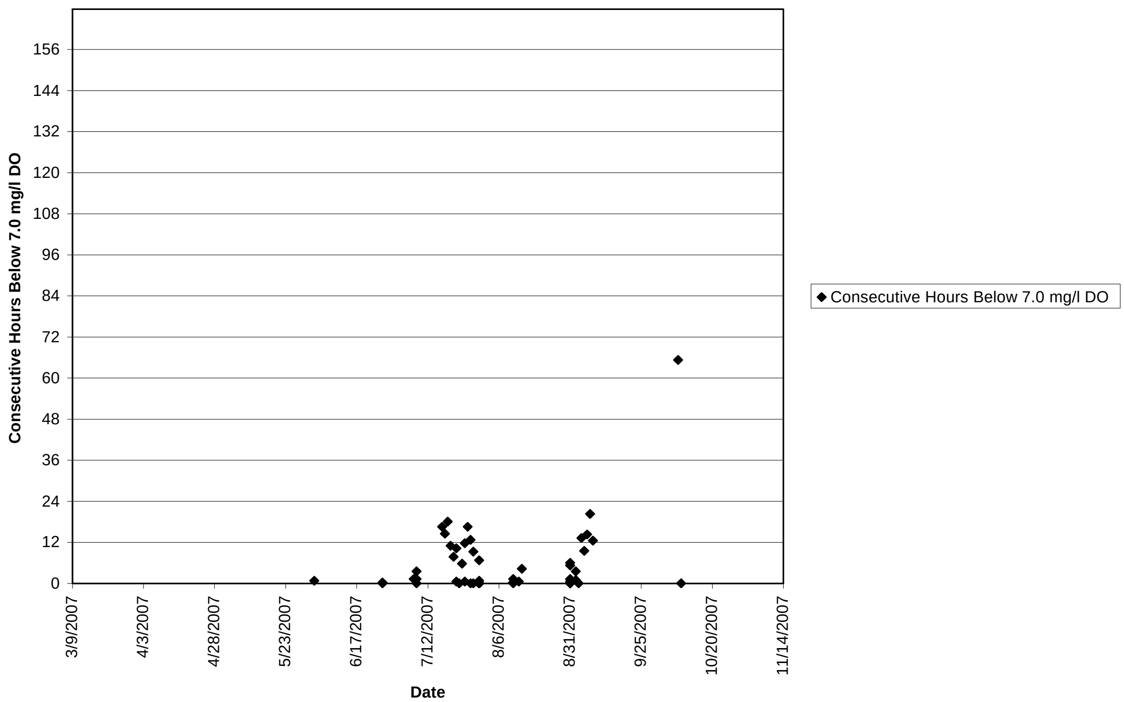


Figure 26. Flow duration interval for DO, 2007 monitoring data for Brown's Creek at 110th St. Points BELOW the line indicate violations of the standard.

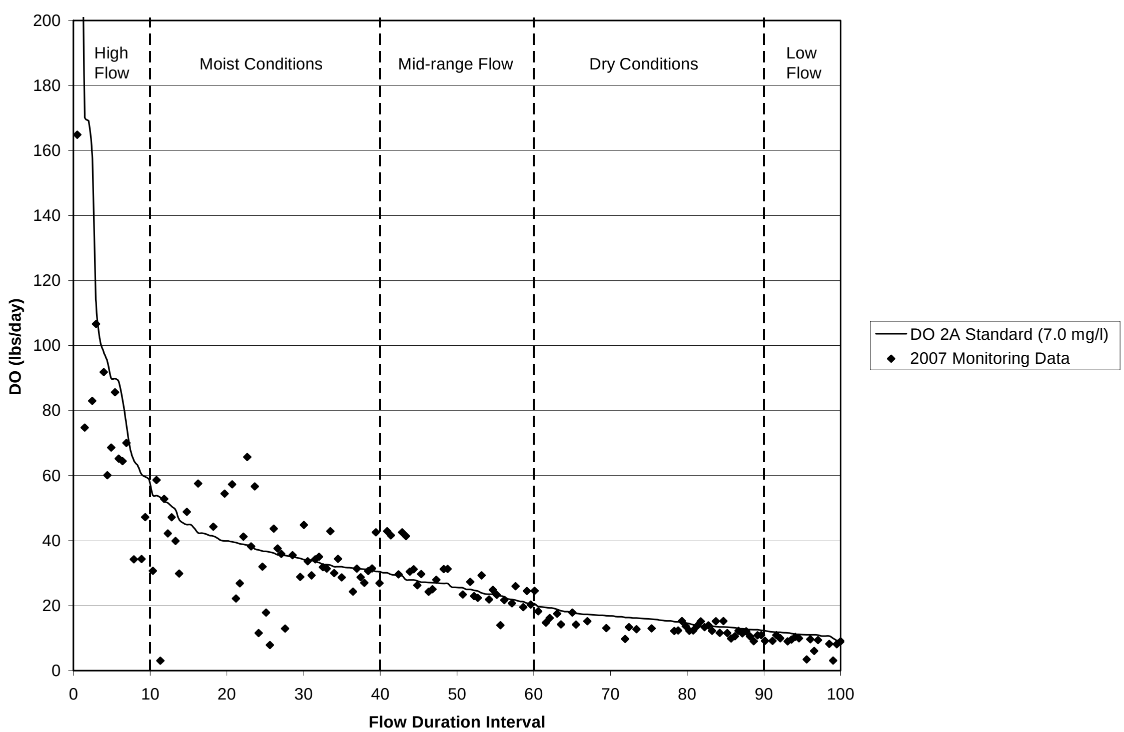


Figure 27. Flow duration interval for DO, 2007 monitoring data for Brown's Creek at Highway 15. Points BELOW the line indicate violations of the standard.

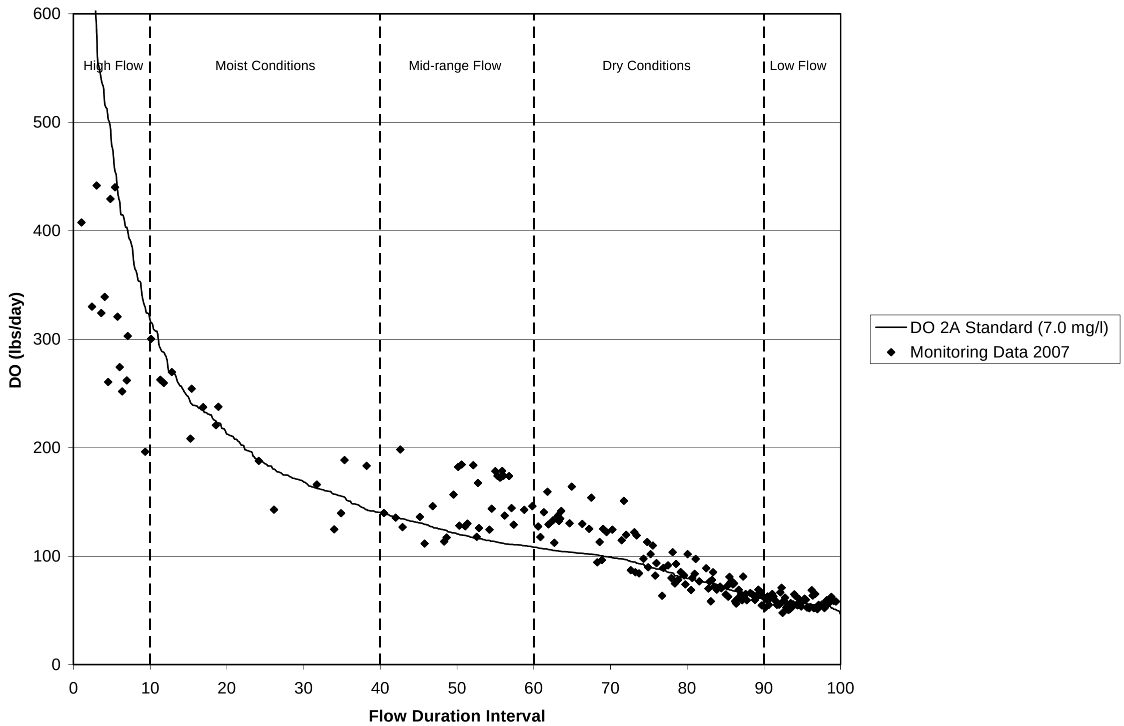


Figure 28. 110th St. total phosphorus load duration curve, 2007 monitoring data. The total phosphorus guideline is the lbs/day equivalent of 0.15 mg/l.

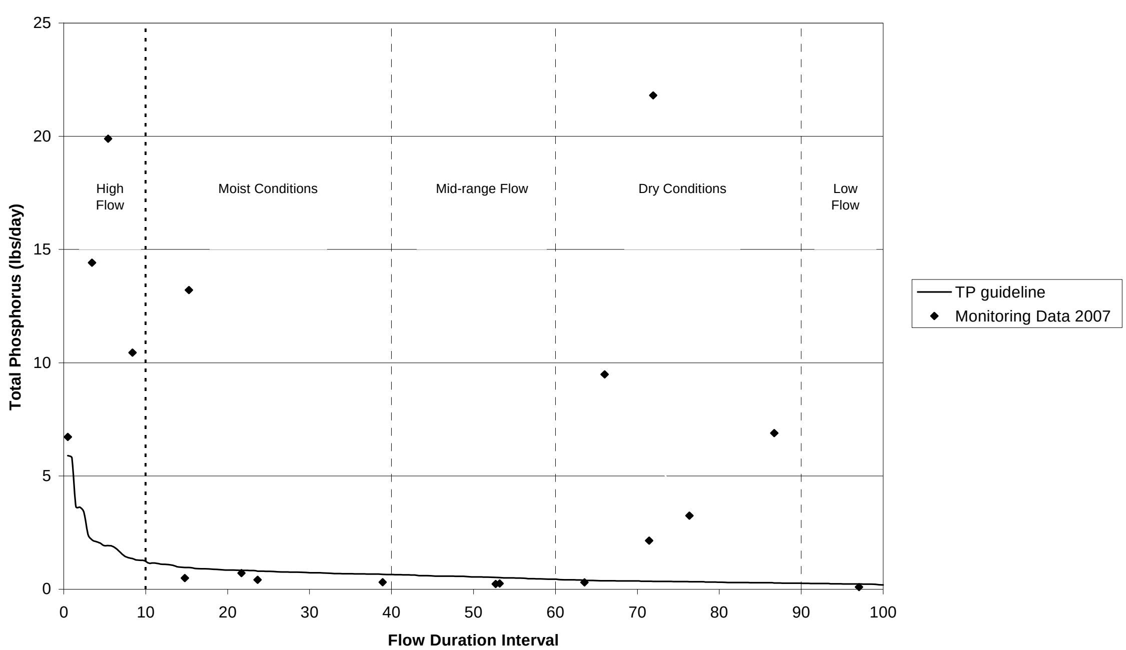


Figure 29. Highway 15 total phosphorus load duration curve, 2007 monitoring data. The total phosphorus guideline is the lbs/day equivalent of 0.15 mg/l.

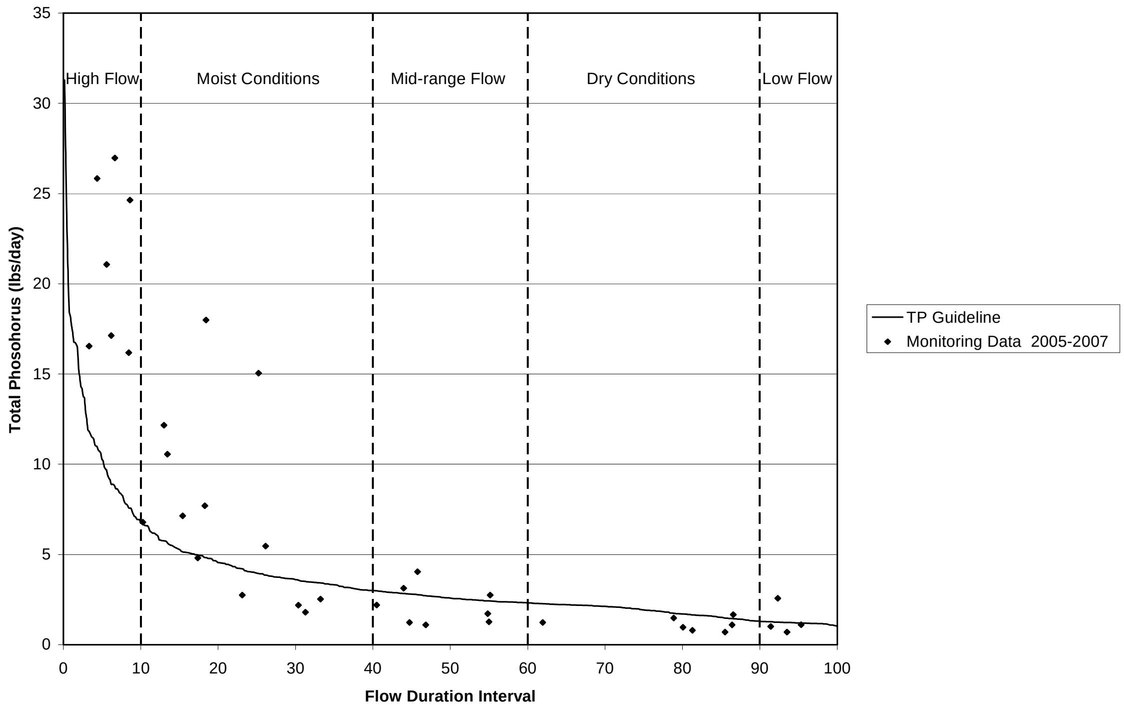
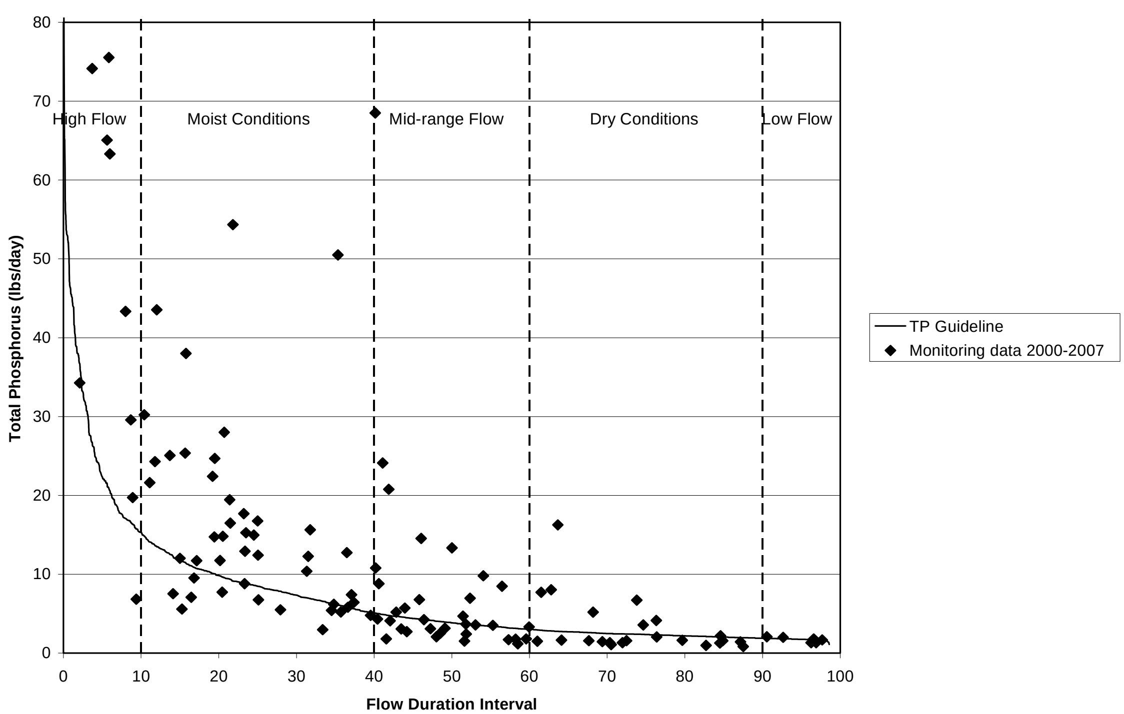


Figure 30. McKusick total phosphorus load duration curve, 2007 monitoring data. The total phosphorus guideline is the lbs/day equivalent of 0.15 mg/l.



Models of sources and causal pathways for dissolved oxygen in Brown's Creek

The sources and pathways leading to low DO are well understood, and models have been developed specifically by the MPCA for low DO TMDLs (Dissolved Oxygen TMDL Protocol and Submittal Requirements (MPCA) 2008). The model shown below has been simplified to reflect conditions most relevant to Brown's Creek (Figure 31).

The CADDIS sufficiency of evidence format was used to evaluate the different sources of low DO in Brown's Creek (Table 12). Chemical and biological data integrated with landscape use patterns pick out several likely sources and eliminate others.

Surface runoff carrying nutrients from the landscape is a possible cause of low DO. At all sites, nutrients increase in high-flow periods (particularly phosphorus, but see nitrogen analyses below). Land use in the sub-watershed of the 110th St. site is both suburban and agricultural. There is no relationship between flow and DO, however, which indicates in-stream processes are just as important as surface runoff. The nutrients brought in by surface runoff can increase respiration and decomposition, causing low DO at low flows, and effects of temperature increase due to vegetation removal can result in lower DO at low flows.

Release from impoundments is another possible source of low DO. Impoundments for agriculture, construction, or irrigation collect nutrients from surface runoff. These areas tend to be heavily fertilized, so the impoundments collect high concentrations of nitrogen and phosphorus that can be released into the watershed during storm events. Impoundments are generally warmer and can increase stream temperatures when they runoff, and increased temperatures physically reduce the concentration of DO. Nutrient inputs chemically and biologically decrease DO. Low flow - low DO events at the mid and downstream sites indicate possible problems with leaching from septic tanks and agricultural impoundments. Levels of DO were not dramatically lower below the few obvious impoundments for agriculture or recreation, however.

There are several natural processes that contribute to lower DO in Brown's Creek, primarily decomposition of wetland material and groundwater inputs. The wetlands in the Gateway Trail area are a likely contributor of low DO to the stream. There is no 'pulse' of low DO after the wetland, and wetlands can absorb nutrients like phosphorus (and Gateway is only sub-watershed with a negative phosphorus budget according to calculations by WCD staff). However, the high rates of decomposition characteristic of wetlands are very likely contributing to low DO in that area. Carbonaceous oxygen demand (CBOD) is higher in the wetland areas but data are not complete enough to evaluate. Organic input in the wetlands area from decaying plant material is likely a net oxygen consumer and contributing to low DO in this area.

The entire reach has also been observed to have a strong groundwater influence, which impacts DO levels. Although groundwater is colder than surface water in summer, groundwater contains less DO. Groundwater inputs actually increase from upstream to downstream in Brown's Creek (Scott Alexander, personal communication). Higher gradient riffle areas (e.g., McKusick) increase DO, mediating the effects of the increasing groundwater contribution at the downstream sites. Low DO concentrations in Brown's Creek are likely the result of a combination of factors, some stronger at some sites than others. Of particular importance are groundwater contributions with low DO at areas that are slow moving, low gradients. These conditions typify the upper and mid reaches of Brown's Creek (110th Street to Gateway and to some extent Diversion), showing a natural mechanism of low DO at these upstream sites.

There is no drastic channel modification of the sort that would have impacted the DO readings from 2007 (i.e., cement channels). Historic channelization through the wetland areas is unlikely to be impacting dissolved oxygen because the original habitat was unlikely to have contained riffles. However, heavy sedimentation rates show that loss of riffle structure is a potential component of lower DO at some downstream sites. Restoration efforts mid-stream by the DNR in 2002 added some riffle areas. It would be useful to study this feature in the future, particularly because of the very high levels of suspended solids coming into Brown's Creek from the watershed and recent development of the area. At this point the loss of structure is an unlikely cause of low DO.

Figure 31. Model of sources and causal pathways for low dissolved oxygen in Brown's Creek.

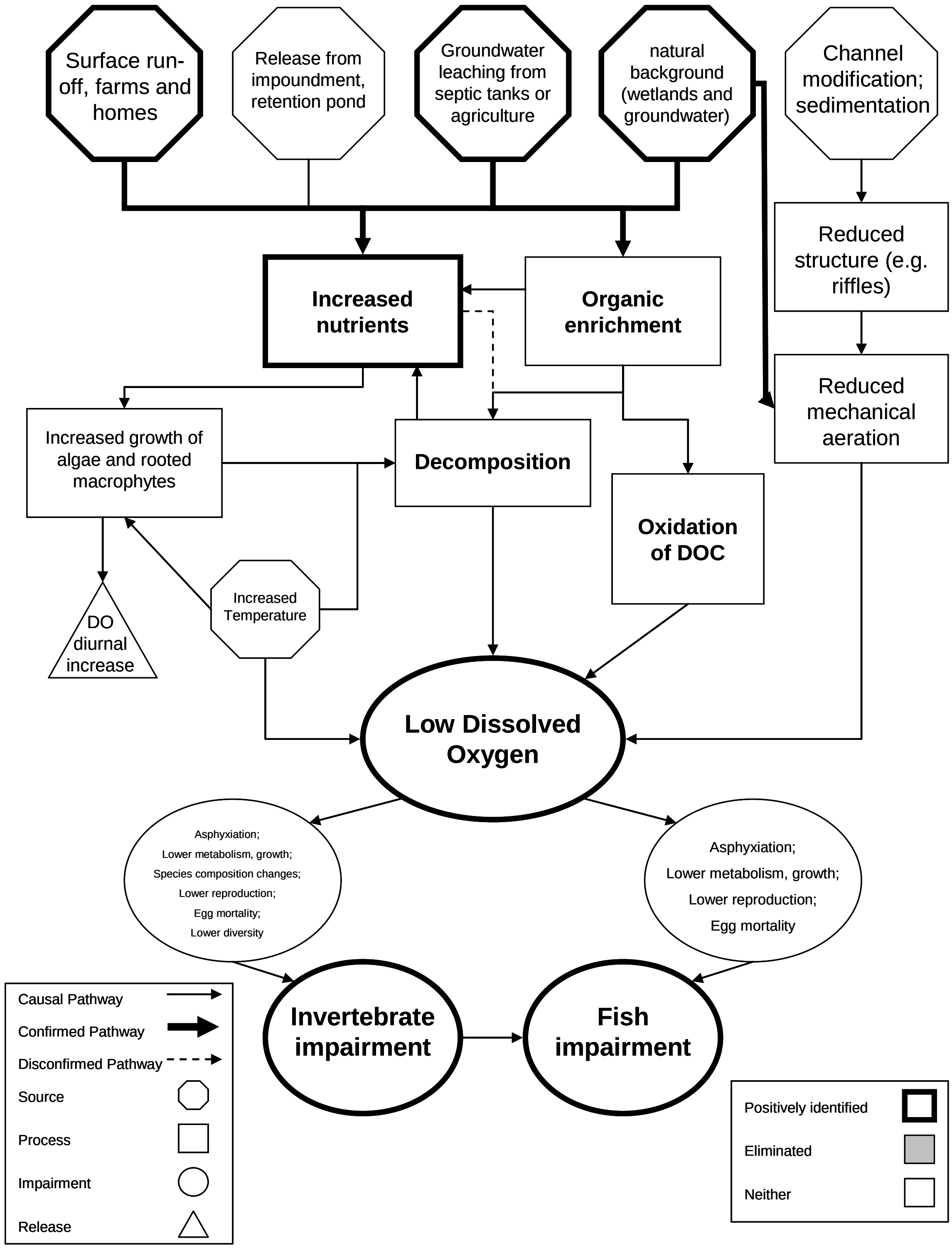


Table 12. Sufficiency of evidence table for sources of low dissolved oxygen in Brown's Creek.

Types of Evidence, Dissolved Oxygen	Surface runoff, farms and homes	Release from impoundments, retention ponds	Natural background (wetlands)	Groundwater leaching (septic tanks)	Groundwater leaching (agriculture)	Channel modification (reduced structure)
Evidence using data from Brown's Creek						
Spatial / temporal co-occurrence	+	0	+	+	+	0
Evidence of exposure, biological mechanism	+	+	+	+	+	+
Causal pathway	+	0	+	+	+	NA
Field evidence of stressor-response	+	0	++	0	NA	NA
Field experiments / manipulation of exposure	NA	NA	NA	NA	NA	NA
Laboratory analysis of site media	NA	NA	NA	NA	NA	NA
Temporal sequence	0	NA	+	+	+	NA
Verified or tested predictions	NA	NA	NA	NA	NA	NA
symptoms	+	0	+	+	0	0
Evidence using data from other systems						
Mechanistically plausible cause	+	+	+	+	+	+
Stressor-response in other field studies	++	++	++	++	++	++
Stressor-response in other lab studies	++	++	++	++	++	++
Stressor-response in ecological models	+	+	+	+	+	+
Manipulation experiments at other sites	NA	NA	NA	NA	NA	NA
Analogous stressors	NA	NA	NA	NA	NA	NA
Multiple lines of evidence						
Consistency of evidence	+	0	+++	+	+	-
Explanatory power of evidence	++	0	++	++	0	-

Conclusion: low dissolved oxygen as a biological stressor in Brown's Creek

Physical and biological data show that low DO is a key stressor leading to biological impairment in Brown's Creek. Dissolved oxygen (DO) levels in Brown's Creek fall below water quality standards for supporting cold water biota characteristic of Class 2A streams. At upper sites DO levels fall below the standard for warm water biotic assemblages (5.0 mg/l). These low levels occur at biologically significant frequencies and durations. Patterns of low DO indicate multiple sources of this impairment, both natural and anthropogenic. Most sites with continuous data show that frequencies and durations of low DO are a serious concern to fish and invertebrate growth, reproduction, and mortality. In particular, the upper three sites (110^{th} St., Gateway, Highway 15) regularly reach DO levels below standards for Class 2B streams. Invertebrate species data support this conclusion, with low numbers of Diptera and low EPT at these sites. Patterns of low DO indicate that multiple sources (natural and anthropogenic) interact to suppress DO below Class 2A standards. Load duration curves indicate that DO 7Q10 standards are violated (with more than half the points below the standard line at flow duration intervals of 99-100%).

Temperature

Temperature standard

The state standard for thermal pollution in Class 2A streams is “no material increase” (7050.0222 Specific Water Quality Standards for Class 2 Waters of the State; Aquatic Life and Recreation). The guidelines used here reflect best professional judgement regarding harmful temperatures to biota. Brown trout threat temperature (18.3°C or 65°F) is the point of physiological stress, reduced growth, and egg mortality. This value is based on a simplified average of values reported in studies showing a low to moderate impact on brown and brook trout (in particular, Wherly et al., 2007). Critical temperature (23.9°C or 75°F) reflects the point at which significant direct mortality can be expected, a value based on literature and expert advice (Wherly et al., 2007; Jason Moeckel, personal communication). Recent work in Minnesota and Wisconsin assesses temperature criteria for trout and arrives at similar numbers to these traditional guidelines (Wehrly et al., 2007). Native brook trout have recently been shown to have the same thermal tolerances as the stocked brown trout (*ibid.*).

Effects of high temperature on cold water assemblages in streams

Temperature is a major factor in determining invertebrate and fish species composition in streams. Increases in temperature due to altered watersheds can lead directly to extirpation of cold water assemblages. Changes in sub-watersheds directly impact the stream areas connected to them, so temperature disturbances often result in patchy distributions of fish and invertebrates (Steffy et al., 2006). Development of the watershed has a direct relationship with stream temperature that impacts both invertebrates and fish (e.g. Wang et al., 2003a and 2003b, respectively). The primary mechanisms are removal of riparian vegetation and increases in impervious surfaces. Increased runoff leads to larger surface water contributions to streams that can overwhelm the ambient groundwater input of cooler water.

Warmer water impacts organisms indirectly due to the relationship with lower DO and directly through changes in growth and reproduction, egg mortality, disease rates, and direct mortality. Macroinvertebrate species have well known tolerances to thermal changes, and community composition of invertebrates is very useful in tracking the effects of increasing temperature. Fish assemblages likewise change with temperature, and cold water adapted species either leave, are unable to reproduce, or die in warmer regimes.

Data evaluation of temperature in Brown’s Creek

Monitoring data (15-minute interval automated sampling) or mean daily temperature plotted over time show that all sites on Brown’s Creek exceed brown trout threat temperatures at some point. The frequency and duration of these temperatures are far greater in the upper sites. Figures 32 through 36 show 2007 temperature daily means or full 15-minute data (the latter in order to show diurnal variation in cases where the such a plot is legible). All but the most downstream site (WOMP) show values of concern for trout.

Figure 37 through Figure 46 show the frequency and duration of temperatures above brown trout threat temperatures along Brown's Creek. Upstream and mid-stream sites show longer and more frequent temperatures above threat level. The higher temperatures at McKusick, a site with high gradient and consisting of riffles and pools characteristic of trout habitat, are alarming and indicate a significant impact of surface runoff in trout habitat. The wide, shallow wetland areas of Brown's Creek near the Gateway site should be the warmest due to shallow, slow moving water exposed to direct sunlight. This area, however, has the fewest episodes of high temperatures. The contrast between Gateway and McKusick is a strong indication that surface runoff from increased impervious surfaces is a major factor in the high temperatures in Brown's Creek.

Preliminary data on invertebrate communities show cold water adapted chironomids are found only at the downstream sites near WOMP (Dr. Len Ferrington, report to the BCWD TAC), particularly *Diamesa*, *Odontomesa,* and *Prodiamesa*. In most trout streams, these chironomids would also be common upstream and these organisms would be expected in Class 2A waters in this area.

The most recent fish survey of Brown's Creek (2008) shows a similar pattern to invertebrates. Warm water tolerant fishes (minnows and chub) are dominant at upstream sites, giving way to cold water fish (brown trout) at the downstream sites (Table 13, Figure 47). The truly coldwater reaches also have fewer species and individuals of warm water tolerant species. The transition from warm water tolerant fish species to cold water species is striking.

Figure 32. Mean daily temperature (°C) in Brown's Creek, 110th St., 2007 monitoring data.

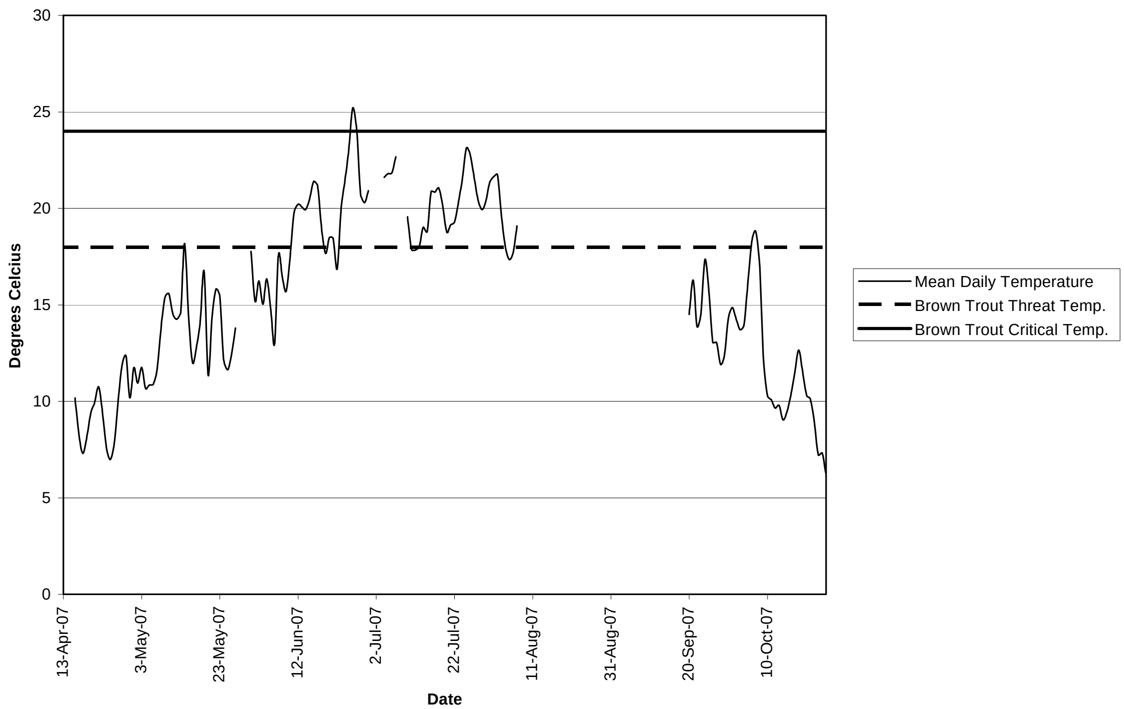


Figure 33. Temperature (°C) in Brown's Creek, Gateway, 2007 monitoring data.

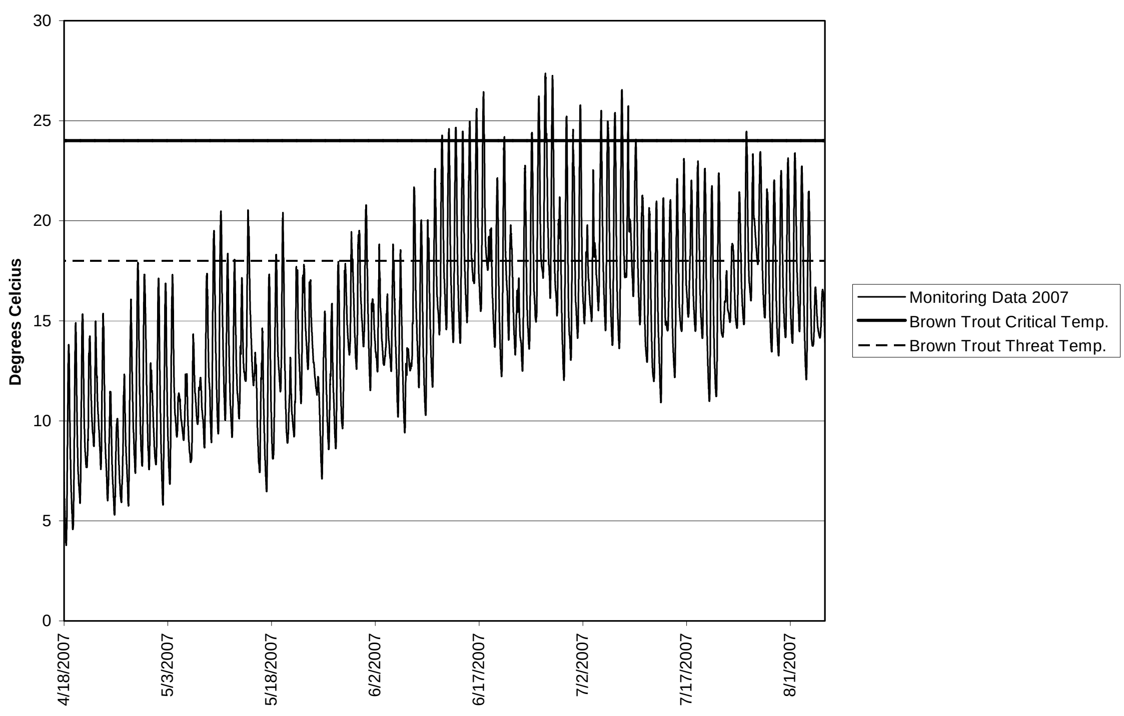


Figure 34. Temperature (°C) in Brown's Creek, Highway 15, 2007 monitoring data.

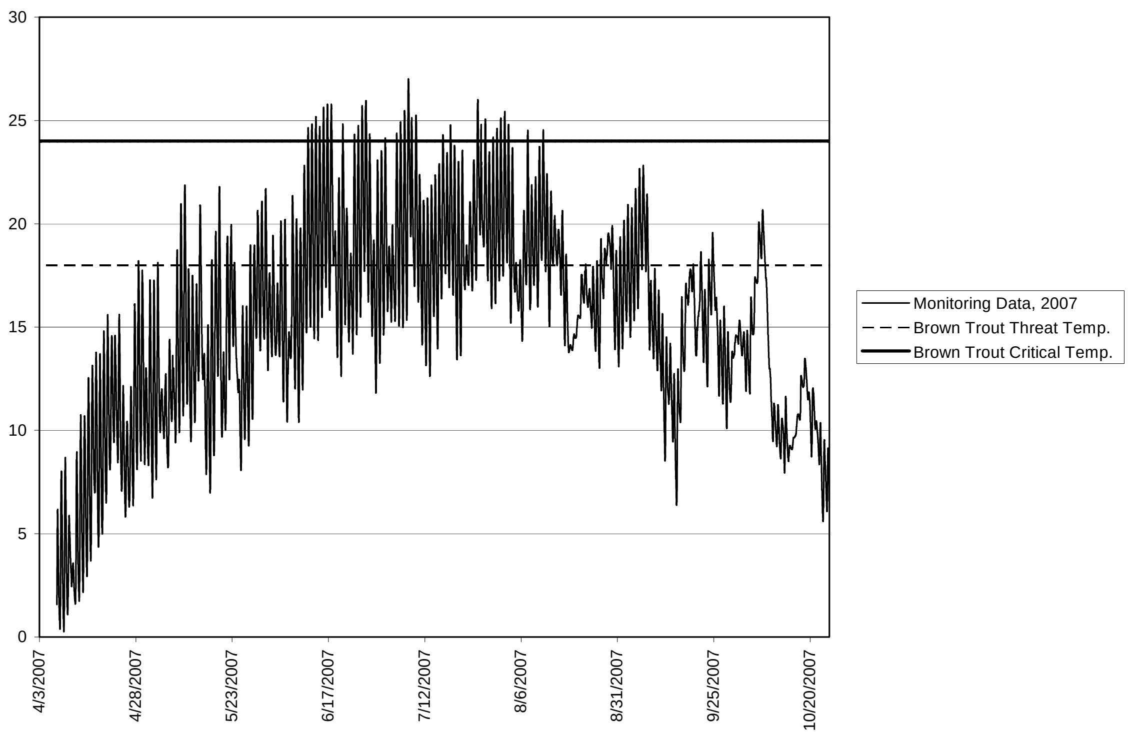


Figure 35. Temperature (°C) in Brown's Creek, McKusick, 2007 monitoring data.

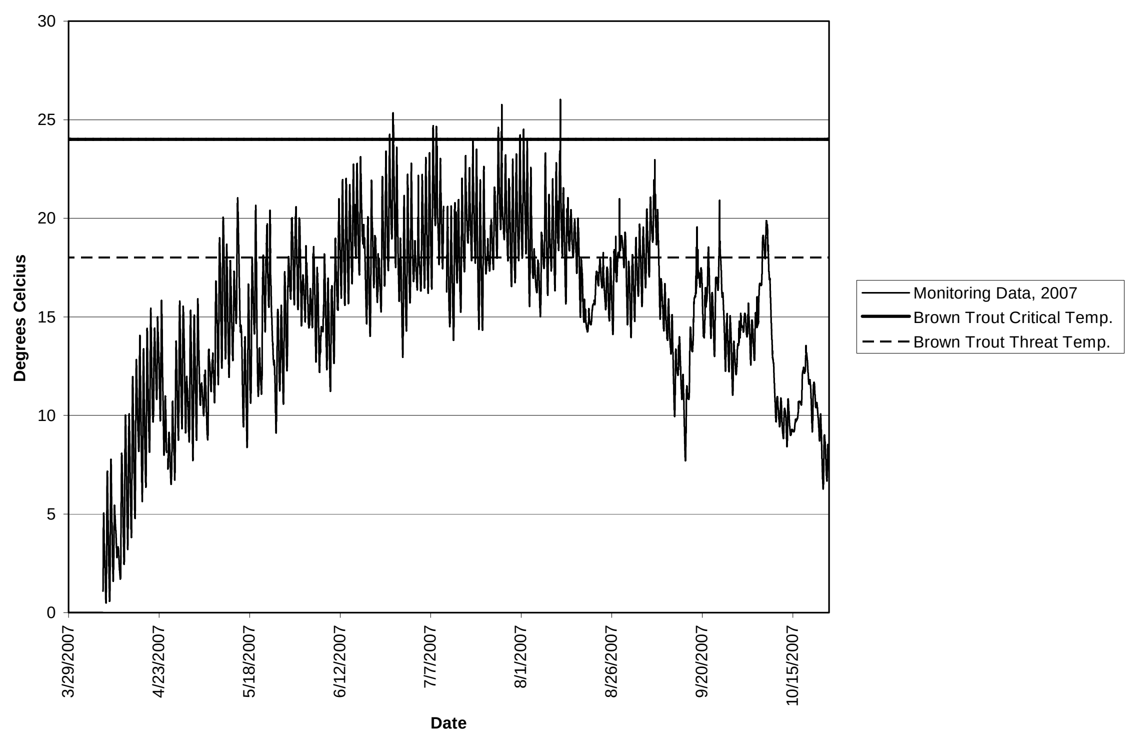


Figure 36. Mean daily temperature (°C) in Brown's Creek, WOMP, 2007 monitoring data.

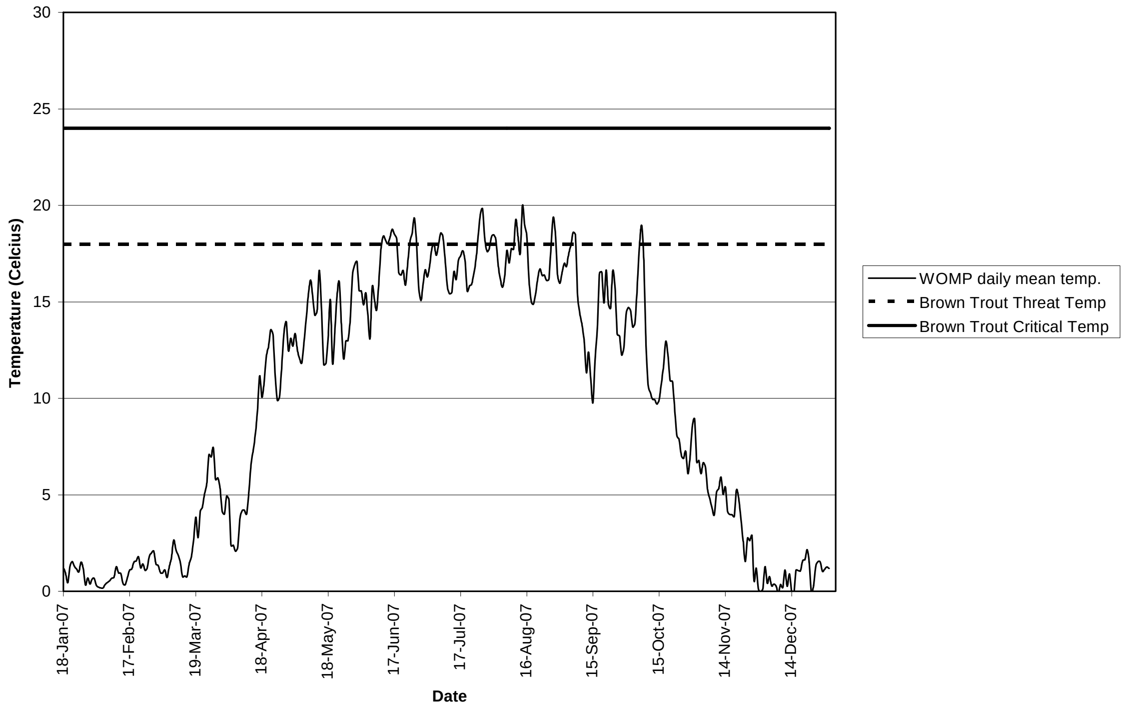


Figure 37. Frequency of 15 minute periods above brown trout threat temperature (65° F, 18° C) at 110th St., Brown's Creek 2007.

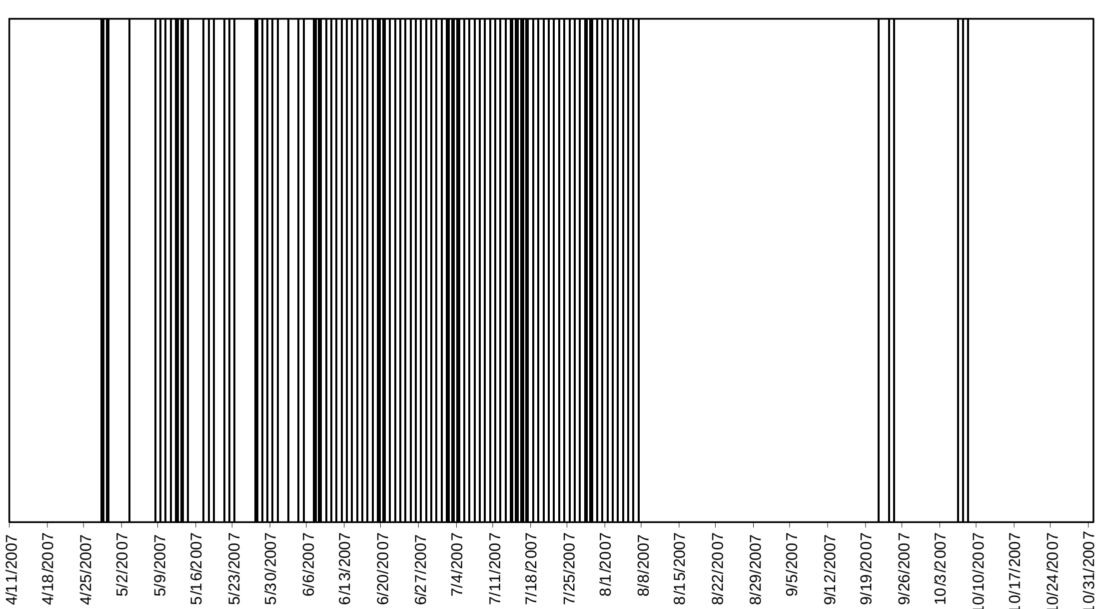


Figure 38. Frequency of 15 minute periods above brown trout threat temperature (65° F, 18° C) at Gateway, Brown's Creek, 2007.

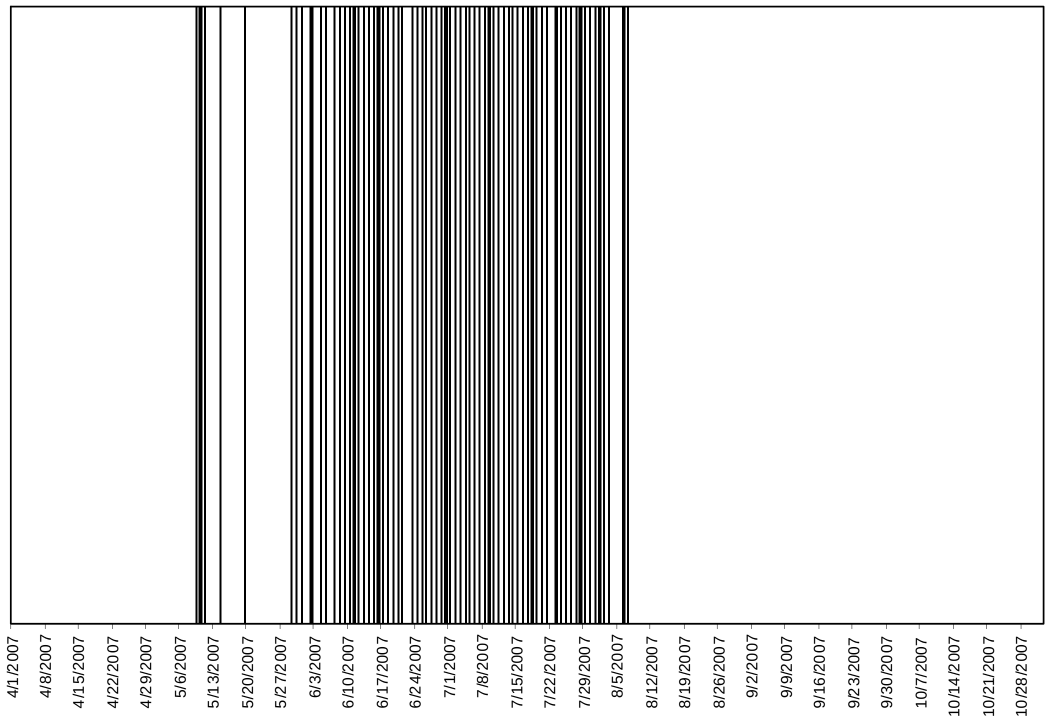


Figure 39. Frequency of 15 minute periods above brown trout threat temperature (65° F, 18° C) at Highway 15, Brown's Creek, 2007.

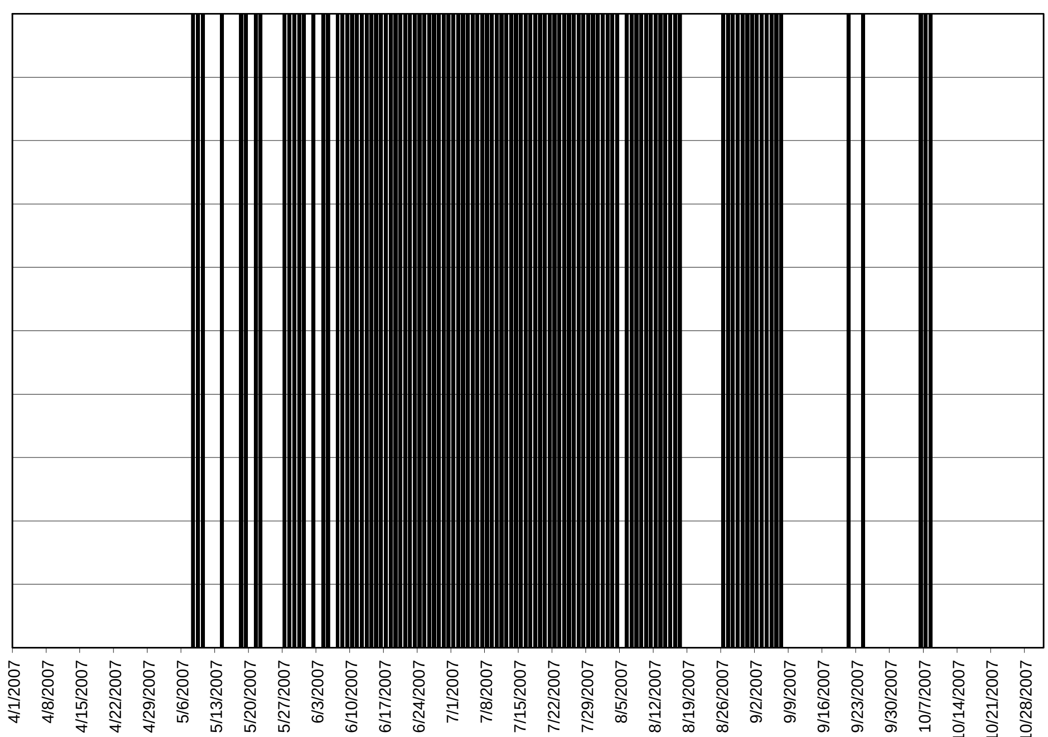


Figure 40. Frequency of 15 minute periods above brown trout threat temperature (65° F, 18° C) at McKusick, Brown's Creek, 2007.

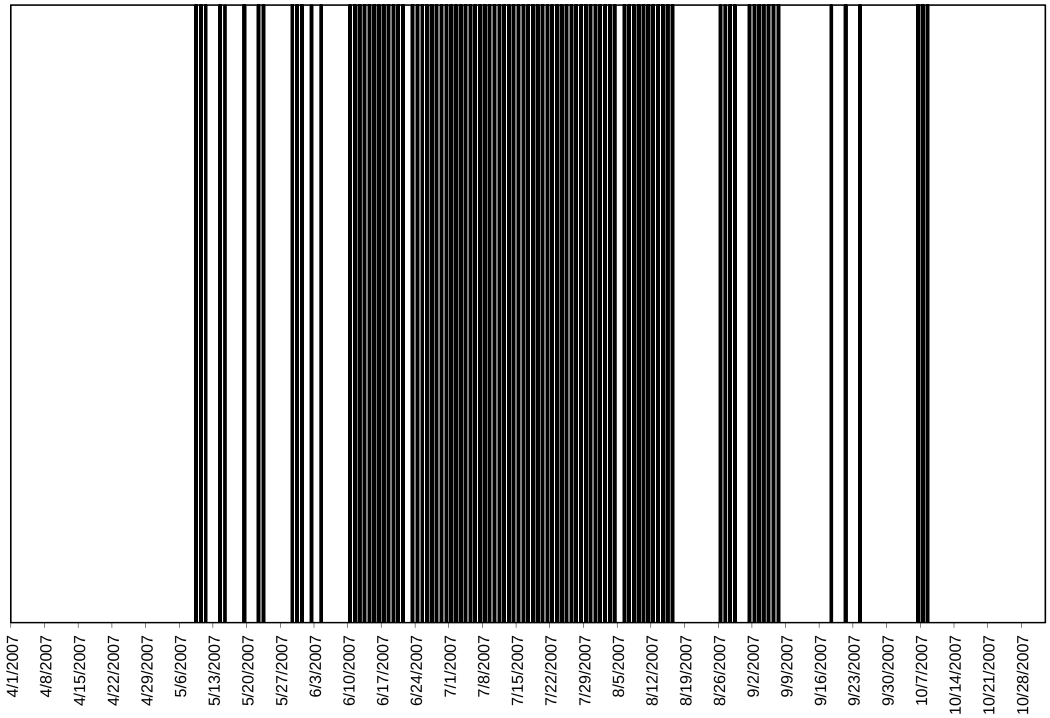


Figure 41. Frequency of 15 minute periods above brown trout threat temperature (65° F, 18° C) at WOMP, Brown's Creek, 2007.

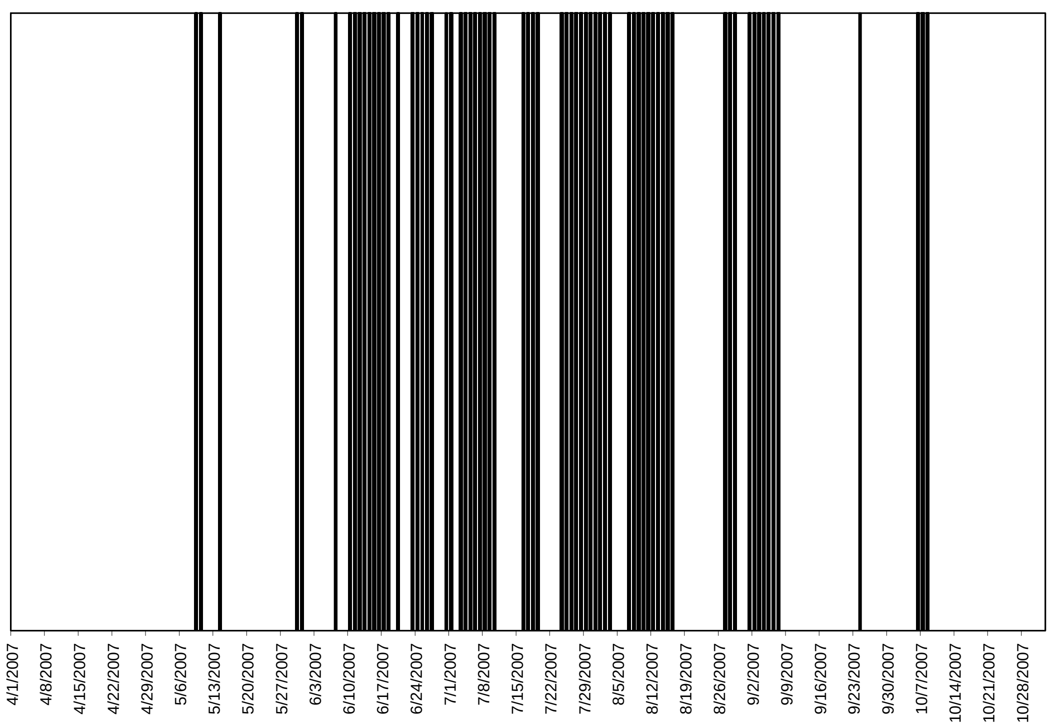


Figure 42. Consecutive hours above brown trout threat temperature (65° F, 18° C) at 110th St., Brown's Creek, 2007.

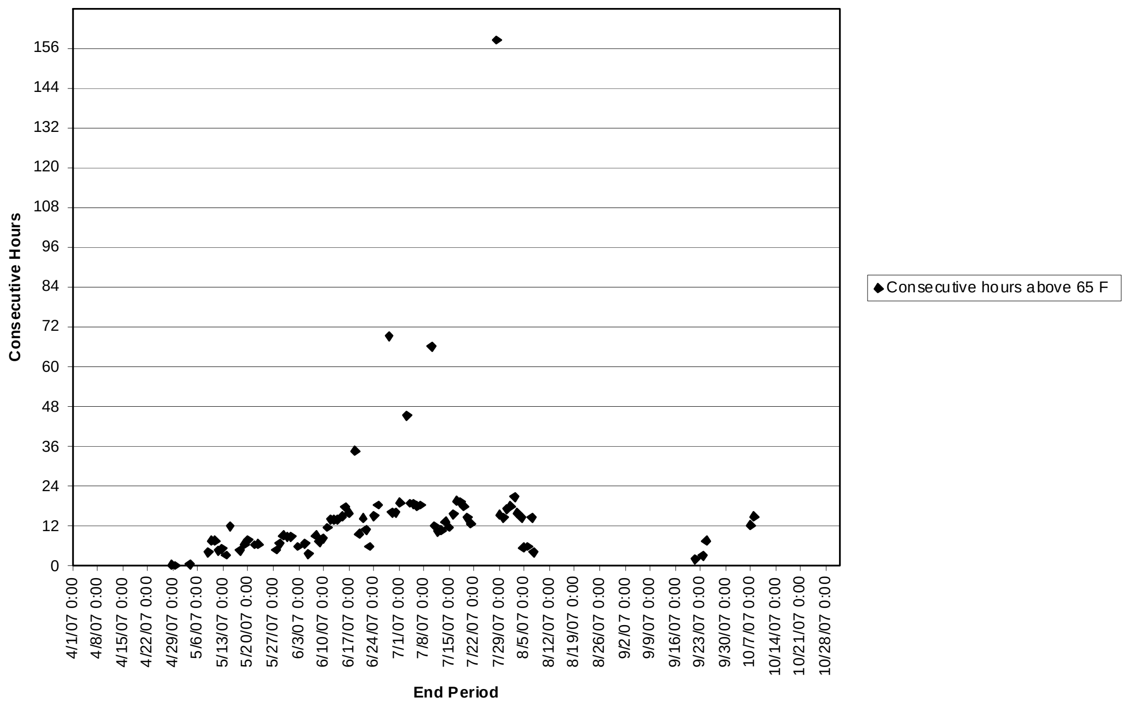


Figure 43. Consecutive hours above brown trout threat temperature (65° F, 18° C) at Gateway, Brown's Creek, 2007.

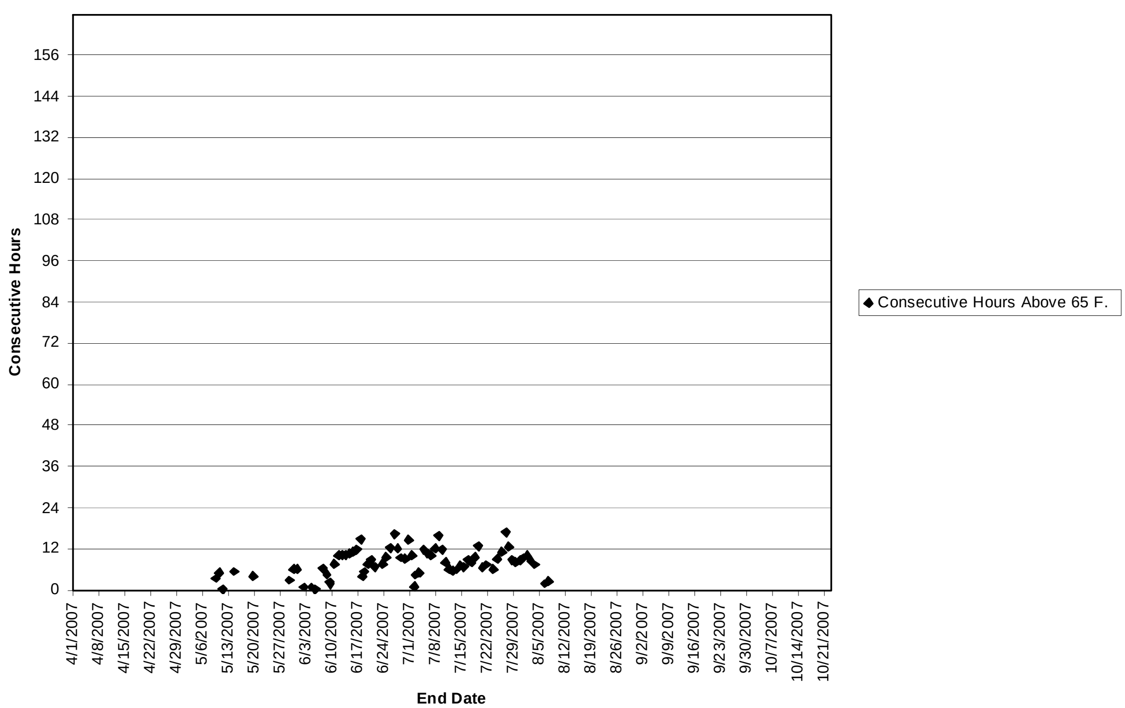


Figure 44. Consecutive hours above brown trout threat temperature (65° F, 18° C) at Highway 15, Brown's Creek, 2007.

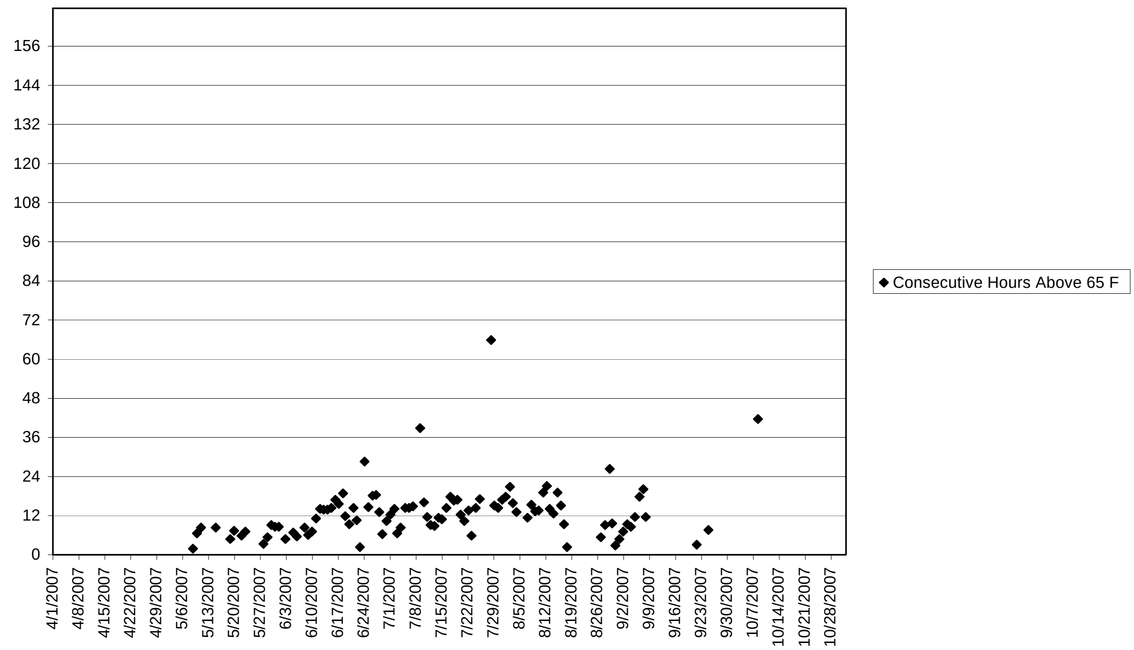


Figure 45. Consecutive hours above brown trout threat temperature (65° F, 18° C) at McKusick, Brown's Creek, 2007.

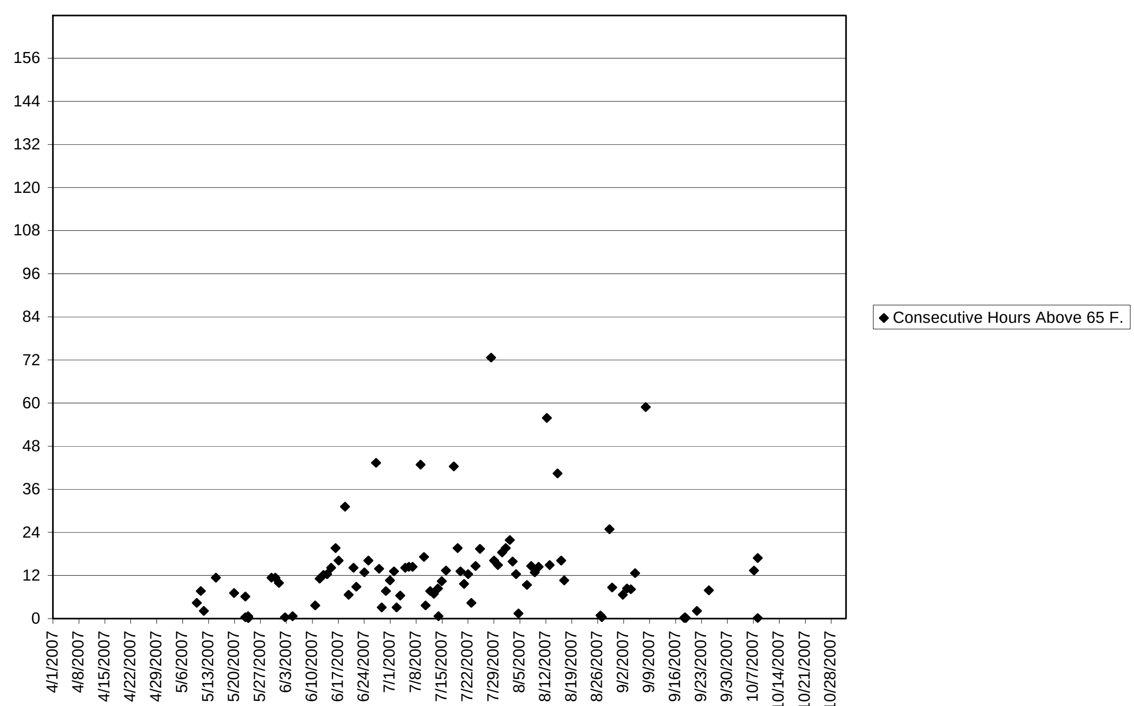


Figure 46. Consecutive hours above brown trout threat temperature (65° F, 18° C) at WOMP, Brown's Creek, 2007.

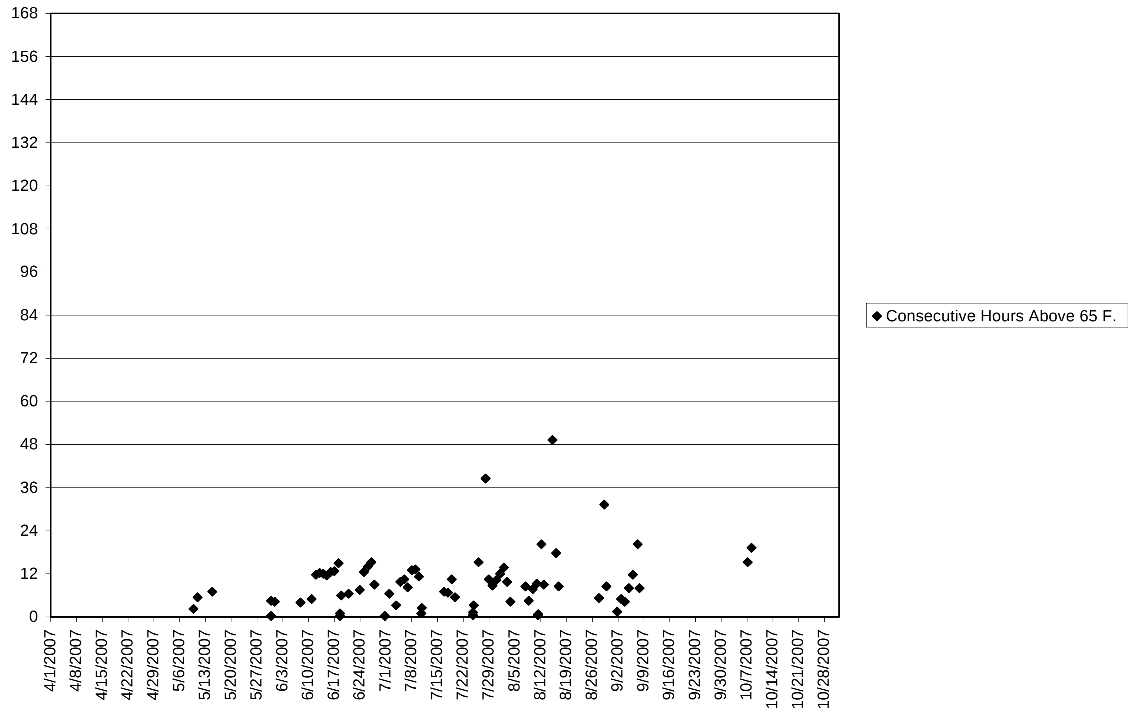
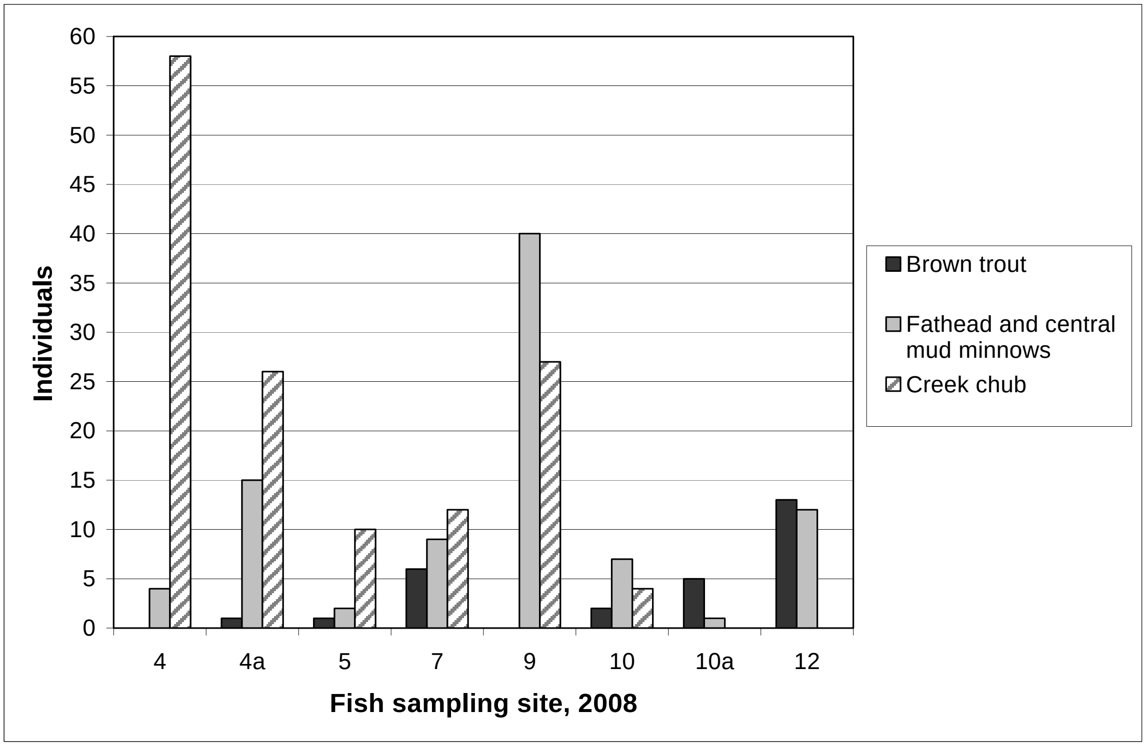


Table 13. Summary of 2008 fish samping data.

Fish monitoring site	Closest monitoring site	# Brown trout	# Fathead and central mud minnows	# Creek chub
4	Highway 15	0	4	58
4a	Highway 15	1	15	26
5	Highway 15	1	2	10
7	(Diversion)	6	9	12
9	(Diversion)	0	40	27
10	McKusick	2	7	4
10a	McKusick	5	1	0
12	WOMP	13	12	0

Figure 47. Fish sampling data from 2008 showing counts of cold water fish (brown trout) and warm water fish (minnows and chub) from upstream (site 4, near Highway 15) to downstream (site 12 near the confluence with the St. Croix).



Models of sources and causal pathways for temperature increases in Brown's Creek

The primary sources expected to impact stream temperature in Brown's Creek are shown in Figure 48. Each pathway is evaluated using current data and background information using the CADDIS method, shown in Table 14.

There is no direct evidence of agricultural discharge as a source of high temperatures, although there are other impoundments that are possible sources of high temperature (golf course retention ponds, stormwater overflow systems) in the immediate watershed area, often adjacent to the stream. Springs can be a major determinant of the success of cold water assemblages in this area, and the distribution of springs is a predictor of trout assemblage health (Wang et al., 2003b). Information on the distribution of springs is summarized in Attachment D. This information will help identify sources and areas of concern.

The most common sources of high temperature in trout streams are increased impervious surfaces and loss of riparian vegetation (*ibid.*). These landscape changes and the mechanisms of temperature increase are definitely a part of the landscape use patterns in Brown's Creek. Impervious surface coverage over 6-11% in a watershed significantly impacts trout populations, and temperature and TSS are the main components of this effect (Wang et al. 2003a and 2003b). Loss of riparian vegetation can also increase temperatures significantly. Some large scale decreases in vegetation have occurred in some sub-watersheds of Brown's Creek, with several acres of forested area cleared for development in 2007.

Finally, many of the high temperatures occur in areas that are slow moving with wider channels. This morphological effect can lead to higher temperatures or exacerbate other sources of higher temperatures. It should be noted, however, that the site near Gateway, which is a wide wetland area, has fewer temperature problems than sites immediately above or below it. Depending on the distribution of springs, this pattern indicates anthropogenic thermal influences.

Figure 48. Model of sources and causal pathways for temperature increases in Brown's Creek.

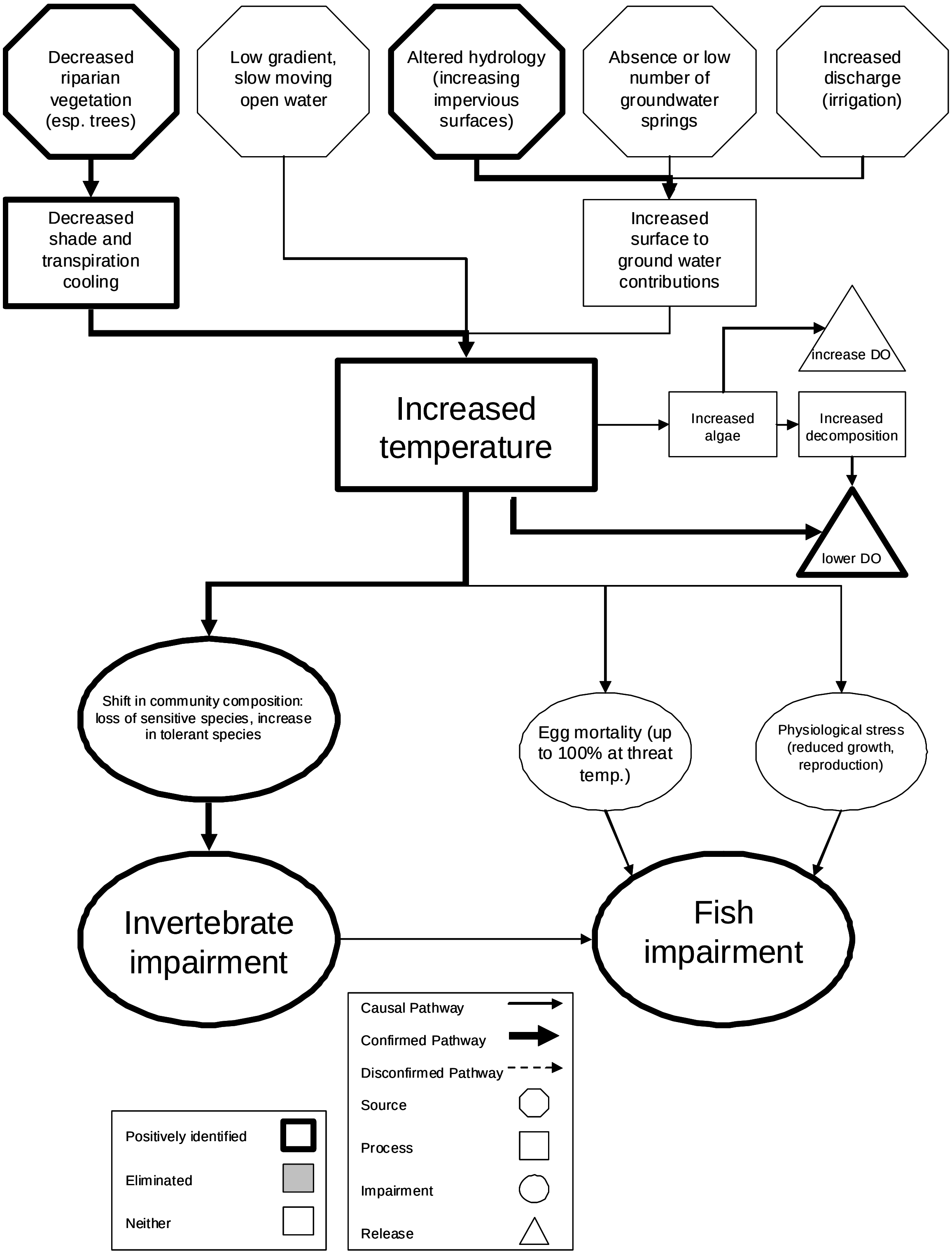


Table 14. Sufficiency of evidence table for sources of temperature increase in Brown's Creek.

Types of evidence, temperature increase	Decreased riparian vegetation	Low gradient (slow moving, open water)	Altered hydrology (impervious surfaces)	Increased discharge (irrigation, release from retention ponds)	Absence or low number of groundwater springs
Evidence using data from Brown's Creek					
Spatial / temporal co-occurrence	+	+	+	NE	+
Evidence of exposure, biological mechanism	+	0	+	+	+
Causal pathway	++	++	++	NE	0
Field evidence of stressor-response	NE	NE	NE	NE	NE
Field experiments / manipulation of exposure	NE	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE	NE
Temporal sequence	+	0	NE	NE	NA
Verified or tested predictions	NE	NE	NE	NE	NE
symptoms	+	+	+	+	+
Evidence using data from other systems					
Mechanistically plausible cause	+	+	+	+	+
Stressor-response in other field studies	++	++	++	++	++
Stressor-response in other lab studies	NA	NA	NA	NA	NA
Stressor-response in ecological models	+	+	+	+	+
Manipulation experiments at other sites	+	NA	+	+	NA
Analogous stressors	+	+	+	+	+
Multiple lines of evidence					
Consistency of evidence	+++	+	+++	0	+
Explanatory power of evidence	++	++	++	0	0

Conclusion: high temperature as a biological stressor in Brown’s Creek

Temperatures in Brown’s Creek exceed guidelines for cold water fish assemblages and reach levels detrimental to the health of trout. The presence of warm water tolerant fish species and the absence of expected cold water invertebrates relate directly to patterns of high temperatures detected in monitoring data. Lack of long term historical data makes it difficult to measure material increase, but temperature guidelines related to physiology of fish and invertebrates show a strong relationship to the biotic impairments. The frequency and duration of warm temperatures in Brown’s Creek are at levels that can produce avoidance behavior and physiological stress in trout. Shifts in community from trout to warm water adapted species are indicative of temperature stress. Patterns of invertebrate species confirm that the upper sites on Brown’s Creek do not support cold water adapted invertebrate species. Much of the temperature (and low DO) at the upper sites is likely to be natural from the Headwaters to Gateway.

On the other hand, physical and biotic data taken together strongly support temperature as an important stressor of the fish communities in the lower portion of Brown’s Creek (downstream from Gateway), and the sources are largely anthropogenic, overwhelming the natural increase in groundwater contribution that would normally keep those areas cooler. Currently available studies of similar streams in Minnesota and Wisconsin support the conclusion that increased surface runoff from impervious surfaces is one of the primary mechanisms of temperature increase responsible for loss of cold water fish and invertebrate assemblages (Wang et al., 2003a).

Copper

Copper water quality standards

Copper toxicity to animals and plants varies with its bio-availability, mediated primarily by pH and hardness. Standards for copper toxicity are often corrected for pH and hardness. Some disagree with this assessment because copper can change form rapidly and affects key organisms more than previously thought (Markich et al., 2005). The more conservative method of correcting for availability is used below in Minnesota's state standards. Copper standards are numeric and defined at three levels. The chronic standard is the highest concentration that will not cause harmful effects with indefinite exposure:

CS: Cu (µg/L) shall not exceed: exp. (0.62[ln(total hardness, mg/L)]-0.570)

The maximum standard is intended to define the limit of immediate harmful effects from short term spikes in concentration. It is defined as:

MS: Cu (µg/L) shall not exceed: exp. (0.9422[ln(total hardness, mg/L)]-1.464)

The final acute value is equivalent to an LD50, the level of exposure that would kill half of the organisms exposed. This final acute value for copper is defined as:

FAV: Cu (µg/L) shall not exceed: exp. (0.9422[ln(total hardness, mg/L)]-0.7703)

Where: exp. is the natural antilogarithm (base e) of the expression in parentheses.

Toxic and sub-lethal effects of copper on fish and invertebrates.

Copper is found naturally in low concentrations, but is relatively rare in Minnesota ground and surface waters. Copper levels in surface water can be the result of mining, herbicides, fungicides, algaecides, and treated waste effluent. Copper in groundwater can be caused by the geology of an area or accumulation from surface sources.

Copper is an essential nutrient at very low levels, but as it increases in concentration it becomes toxic to animal and plant life by binding to key organic molecules (ligands) and interfering with waste removal from blood or hemolymph. Copper also has non-lethal but substantively harmful effects on aquatic life at low concentrations. Specific biological effects of copper on fish at non-toxic levels make it useful to model the causal pathway between copper and impairments for fish and invertebrates separately.

Copper interferes with olfaction in fish. Fish can detect copper at relatively low levels, changing behavior to avoid low concentrations. Copper is often used to chase fish into nets due to the strength of avoidance behavior. This change in behavior reduces feeding, inhibits thermoregulation, and ultimately results in lower growth rates. Copper intoxication can also result in etiological shifts that reduce the growth, reproduction, and survival of fish.

Fish eggs are particularly sensitive to copper, with little or no survival of eggs at copper levels that are not harmful to adults.

Fish can become acclimated to copper after some time at low levels of exposure, shifting behavior back to normal. However, acclimated fish generally lose the ability to detect acute levels. At this stage, egg mortality is high. Of particular importance for trout restoration is that interference with olfaction causes increased hybridization when males inseminate the eggs in a redd of a different species.

Finally, because different macroinvertebrates exhibit varying copper tolerances, copper can influence macroinvertebrate species composition as well as directly impacting growth, reproduction, survival, and life cycle phenology. In general, benthic invertebrates are most sensitive to copper accumulation in sediments (Ye et al., 2007). How levels of copper affect algal dynamics in streams is not as well studied as lake systems.

Data evaluation for copper in Brown's Creek

Copper toxicity standards are most often expressed as a function of hardness. Plotting copper against hardness for available monitoring data (2000-2007) from all Brown's Creek sites together shows the total number of times copper standards were exceeded (Figure 49). Caution should be taken with the copper analysis shown, however, since most of the data is from 2007, so not all years are equally represented at all sites. The data is also somewhat patchy, so the analyses shown should be understood as a very conservative estimate of the minimum copper levels in Brown's Creek.

Breaking down this information by site, copper values exceeding the standards are found primarily at the two downstream sites (McKusick and WOMP) with a few values above standards at Diversion (Figure 50). The monitoring data for the two lowest sites can be broken down into analyses showing hardness specific standards and water quality duration curves (Figure 52 and Figure 54). Not all high copper concentrations shown on the water quality duration curves are violations because they occur at time of high hardness, which increases the standard. Hardness decreases with increased surface water runoff as indexed by total suspended solids (Figure 60).

Landscape use shows some significant patterns (Figure 55 through Figure 57). Sub-watersheds and landscape patterns are shown in Figure 61. Agricultural land use does not appear to have any pattern of relationship with high copper levels (Figure 55).

The pattern with copper exceedences is associated with the number of homes in the watershed, with increases in homes co-occurring with a small increase in high copper values beginning at CBC-13 and again at SCT-R2 on to the confluence (Figure 56). Golf course land use increases dramatically just upstream from the highest bump in copper exceedences (Figure 57). It is difficult at this time to differentiate golf course from home sources of copper, since algaecides, herbicides, and fungicides are characteristic of both land uses. Algaecides are sold in local mega-hardware stores and are sometimes reported by staff to be useful in ponds and yards, not just swimming pools (the intended target as per chemical labeling). A sign on a homeowner's pond was reported to advertise an algaecide company in 2006 (M. Westrick personal communication). Significant levels of herbicides MCPP, MCPA, dicholoroprop, and 2,4 DB were detected at CBC 16 (report from 2008 data, Pace Analytical). This indicates that chemicals are running off in surface water from homes and/or golf courses, and copper compounds are found in chemicals or products often used in tandem with these herbicides.

The relationship between increased suspended solids and copper concentrations (Figure 58) also indicates that the copper is coming from surface sources. This relationship is even stronger at the WOMP site with the highest copper levels (Figure 59). Compounding this effect is the fact that hardness decreases during runoff events due to dilution, which increases copper toxicity (Figure 60).

The timetable of 2007 exceedences may be useful in identifying periods of chemical application that could differentiate home from golf course use (Table 15).

Figure 49. Copper concentrations from monitoring data at all sites, Brown's Creek 2000-2007 with hardness corrected standards.

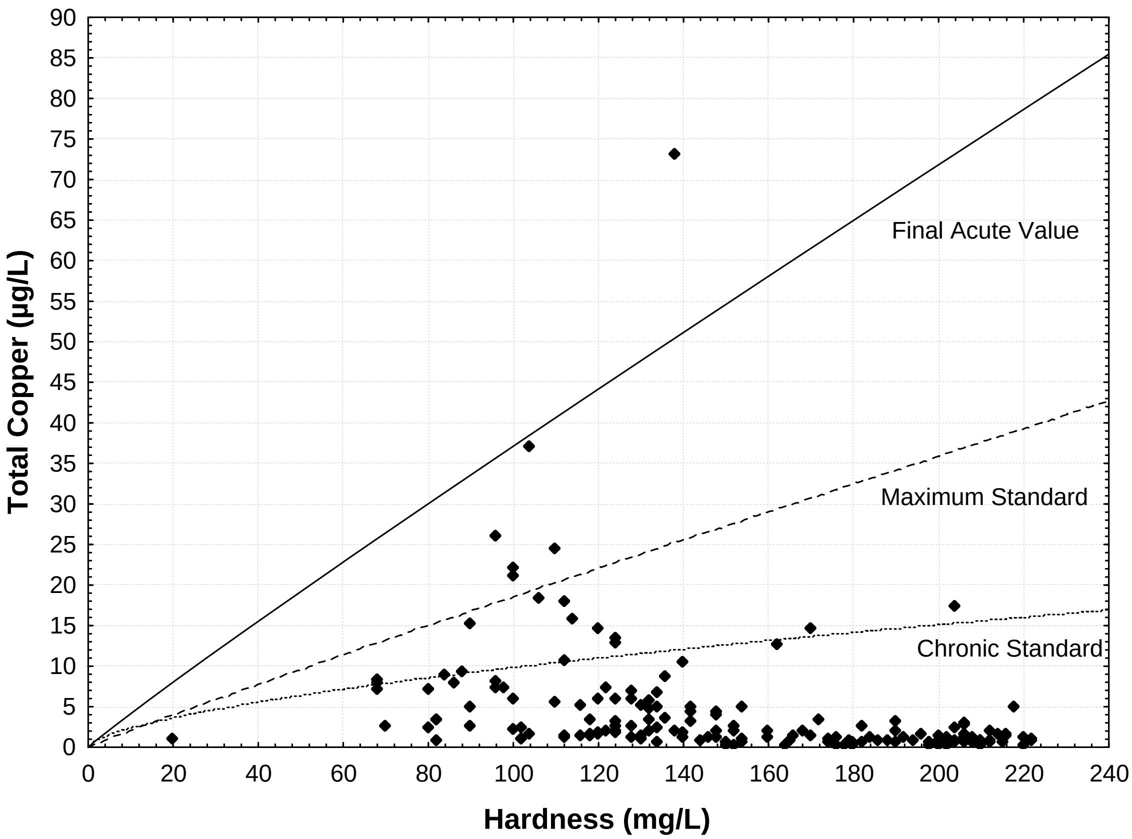


Figure 50. Copper concentrations from monitoring data at each site on Brown's Creek with hardness corrected standards.

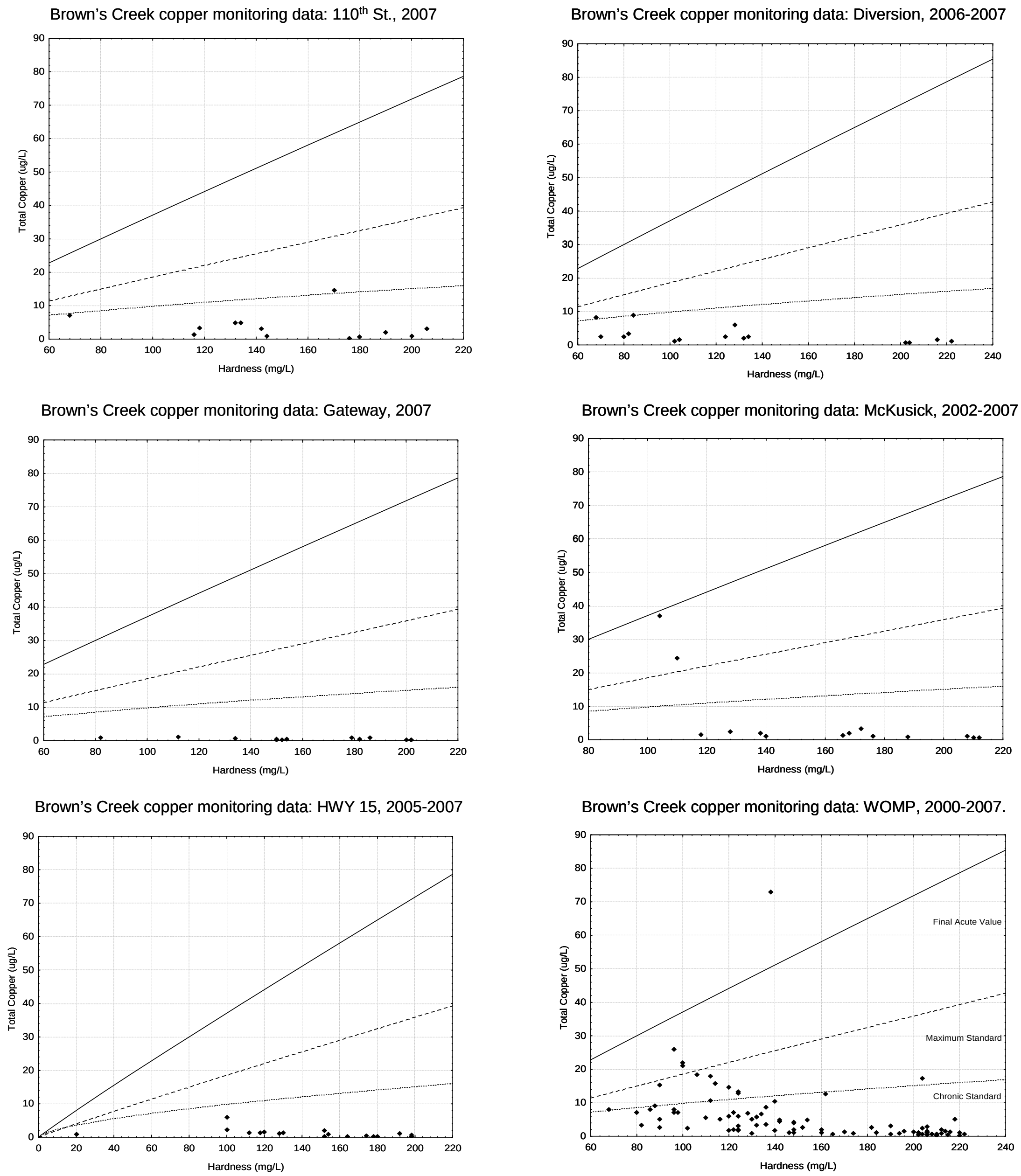


Figure 51. Copper concentration monitoring data from McKusick, Brown's Creek, with hardness corrected standards.

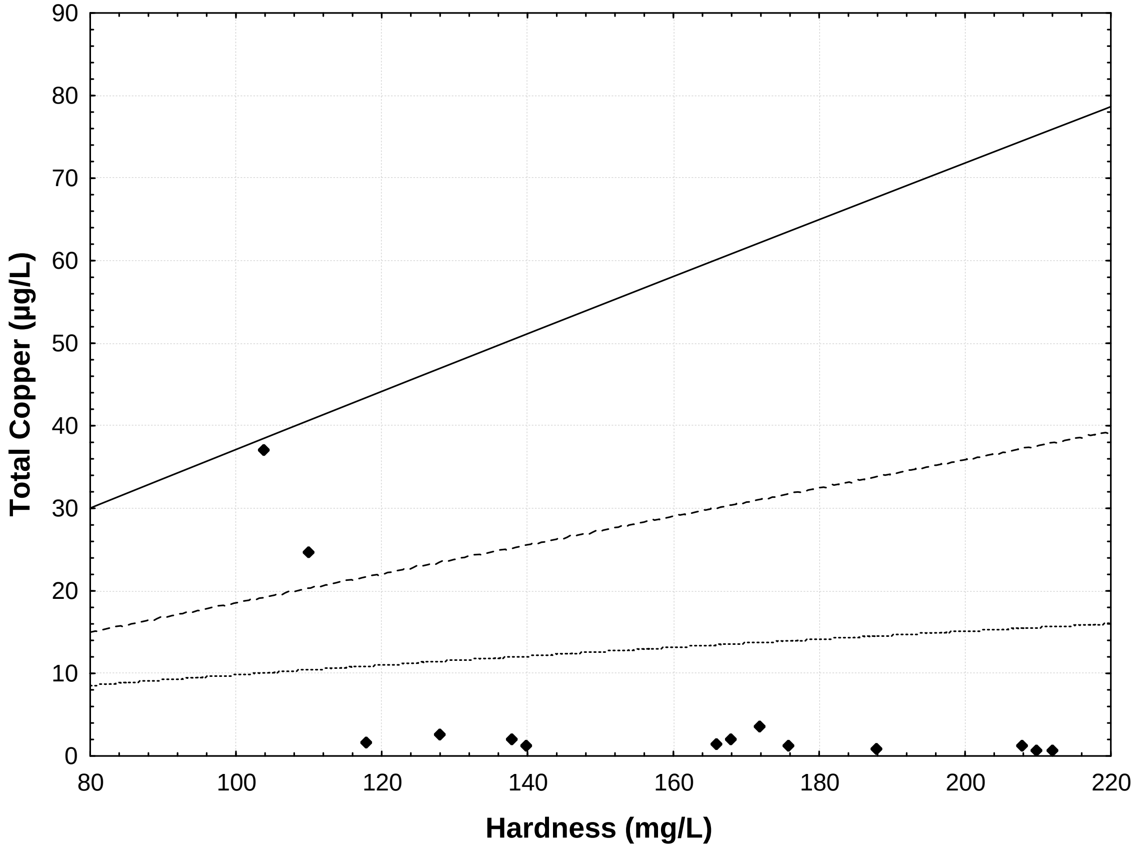


Figure 52. Copper water quality duration curve from McKusick, Brown's Creek, with points above the hardness corrected standard shaded. Note that the standard can not be calculated for all points due to lack of hardness data; therefore some data points may exceed the standard even if not noted.

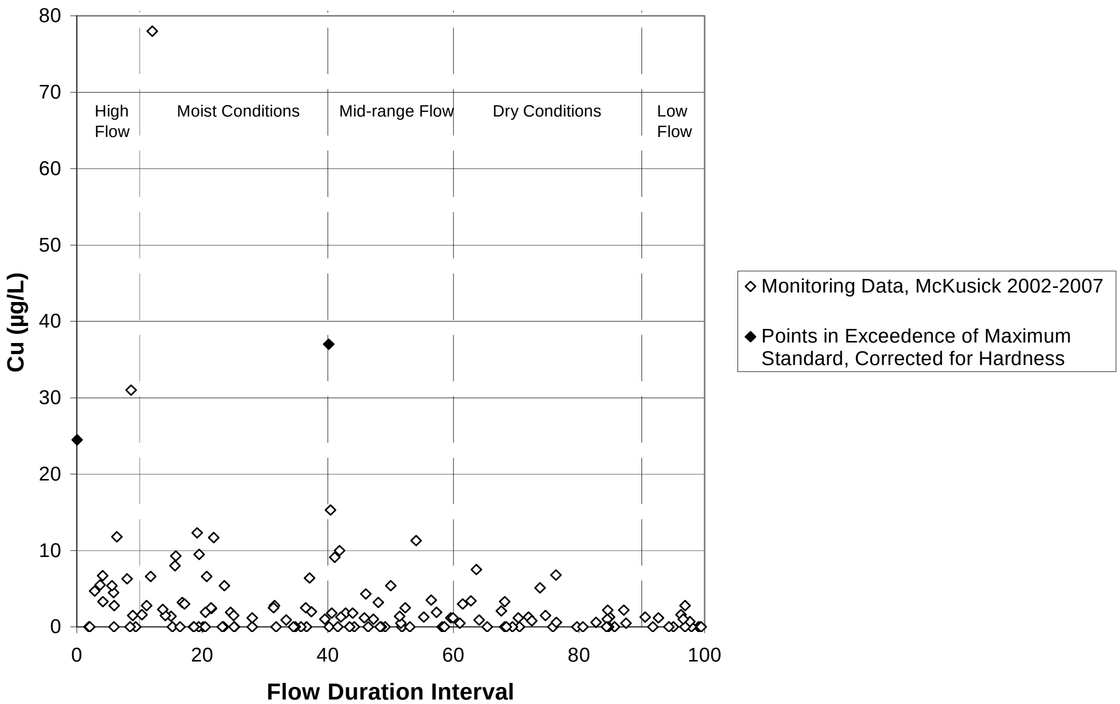


Figure 53. Copper concentration monitoring data from WOMP, Brown's Creek, with hardness corrected standards.

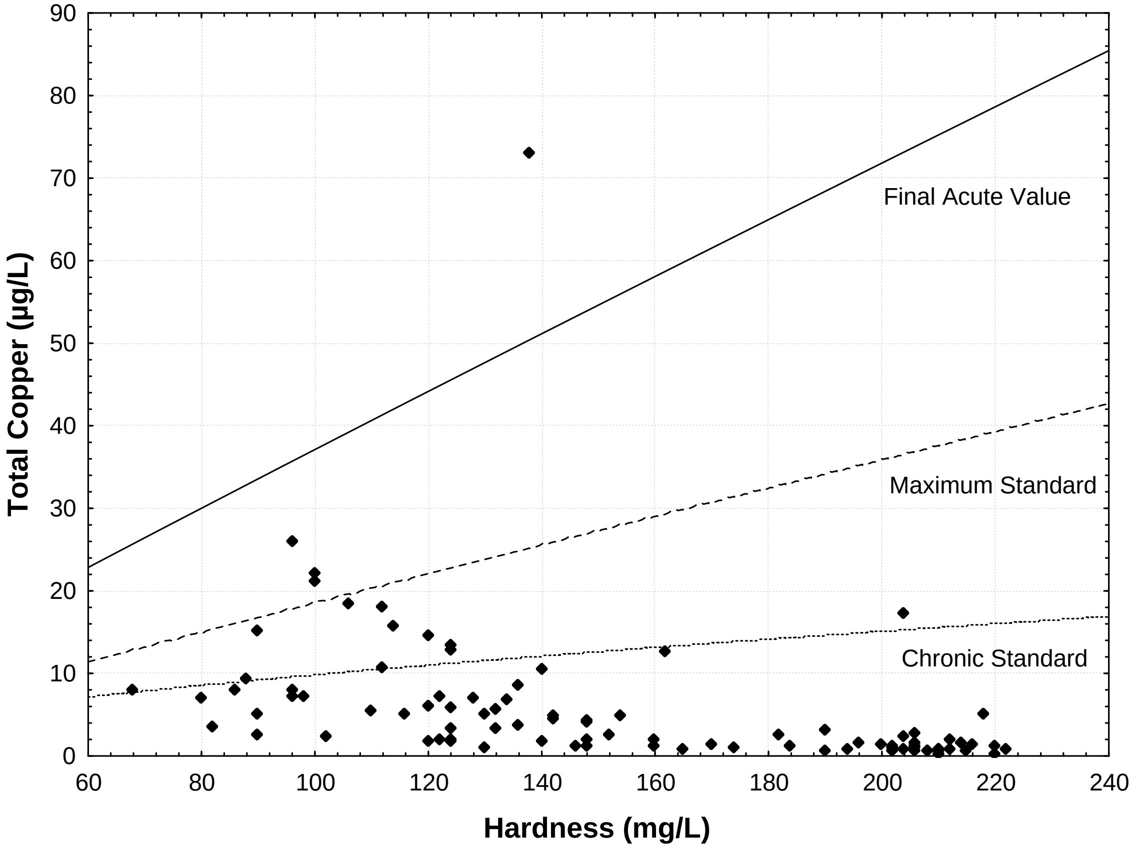


Figure 54. Copper water quality duration curve from WOMP, Brown's Creek, with points above the hardness corrected standard indexed with shaded points. Note that the standard can not be calculated for all points due to lack of hardness data; therefore some data points may exceed the standard even if not noted.

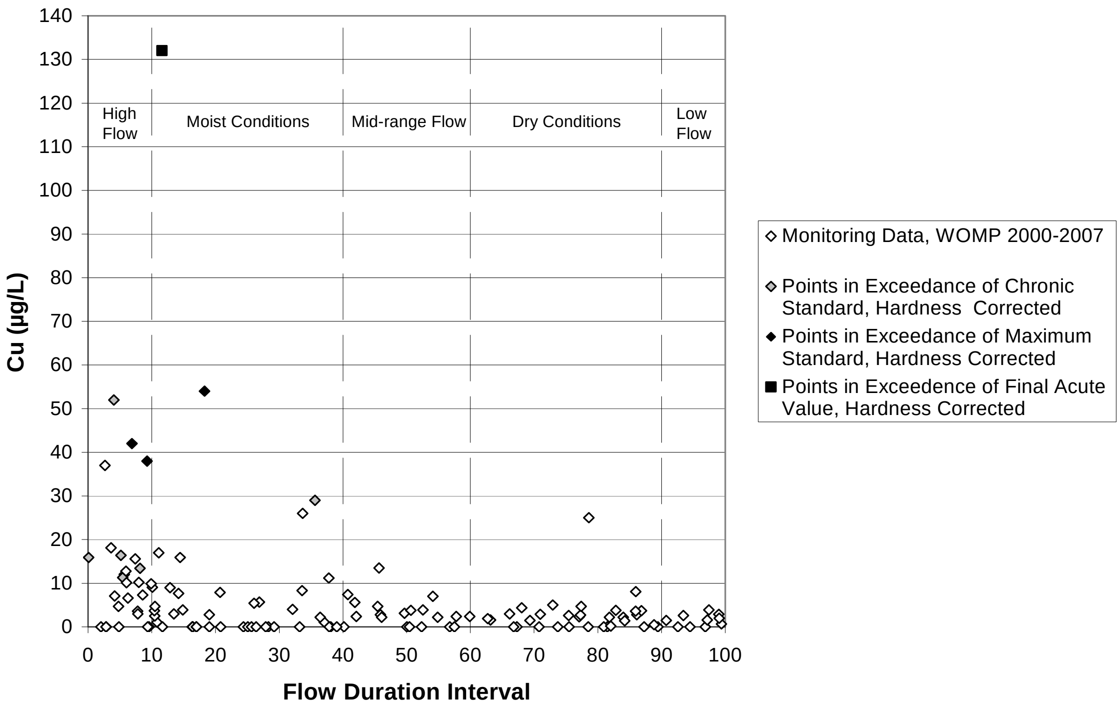


Figure 55. Percent landscape cover used for agriculture in sub-watersheds of Brown's Creek plotted against the non-cumulative number of times copper levels exceeded standards at monitoring stations immediately downstream (upstream on the left).

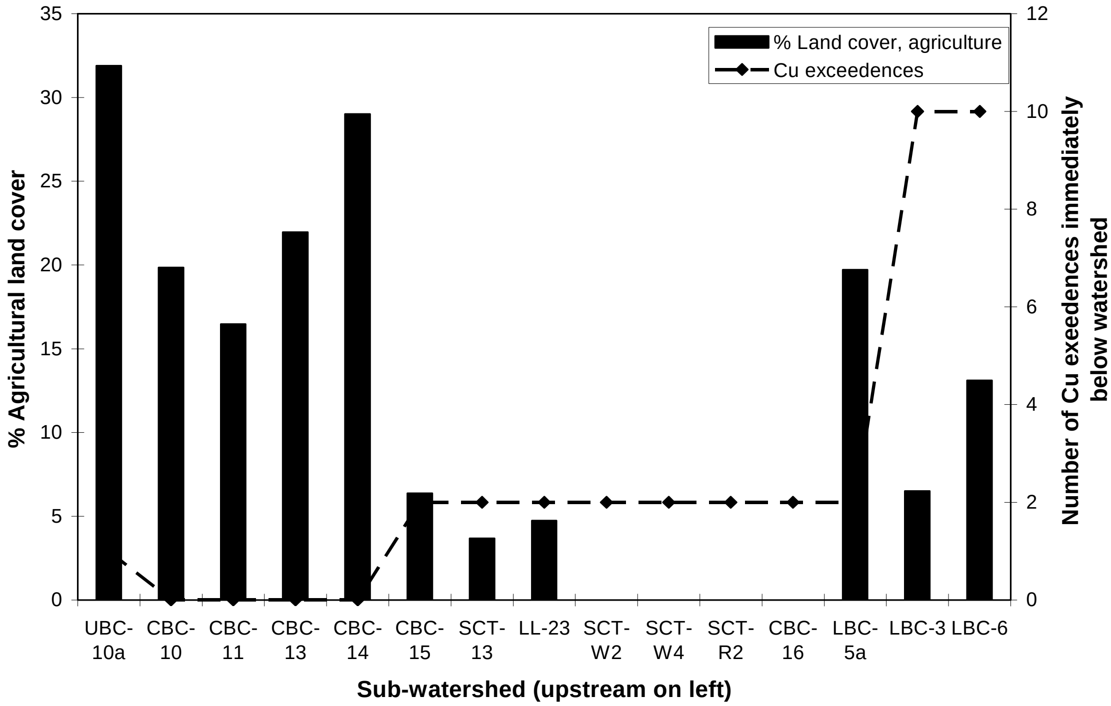


Figure 56. Percent landscape covered by homes in sub-watersheds of Brown's Creek plotted against the non-cumulative number of times copper levels exceeded standards at monitoring stations immediately downstream (upstream on the left).

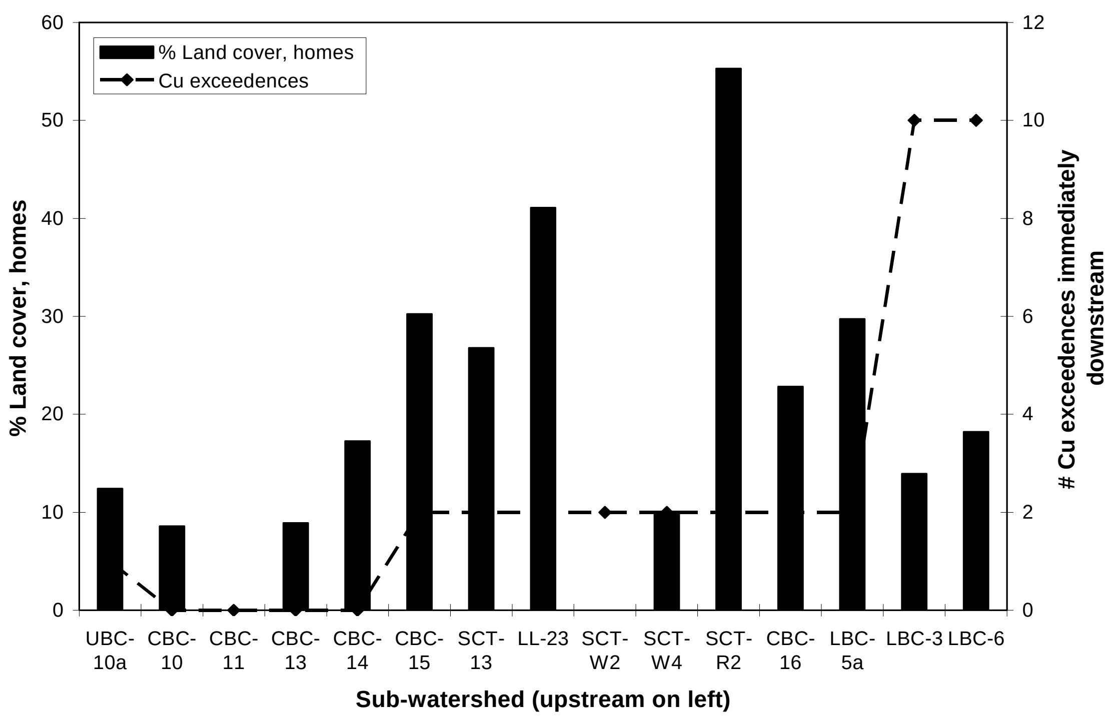


Figure 57. Percent landscape cover used for golf courses in sub-watersheds of Brown's Creek plotted against the non-cumulative number of times copper levels exceeded standards at monitoring stations immediately downstream (upstream on the left).

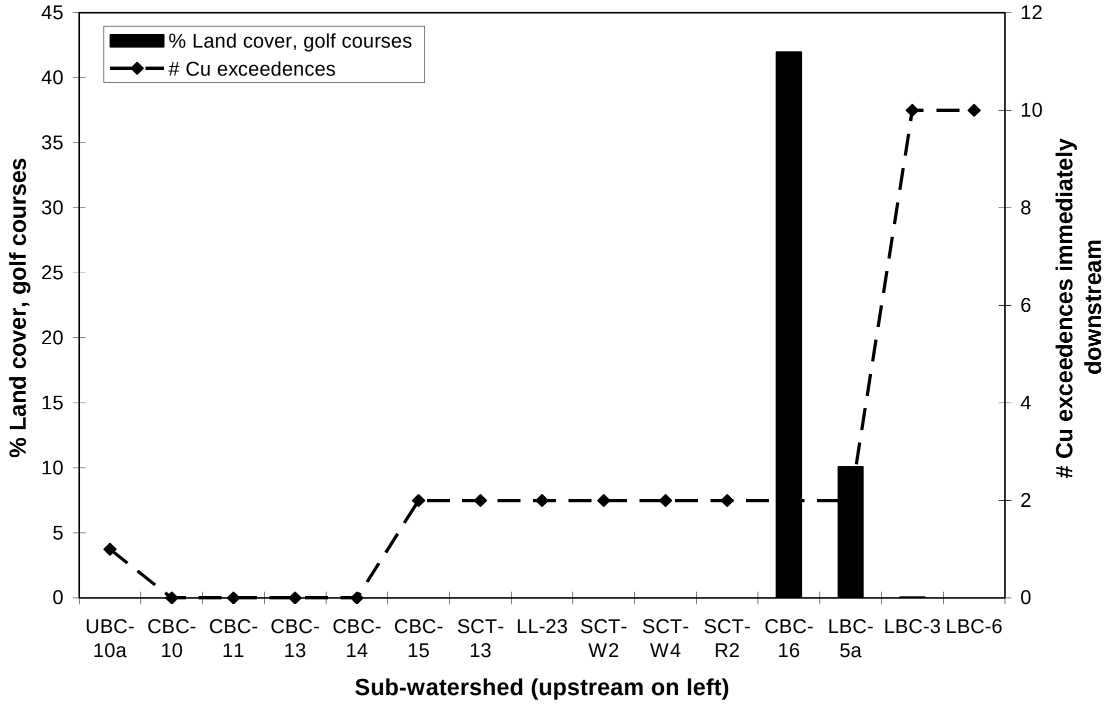


Figure 58. Copper plotted against suspended solids, all sites on Brown's Creek. Monitoring data from 2002-2007.

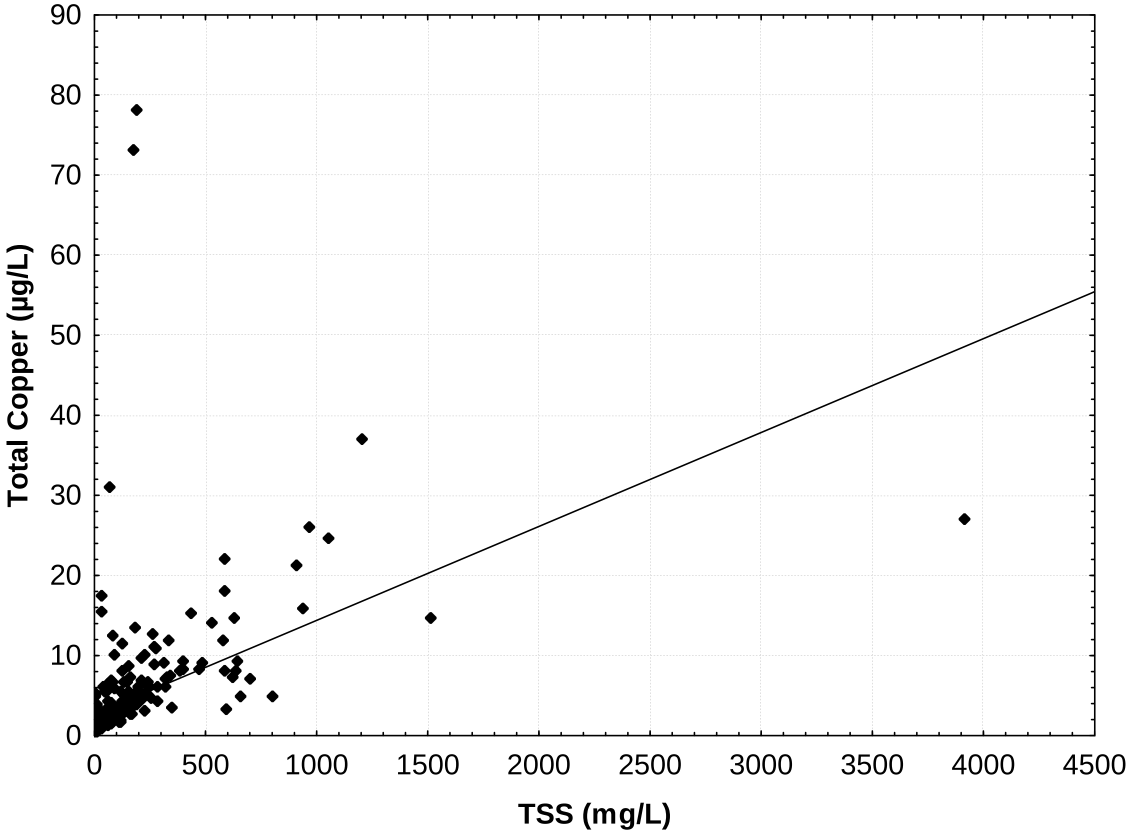


Figure 59. Copper plotted against suspended solids on Brown's Creek, WOMP site. Monitoring data from 2007.

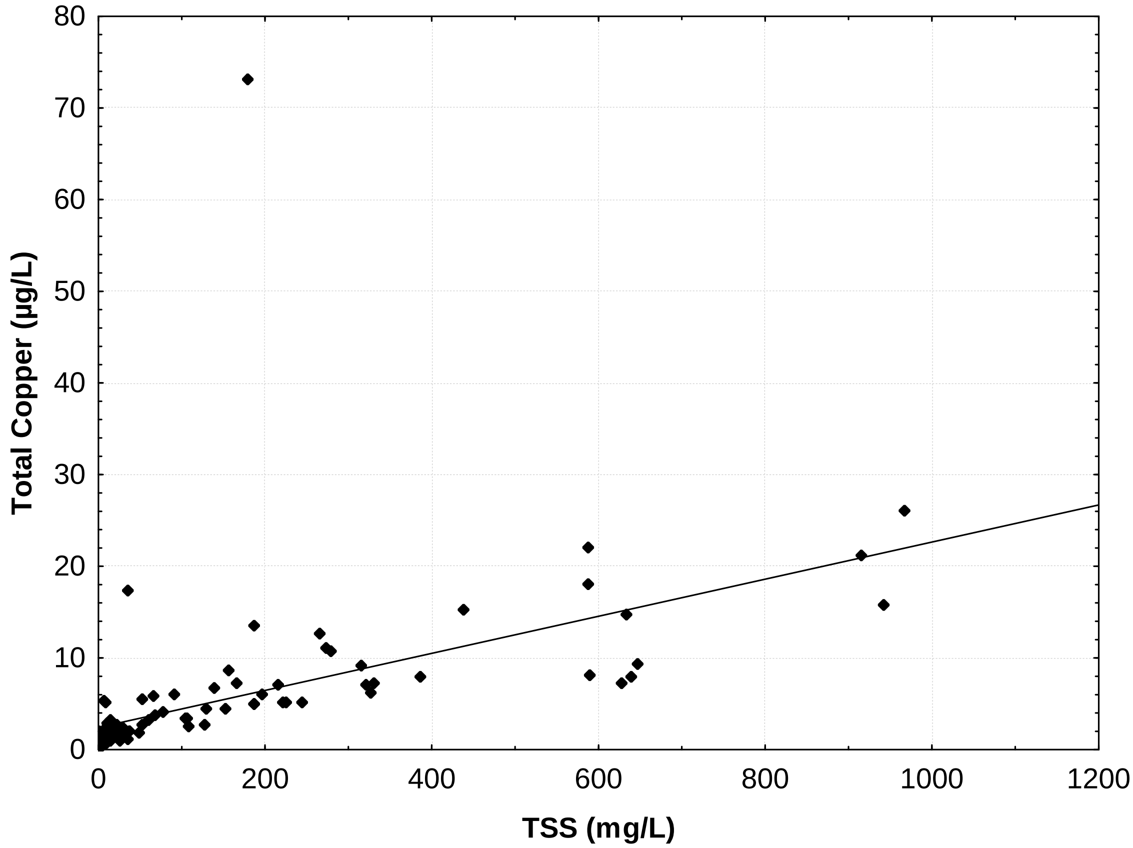


Figure 60. Total hardness plotted against suspended solids on Brown's Creek, WOMP site. Monitoring data from 2007.

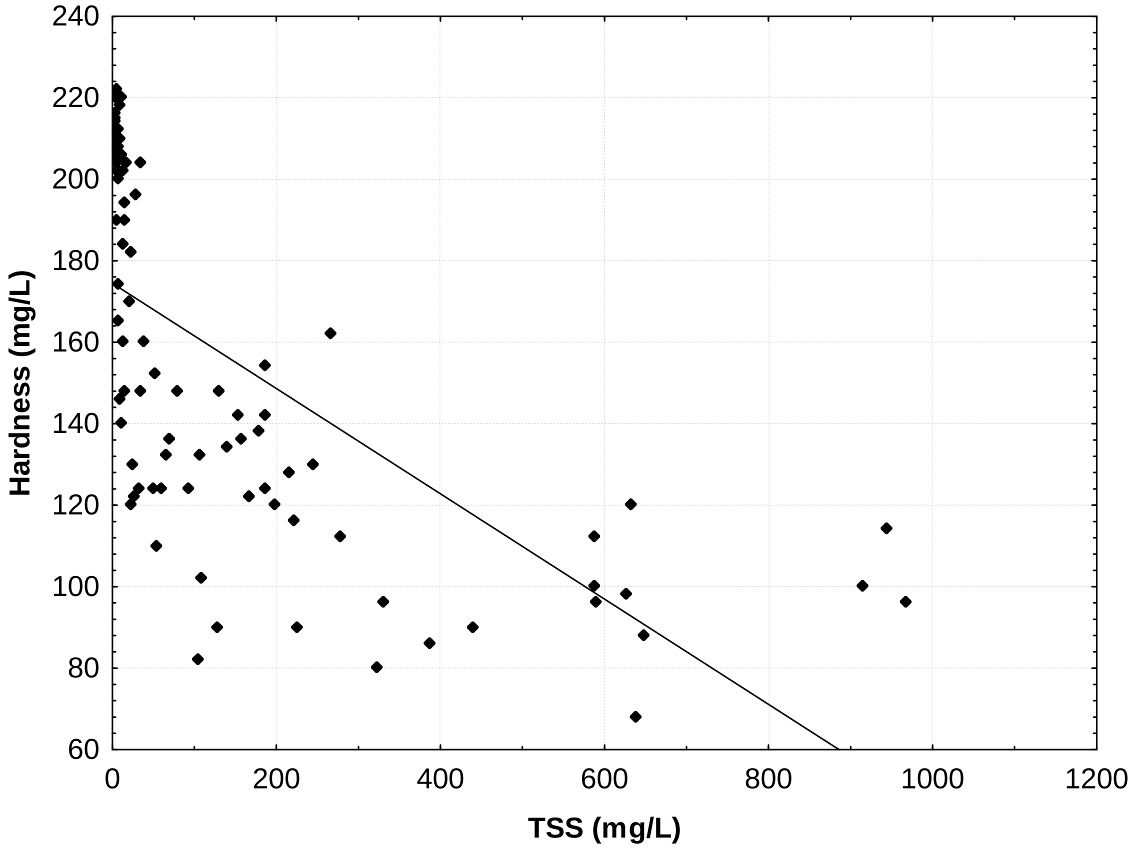
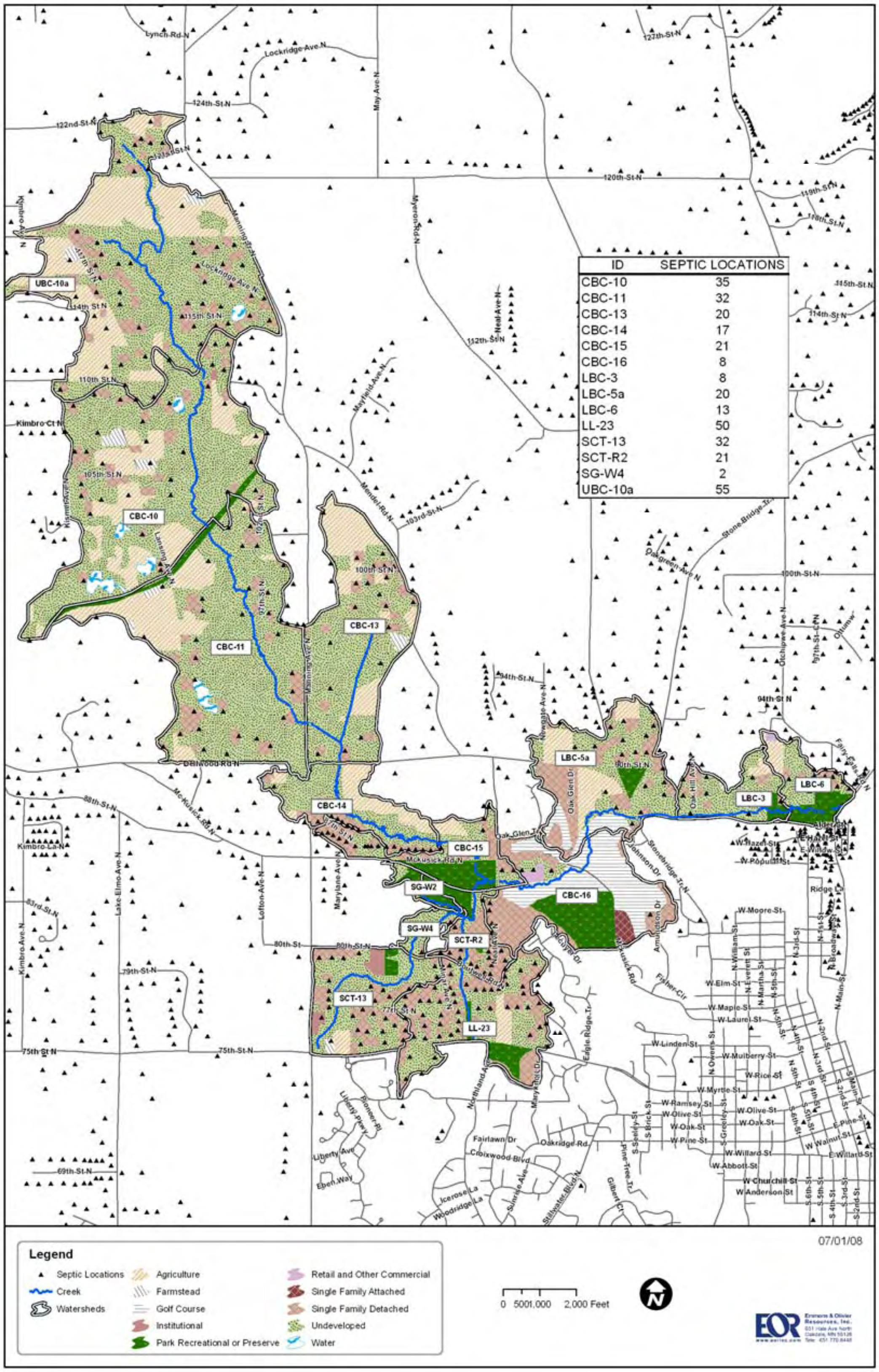


Figure 61. Map of land use in the Brown's Creek watershed, by sub-watershed.



ID	SEPTIC LOCATIONS
CBC-10	35
CBC-11	32
CBC-13	20
CBC-14	17
CBC-15	21
CBC-16	8
LBC-3	8
LBC-5a	20
LBC-6	13
LL-23	50
SCT-13	32
SCT-R2	21
SG-W4	2
UBC-10a	55

Table 15. Dates that concentrations of copper were detected above standards in Brown's Creek. Not all sites were sampled in all years or dates. Boxes outlined show common dates with a significant pulse of copper through all sites.

Site	Cu above chronic standard	Cu above maximum standard	Cu above final acute value
110th St.	11 Aug. 2007		
Diversion	30 Mar. 2007		
	$\boxed{\text{13 Aug. 2007}}$		
McKusick	$\boxed{\text{13 Aug. 2007}}$		
	28 Aug. 2007		
WOMP	28 Mar. 2002	21 June 2002	$\boxed{\text{13 May 2005}}$
	8 May 2002	6 Sept. 2002	
	19 June 2002	4 Aug. 2005	
	10 July 2002	26 Aug. 2005	
	28 July 2002	$\boxed{\text{13 Aug. 2007}}$	
	19 April 2004		
	30 May 2004		
	28 Oct 2004		
	$\boxed{\text{19 May 2005}}$		
	25 July 2005		
	4 Oct. 2005		
	24 Aug. 2006		
	28 Aug. 2007		

Models of causal pathways for copper in Brown's Creek

The sources and causal pathways of copper impairments to Brown's Creek are shown in Figure 62 and Figure 63. Invertebrates and fish are separated in this case because of the different mechanisms by which copper harms these organisms. Sufficiency of evidence methods following the CADDIS procedure were used to sort out strength of evidence for different sources and pathways.

Based on the data discussed above, sources of copper in Brown's Creek are almost certainly algaecides, fungicides, and/or herbicides from golf course application and/or home use. This includes surface runoff from application of chemicals to lawns and overflow from irrigation ponds, retention ponds, or home ponds that have collected herbicides from lawn runoff or had direct treatment with algaecides.

The episodic occurrence of toxic copper values suggest slightly stronger evidence for surface runoff as a primary pathway. There is no evidence of copper in groundwater, and MPCA reports on emissions from local sources (e.g. power plants) do not show any significant local atmospheric sources of copper. Copper can also enter aquatic systems via treated wood, which is an issue if piers and other structures are common, but piers are not common or regularly placed on Brown's Creek. It is possible, however, that the railroad ties near the McKusick site have been treated, which could account for copper at the downstream sites. The rates at which copper is released from treated wood do not support this source as a high concern (Brooks, 2004). Non-local atmospheric sources may play a role (e.g. automobile exhaust) in copper deposition that runs off in storm events, but the spatial distribution of copper in Brown's Creek relative to landscape patterns do not support the pathway of copper from atmospheric sources.

Figure 62. Model of causal pathways for copper in Brown's Creek, fish impairment.

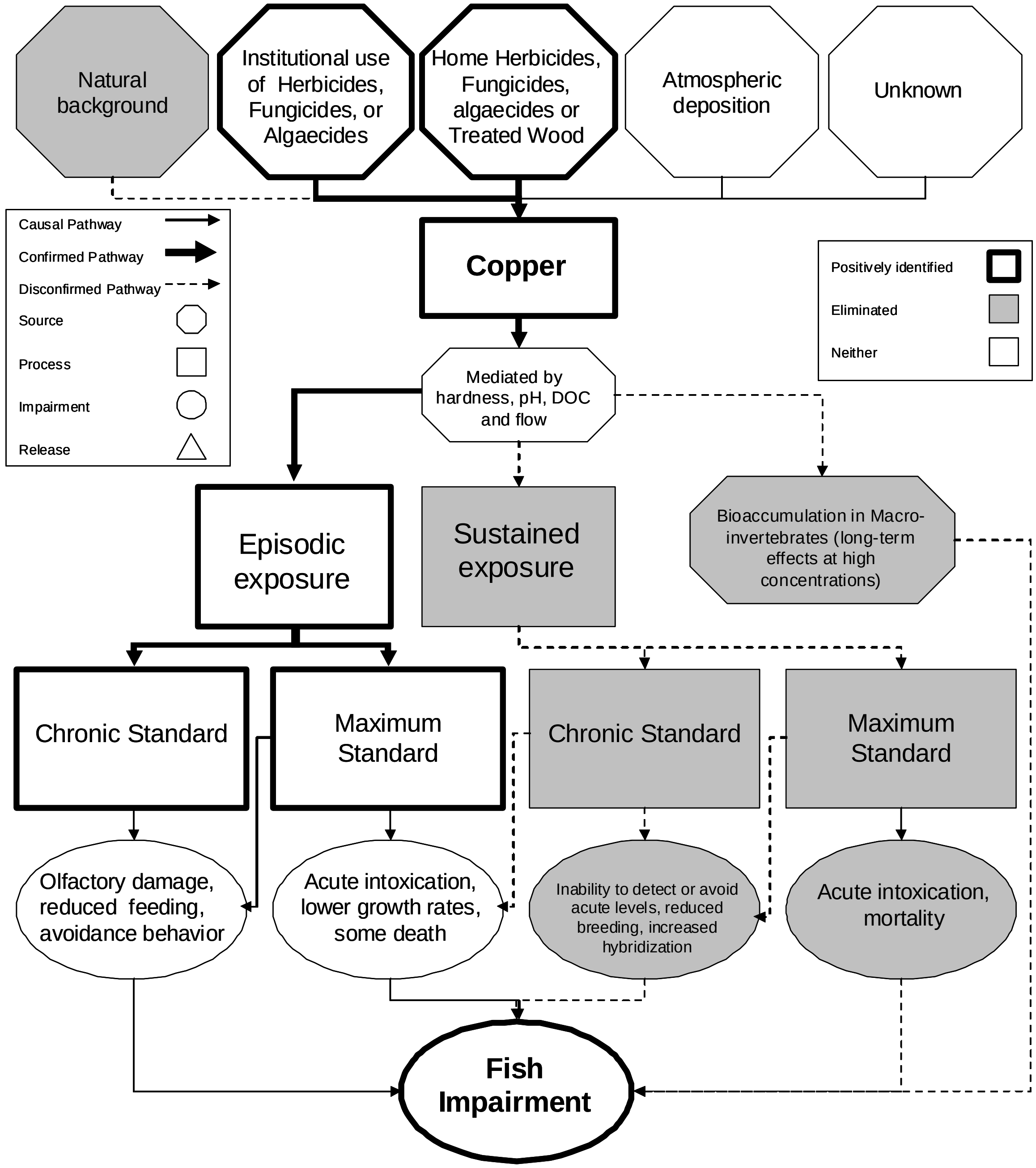


Figure 63. Model of causal pathways for copper in Brown's Creek, invertebrate impairment.

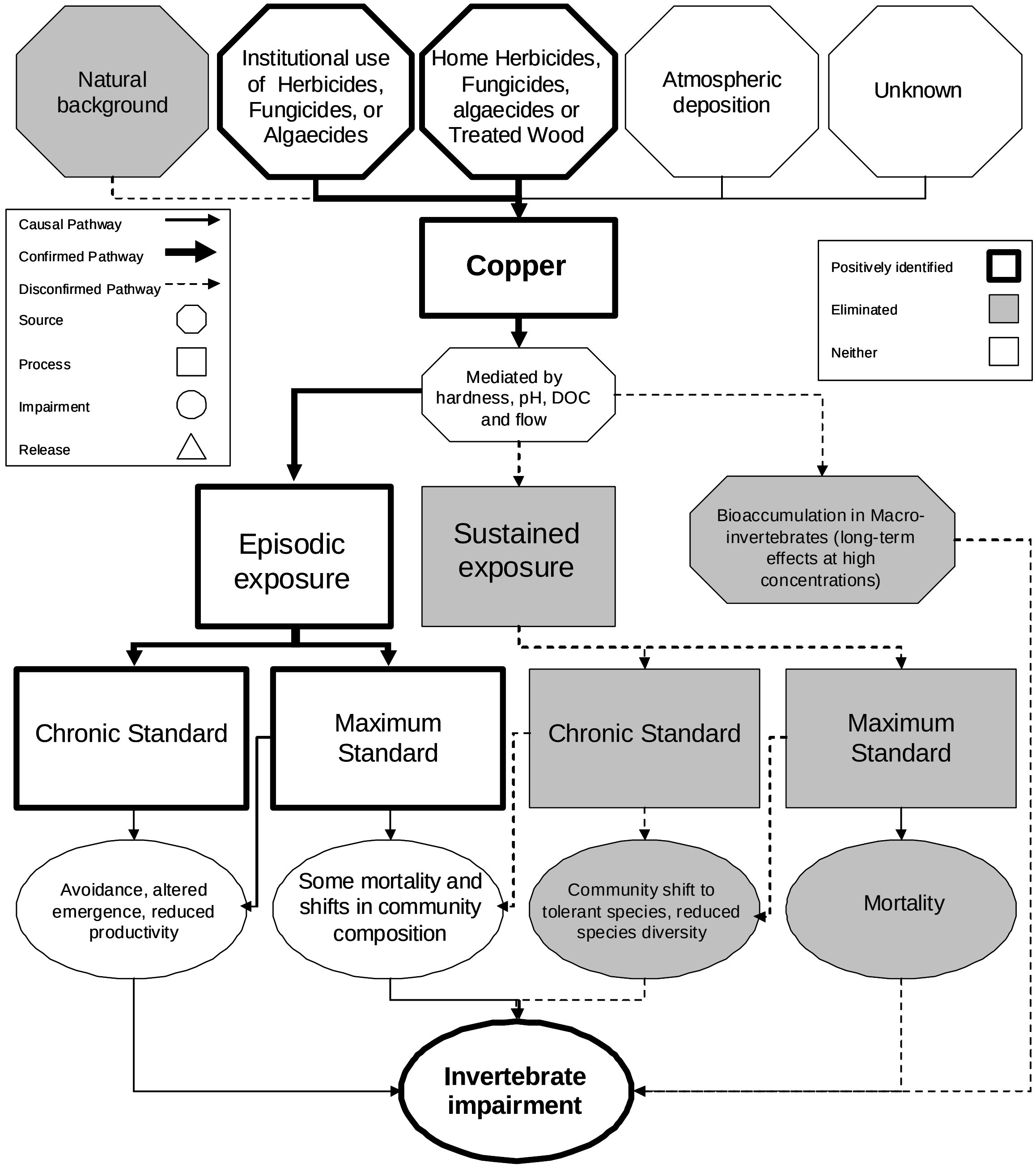


Table 16. Sufficiency of evidence for copper sources in Brown's Creek.

Strength of Evidence, Copper	Natural background	Institutional use of herbicides, fungicides, algaecides	Home use of herbicides, fungicides, algaecides	Atmospheric deposition (automobiles, power plants, burning wood)	Treated lumber (piers)
Evidence using data from Brown's Creek					
Spatial / temporal co-occurrence	---	+	+	-	-
Evidence of exposure, biological mechanism	NE	+	+	NE	NE
Causal pathway	0	++	++	NE	NE
Field evidence of stressor-response	-	++	++	0	0
Field experiments / manipulation of exposure	NE	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE	NE
Temporal sequence	-	+	+		
Verified or tested predictions	NE	NE	NE	NE	NE
symptoms	-	NE	NE	NE	NE
Evidence using data from other systems					
Mechanistically plausible cause	+	+	+	+	+
Stressor-response in other field studies	+	+++	+++	NE	+
Stressor-response in other lab studies	NE	+	+	NE	+
Stressor-response in ecological models	NE	NE	NE	NE	NE
Manipulation experiments at other sites	NE	NE	NE	NE	NE
Analogous stressors	+	+	+	+	+
Multiple lines of evidence					
Consistency of evidence	-	+++	+++	-	--
Explanatory power of evidence	-	++	++	0	-

Conclusion: copper as a stressor in Brown's Creek

The biota of Brown's Creek are exposed to episodic pulses of high copper concentrations, particularly at lower sites. The levels detected are enough to cause avoidance behavior in fish, some physiological stress in fish and invertebrates, and kill eggs of fish and invertebrates. Copper concentrations in samples from lower Brown's Creek sites (McKusick and WOMP) exceeded chronic standards and maximum standards at various sampling dates. On one occasion at WOMP, copper concentrations exceeded the final acute value. Copper is a fish repellent that produces strong avoidance behavior at low concentrations. At higher concentrations, it has detrimental sub-lethal and lethal effects on fish and invertebrates. Data support the identification of home and industrial algaecide or fungicide use in the Brown's Creek watershed as the primary candidate source of this stressor. To date, the data show that copper is primarily a concern for the fish impairment in lower Brown's Creek, but not for the impairments on the upstream reach. Invertebrates may or may not be affected, and concentrations in sediment need to be assessed to determine this impact. Copper pulses at lower flows suggest it is spiraling in the system to some extent (transporting from solution to sediment and releasing from sediment to solution as it passes downstream into the St. Croix). Available evidence shows copper impacts relate most directly to algaecide, herbicide, and/or fungicide use on golf courses and possibly by homeowners. The source could be treatment of ponds, lawns, or both.

Nitrate / Nitrite (NOx)

NOx guidelines

There is no nitrate/nitrite standard for surface waters in MN. In-stream NOx concentrations from Brown's Creek were compared to a guideline of 0.26 mg/l, the 75^{th} percentile of data (1970 through 1992, annual) from minimally impacted streams in the north central hardwood forests ecoregion (McCollor et al., 1993). The analysis below also uses levels of nitrite known to cause disease in fish as well as levels known to cause lethal and non-lethal impacts on aquatic biota. Nitrite levels of 0.5 mg/l are known to cause brown blood disease in fish as nitrite binds to oxygen-carrying cells and causes serious physiological stress (similar to blue baby disease in humans). Nitrite levels of 1.0 mg/l or higher cause severe physiological stress and significant mortality in trout (Bartlett et al., 1998). Similar effects are known for invertebrates but is less well studied (most fish data come from aquaculture). The 0.5 mg/l and 1.0 mg/l *nitrite* levels are used below against data plots of *total NOx* (nitrate + nitrite). Inconsistencies in the original data set show extremely high values of nitrite; because nitrite rapidly oxidizes, these values are likely in error but total nitrate + nitrite is not. The comparison of total NOx to the nitrite guidelines is a conservative approach and consequently shows the *potential* for disease in trout. More detailed study of nitrite is highly desirable.

Effects NOx in streams

Nitrate and nitrite enter stream water through various natural and anthropogenic sources. Nitrogen naturally cycles through aquatic systems, where common sources include any organic debris, decomposing organic materials, and animal wastes. Adjacent wetlands are a major source of nitrogen in streams. Anthropogenic sources include septic leaks, sewage, and surface runoff carrying fertilizers and organic materials. Even in streams with mixed wetland and human altered landscapes, there is a strong increase in nitrogen with anthropogenic activity (Robertson et al., 2006).

Nitrogen inputs to streams can increase decomposition, and can lower dissolved oxygen both biologically (increased respiration) and chemically (oxidation of nitrite to nitrate). Nitrite is also directly toxic to organisms. Most NOx occurs as nitrate because nitrite rapidly oxidizes to nitrate under aerobic conditions. However, nitrite can increase in heavy septic or sewage loads or very rich organic environments, particularly in anoxic or basic conditions. Bacteria also convert ammonia to nitrite and nitrite to nitrate. Small amounts of nitrite have been shown to negatively impact both invertebrate and fish populations in streams similar to Brown's Creek (Stanley, et al. 2008).

NOx increases impact aquatic organisms by a variety of mechanisms (reviewed in Camargo et al., 2006). Chemically, NOx is an oxygen sink as nitrite is rapidly oxidized to nitrate. Bacteria denitrify NOx into nitrogen gas (N_2), but the rates of this conversion are most often far slower than NOx input into aquatic systems. NOx also tends to increase hydrogen ion concentrations without adding any buffering capacity. Nitrogen is a fertilizer that increases productivity of algae (leading to eutrophication) and shifts algal and macrophyte communities in ways that impact the trophic system and water quality.

Nitrate and nitrite can be directly toxic. Nitrite is much more toxic than nitrate, binding with hemoglobin and other oxygen receptors (forming methemoglobin in humans, often known as 'blue baby disease'). In fish, this causes brown blood disease (Das et al., 2004). This disease inhibits growth and reproduction and can lead to death. Similar problems occur for aquatic invertebrates, although there is less information available about exact levels of toxicity.

Recent work in Wisconsin streams similar in size and structure to Brown's Creek shows that human land use is the major driver in hypersaturation of nitrate (Stanley et al., 2008). Nitrogen inputs to streams in the St. Croix, Mississippi, and Missouri River watersheds are directly related to hypoxia in the Gulf of Mexico, but Stanley et al. have determined that levels of nitrate (and not just nitrite) similar to Brown's Creek are producing local effects. The scientific understanding of the forms nitrogen takes as it cycles in streams is surprisingly limited and until recently most work has been done in forested landscapes.

Data evaluation of NOx in Brown's Creek

Rapid oxidation makes it difficult to measure nitrite in a system, so nitrate and nitrite are often treated together as NOx. Measurements of nitrite in Brown's Creek were exceptionally high in many cases, casting some doubt on the analytical accuracy. If these values are correct, serious levels of brown blood disease would be detected. It is more conservative to treat NOx directly without separating the two components. Consequently, the standards for fish disease on the data analyses below should be taken as cautionary, data points representing *potential* impacts of the nitrite component.

Mean values of NOx at all sites except McKusick are above the ecoregion guideline (Figure 64). The range of values show periods of NOx where nitrite concentrations are potentially in excess of levels known to cause brown blood disease in trout (0.5 mg/l). This is level of nitrite can cause high levels of mortality in trout eggs. Some values exceed levels known to cause severe physiological stress (1.0 mg/l), levels leading to mortality in adults, and 100% mortality of eggs (Gateway, Highway 15, and WOMP).

Upstream sites show highest NOx at periods of low or moderate flow (Figure 65 and Figure 66). Downstream sites show high levels at all flows (Figure 67 and Figure 68). The numbers of registered septic systems per sub-watershed are shown in Figure 69.

Figure 64. Mean NOx using all available data (2000-2007) at each Brown's Creek monitoring site, showing minimum and maximum values. Guidelines are for nitrite, so exceedences of guidelines indicate *potential* for disease.

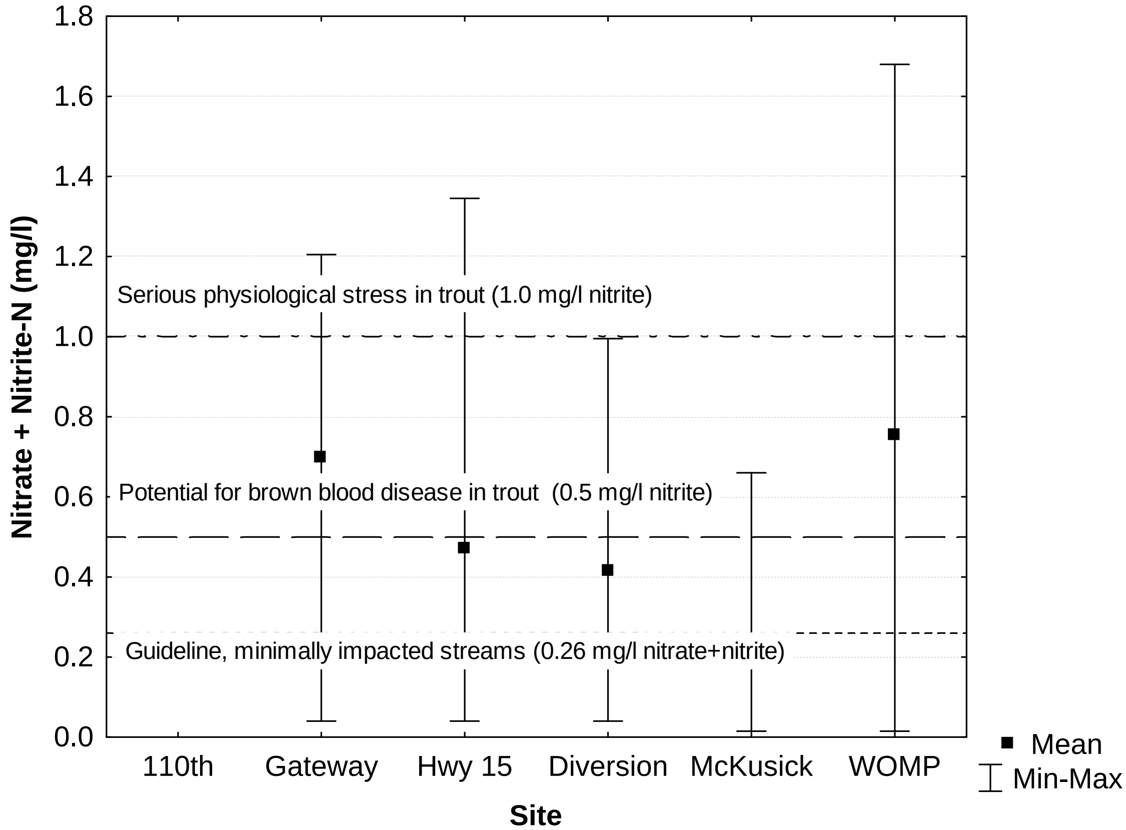


Figure 65. Load duration curve for Brown's Creek 2007 nitrate / nitrite monitoring data at 110th St., with NOx guideline of 0.26 mg/l converted to lbs/day.

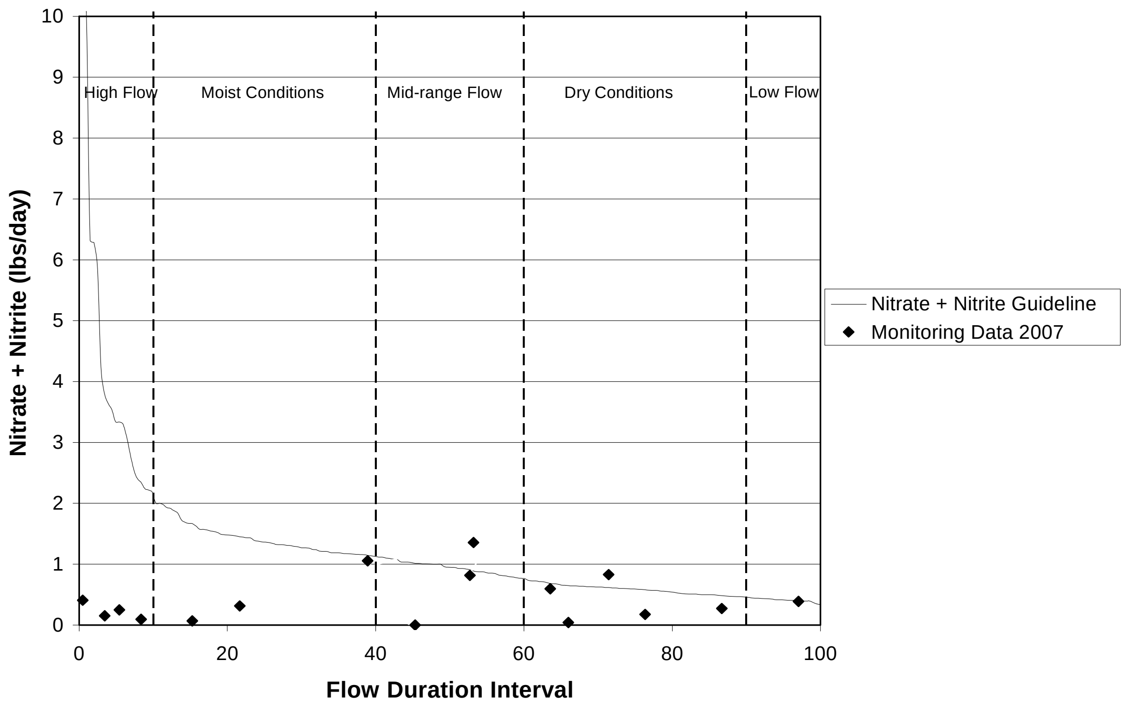


Figure 66. Load duration curve for Brown's Creek 2007 nitrate / nitrite monitoring data at Highway 15, with NOx guideline of 0.26 mg/l converted to lbs/day.

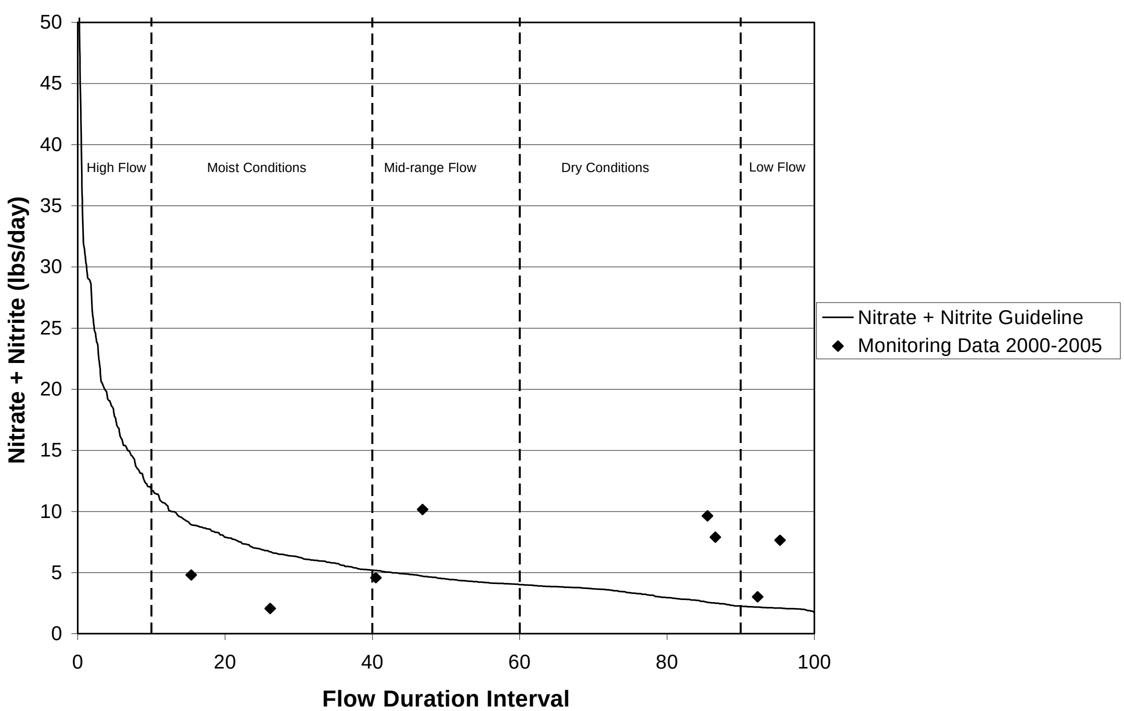


Figure 67. Load duration curve for Brown's Creek 2007 nitrate / nitrite monitoring data at McKusick, with NOx guideline of 0.26 mg/l converted to lbs/day.

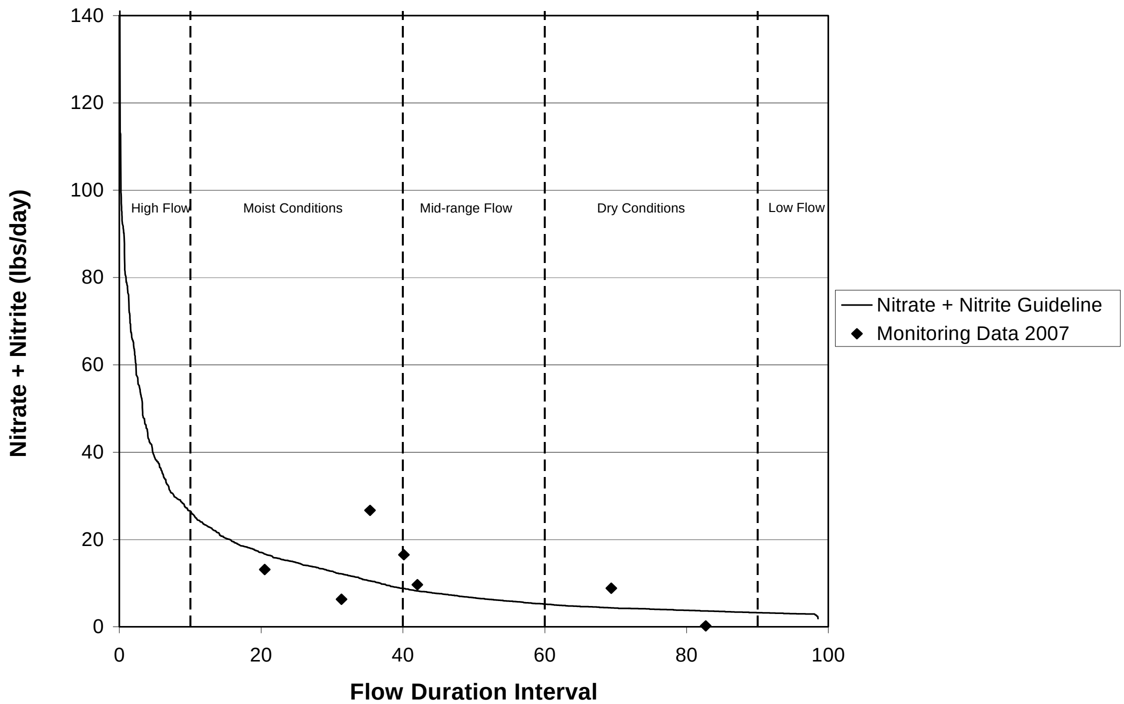


Figure 68. Load duration curve for Brown's Creek 2007 nitrate / nitrite monitoring data at WOMP, with NOx guideline of 0.26 mg/l converted to lbs/day and guidelines for disease levels from published literature converted to lbs/day.

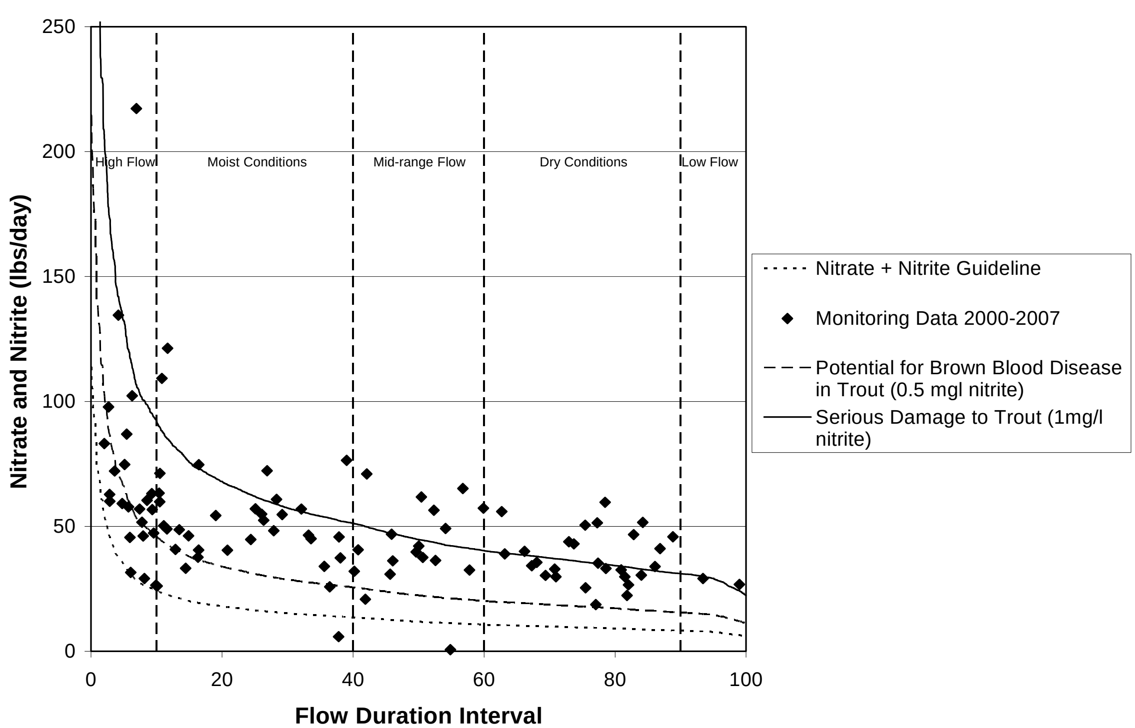
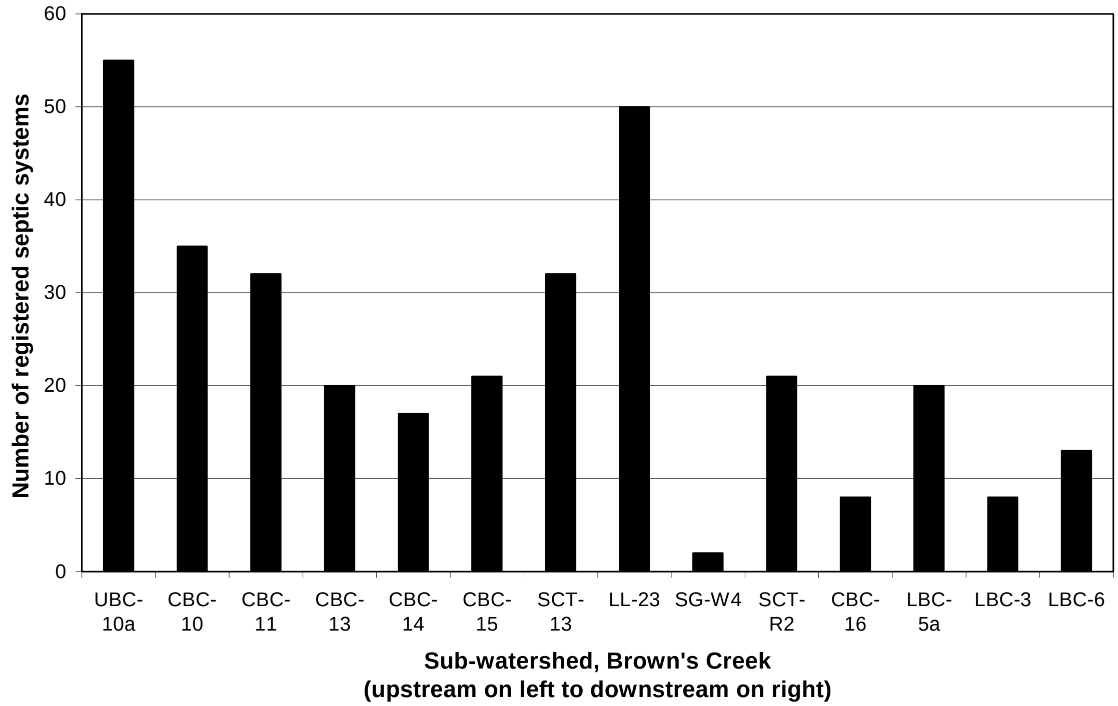


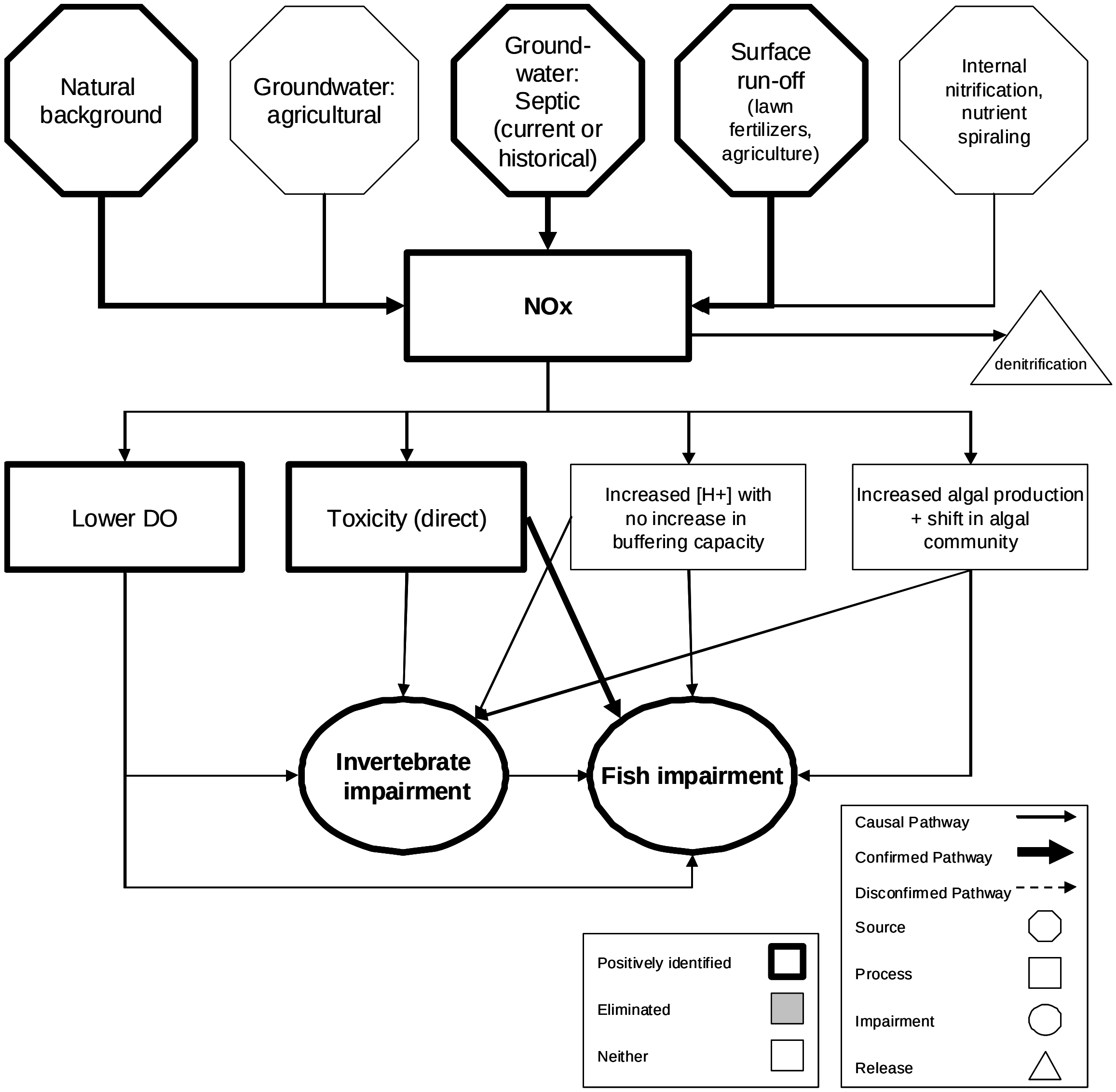
Figure 69. Number of permitted septic systems in sub-watersheds of Brown's Creek. Upstream watersheds are on the left, downstream on the right.



Models of sources and causal pathways for NOx in Brown's Creek

Sources and pathways of NOx are shown in Figure 70. Data limitations prevent a full analysis using the CADDIS sufficiency of evidence system. However, some specific pathways are supported by the data. Higher NOx levels at moderate to low flows at upper sites on Brown's Creek indicate natural cycling of nitrogen through the system from wetlands and agricultural runoff. Downstream, the number of high NOx points rapidly increases, particularly at WOMP. Data discussed above indicate likely multiple sources since high levels of NOx occur at all flows. Low flow values indicate internal cycling or groundwater sources (natural and leaking septic systems). Nitrogen at high flow indicates input from surface runoff, and the occurrence of this effect only at lower sites is characteristic of lawn and/or golf course fertilizers in runoff. The number of permitted septic systems increases dramatically in the sub-watershed of the site with the highest values of nitrogen (WOMP, Figure 68), and septic leaking is a concern given these values. Un-permitted or abandoned septic systems may also play a role here. The relationship between NOx and lower DO makes this stressor even more important as one contributing cause of another key stressor.

Figure 70. Model of sources and causal pathways for nitrate / nitrite in Brown's Creek.



Conclusion: NOx as a biological stressor in Brown's Creek

Nitrogen levels in Brown's Creek are high at all sites, but particularly high at the WOMP site farthest downstream. Levels of NOx (nitrate + nitrite) in Brown's Creek are consistently above ecoregion guidelines for minimally impacted streams. Data indicate that NOx levels result from multiple sources. Likely sources are natural input from wetlands, surface runoff carrying fertilizers and organic material, and inputs from septic system leaks (particularly at the WOMP site). The nitrite data in Brown's Creek, particularly at WOMP, are sufficient to be a concern for the health of fish and invertebrates. It is recommended that fish be directly monitored for brown blood disease and that more accurate information on the level of nitrite is collected.

Unionized ammonia

Unionized (NH_3) ammonia is a product of decomposition indicating natural or anthropogenic organic input. In many stream systems, unionized ammonia comes from leaking septic to the groundwater, sewage or fertilizer in the surface water, and natural input from wetland areas. Increases in other nutrients can cause eutrophication, which also leads to more unionized ammonia through decomposition.

The state chronic standard for Class 2A waters is 16 µg/l, and the standard for Class 2B waters is 40 µg/l. Unionized ammonia is toxic to aquatic animals, impairing respiration and the ability to discharge waste ions. Final acute values for fish are well reflected by the Class 2A state standards, but some invertebrates have been shown to have final acute values much lower than the Class 2A standards (e.g., mussels; Hickey et al., 1993).

Data from Brown's Creek show only a few points of NH_3 in excess of standards. The unionized fraction was calculated using the standard formula from Emmerson et al. (1975):

$$\% \ NH_3 = 100/10(pK_a - \mathrm{pH}) + 1$$

$$pK_a = 0.09 + 2730/°\mathrm{Kelvin}$$

The uppermost site at 110th St. had one NH_3 point above the standard in 2007. This occurred at high flow, indicating a source in the watershed entering via surface water runoff (Figure 71). Downstream, the Highway 15 site showed two points in excess of Class 2A standards in 2007 (Figure 72). These occurred at low flow, which is more indicative of internal additions (decomposition) or groundwater input (leaching from septic or agricultural impoundments). Finally, the lowest site (WOMP) had NH_3 in excess of Class 2A standards at both high and low flows, indicating multiple sources (Figure 73).

The occurrence of high unionized ammonia values is infrequent in Brown's Creek. It is unlikely that NH_3 is a dominant stressor of the biota. However, the sources of unionized ammonia are useful in diagnosing other stressor sources. Groundwater analysis does not show any problems with high ammonia (Scott Alexander, personal communication). At this point possible sources are not identifiable. It is important to keep monitoring this potential stressor since there were so few data points. Periods of high NH_3 may have been missed, and future monitoring should include pH and temperature values at the same time as nitrogen samples so the unionized component can be differentiated (separating unionized ammonia from ammonium).

Finally, because fish show a marked avoidance response to ammonia, even a few pulses, when taken in concert with other stressors, can be responsible for fish leaving the system. For these reasons, ammonia should be considered an issue of concern and potential stressor.

Figure 71. Load duration curve for un-ionized ammonia, 110th St., Brown's Creek monitoring data 2007 (flow from all available data).

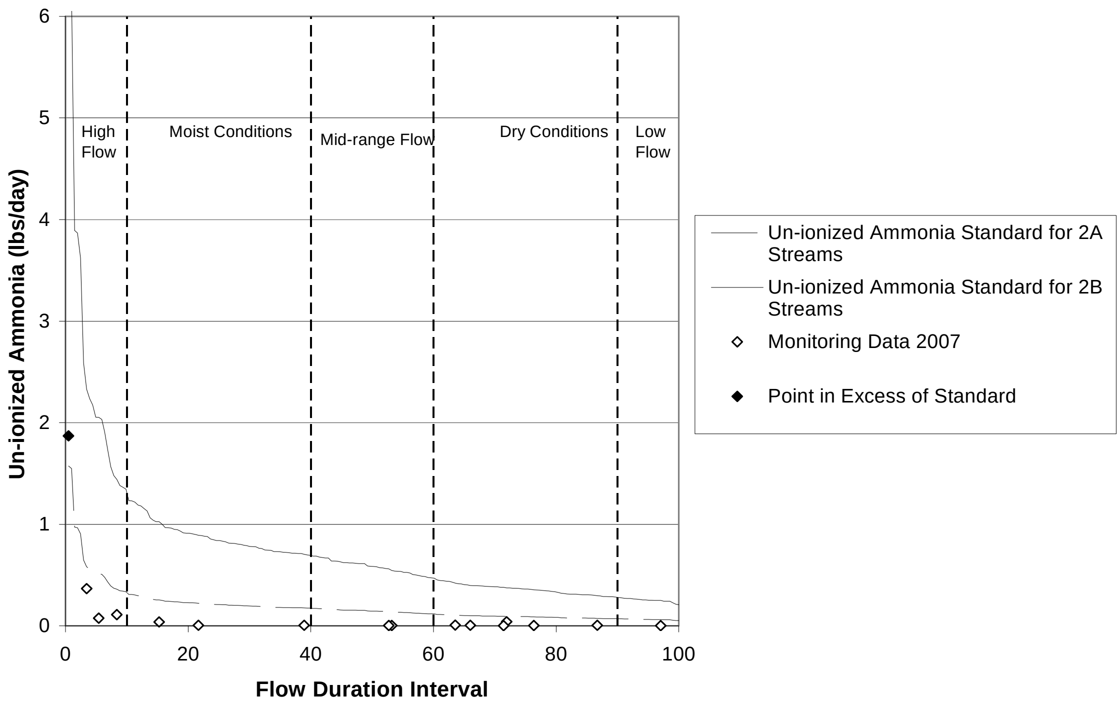


Figure 72. Load duration curve for un-ionized ammonia, Highway 15, Brown's Creek monitoring data 2007 (flow from all available data).

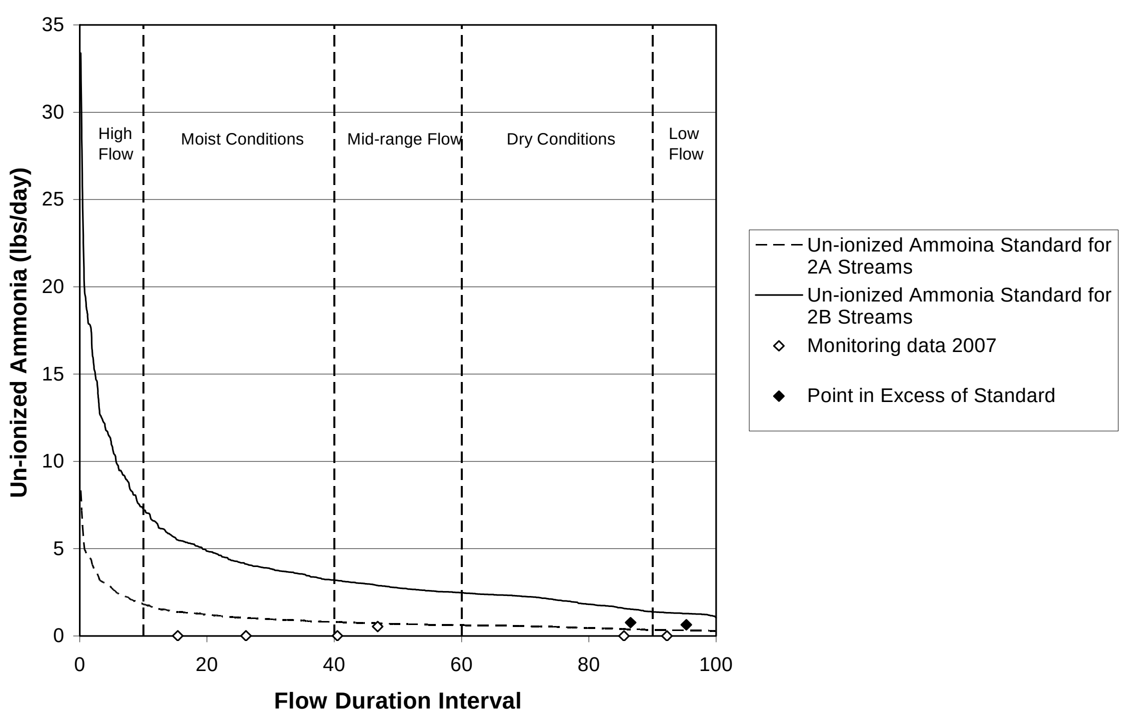
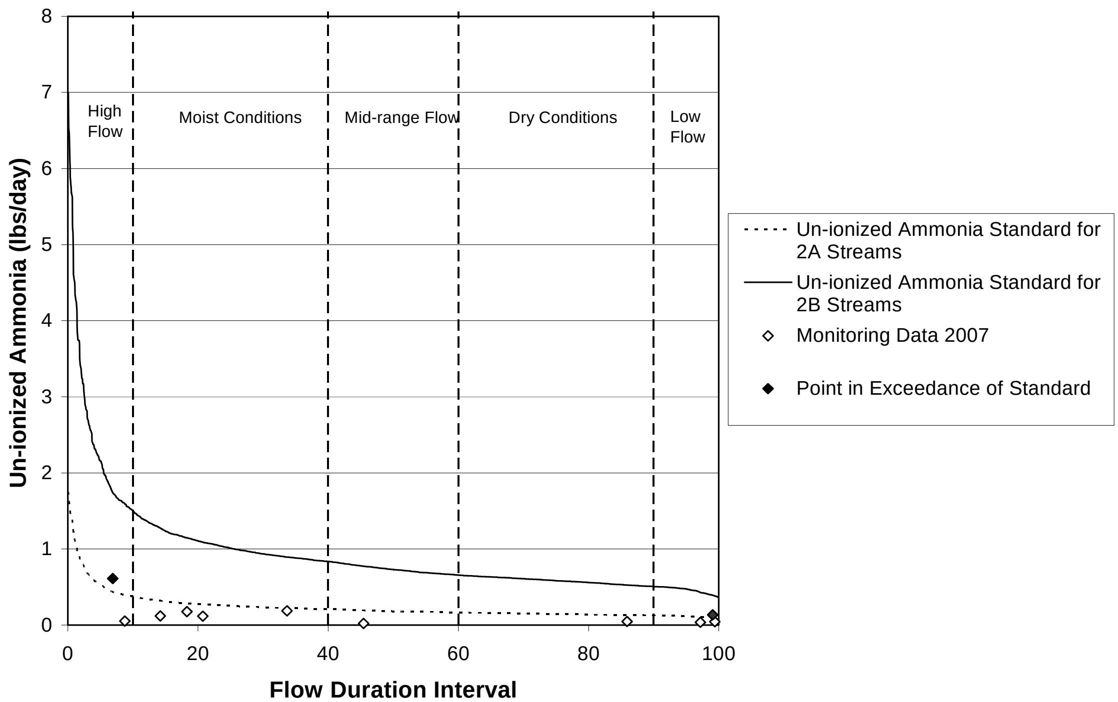


Figure 73. Load duration curve for un-ionized ammonia, WOMP, Brown's Creek monitoring data 2007 (flow from all available data).



Ratio of groundwater to surface water in Brown's Creek

Data concerning the chemistry of groundwater and location of groundwater inputs to Brown's Creek are forthcoming from Scott Alexander, University of Minnesota. The distribution of springs assessed by field surveys show that Brown's Creek has significant groundwater input. This produces cooler temperatures but naturally lower DO. Groundwater inputs increase going downstream, but DO values increase as well due to higher gradients and riffle areas. Groundwater temperatures should keep the stream cool enough in summer (and warm enough in winter) to support healthy trout populations, but surface water warming effects in summer are inhibiting this effect. There is no evidence that groundwater is contributing nutrients or copper to Brown's Creek.

CONCLUSION: MULTIPLES STRESSORS INTERACT TO PRODUCE BIOLOGICAL IMPAIRMENTS IN BROWN'S CREEK

Data from Brown's Creek show that multiple interacting stressors explain the biological impairments for fish and invertebrates. High suspended solids, low dissolved oxygen, high temperatures, copper, nitrogen, and habitat quality are the key stressors identified using the CADDIS sufficiency of evidence system. Overall, these stressors interact to cause avoidance in fish and vagile invertebrates as well as physiological stress that reduces growth and reproduction. The failure of permanent establishment of introduced cold water fish species and pattern of macroinvertebrate community composition indicate that these stressors in concert are responsible for mortality of eggs, adults, or both.

The identified stressors have common sources relating to surface water runoff to the stream. Impervious surfaces in the watershed result in higher surface water inputs relative to groundwater, increasing temperature. Runoff also carries suspended solids, copper, and nutrients. Patterns of low dissolved oxygen are more complicated and sources are most likely natural in the upstream areas. Rosgen analysis shows most of the stream banks are stable, but some changes in vegetation along Brown's Creek reduces shading (increasing temperature) and exacerbates the impact of surface runoff. The distribution of registered (and unregistered) septic systems is a concern, along with other sources of high phosphorus and nitrogen such as agriculture and lawn care.

Combined, these identified stressors are responsible for the distribution of species showing lack of cold water assemblages of fish and invertebrates in Brown's Creek. The better cold water fish assemblages in cooler years combined with watershed improvements from 1998 to 2004 show that the mechanisms leading to impairment can be successfully addressed.

Table 17. Summary of primary stressors. "P" indicates that the potential stressor is a primary stressor for the listed impairment, "S" indicates that the potential stressor is a secondary stressor, "–" indicates that the potential stressor likely is not a stressor on the biota of Brown's Creek, and "?" indicates that there is not enough information to determine if it is a stressor.

Stressor	Upper Reach (07030005-587) Invert Impairment	Upper Reach (07030005-587) Fish Impairment	Lower Reach (07030005-520) Fish Impairment
TSS	S	S	P
Dissolved oxygen	P	P	S
Temperature	P	P	P
Copper	–	–	P
Habitat loss and fragmentation	S	S	S
NO_x	S	S	S
NH_3	?	?	?

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Attachments

Attachment A. Status Report for Phase I of the Brown's Creek Biological TMDL.

Attachment B. History of Brown's Creek Impairment Listing by the MPCA.

Attachment C. Geomorphic Analysis of Brown's Creek.

Attachment D. Riparian and Groundwater Dependent Vegetation Maps.

Attachment E. Bioassessment of Macroinvertebrates at Five Sites on Brown's Creek Near Stillwater, Minnesota

Attachment A. Status Report for Phase I of the Brown’s Creek Biological TMDL.

M E M O R A N D U M

To: Craig Affeldt
Jeffery Jasperson
Minnesota Pollution Control Agency

From: Marcey L. Westrick, Jay Riggs, Karen Kill, and Travis Thiel

Subject: Status Report for Phase I of the Brown's Creek Biological TMDL **Date:** June 25, 2007

The purpose of this memorandum is to provide a status update on the work performed under Phase I of the Brown's Creek Biological TMDL. During Phase I, the Stressor Identification Process was initiated, and a significant amount of data was collected from Highway 15 north to 110th Street, from the time period of February through June 2007. Summaries of the data collected and the analyses performed during the Phase I study are below. Individual topic reports that are more detailed are included as attachments to this memorandum.

While this data has been extremely useful to help characterize this reach of Brown's Creek, the scope of the project has changed to include the entire stretch of Brown's Creek from 110th Street to the St. Croix River. The reason for the change of scope of the Phase I project is due to the fact that an error was found in the MPCA rule that lists the assessment units for Brown's Creek. As a result, the MPCA is proposing to change the assessment unit and hence the 303(d) listing for Brown's Creek. Where previously the creek was listed as impaired due to a low Index of Biotic Integrity score based on class 2B criteria, the entire trout stream below 110th to the St. Croix River will now be impaired based on class 2A criteria and the stream will be listed as being impaired due to a lack of cold waters fisheries. The remaining previous impairment for macroinvertebrates will remain unchanged but will extend to the St. Croix River. Phase II of the Brown's Creek Biological TMDL will address this change in listing (Table 1).

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Table1. Brown's Creek 303(D) Listing

	Brown's Creek Original Listing	Brown's Creek New Listing
Pollutant or stressor:	Low fish IBI Low macroinvertebrate IBI	Lack of coldwater assemblage; Low macroinvertebrate IBI
River Identification:	07030005-587	07030005-520
Impairment:	Aquatic life	Aquatic life
Year first listed:	2002	2002
Target start/completion:	2006/2009	2006/2009
CALM category:	5A – Impaired by multiple pollutants and no TMDL study plan is approved by EPA	5A – Impaired by multiple pollutants and no TMDL study plan is approved by EPA
Priority ranking:	High	High

Water Quality Monitoring

Water quality monitoring took place at three sites (Figure 1) during the course of the Phase I study. Data collected at these sites includes the following:

- Alkalinity
- Hardness
- Chloride
- Total phosphorus (TP)
- Dissolved phosphorus (DP)
- Total Kjeldahl nitrogen (TKN)
- Nitrate+nitrite-N (NO_x)
- Ammonia (un-ionized NH_3)
- Turbidity
- Total suspended solids (TSS)
- Volatile suspended solids (VSS)
- Total organic carbon (TOC)
- Biochemical oxygen demand (BOD)
- Dissolved oxygen
- Temperature
- Conductivity
- Copper (Cu)
- Lead (Pb)
- Nickel (Ni)
- Zinc (Zn)
- Cadmium (Cd)
- Chromium (Cr)

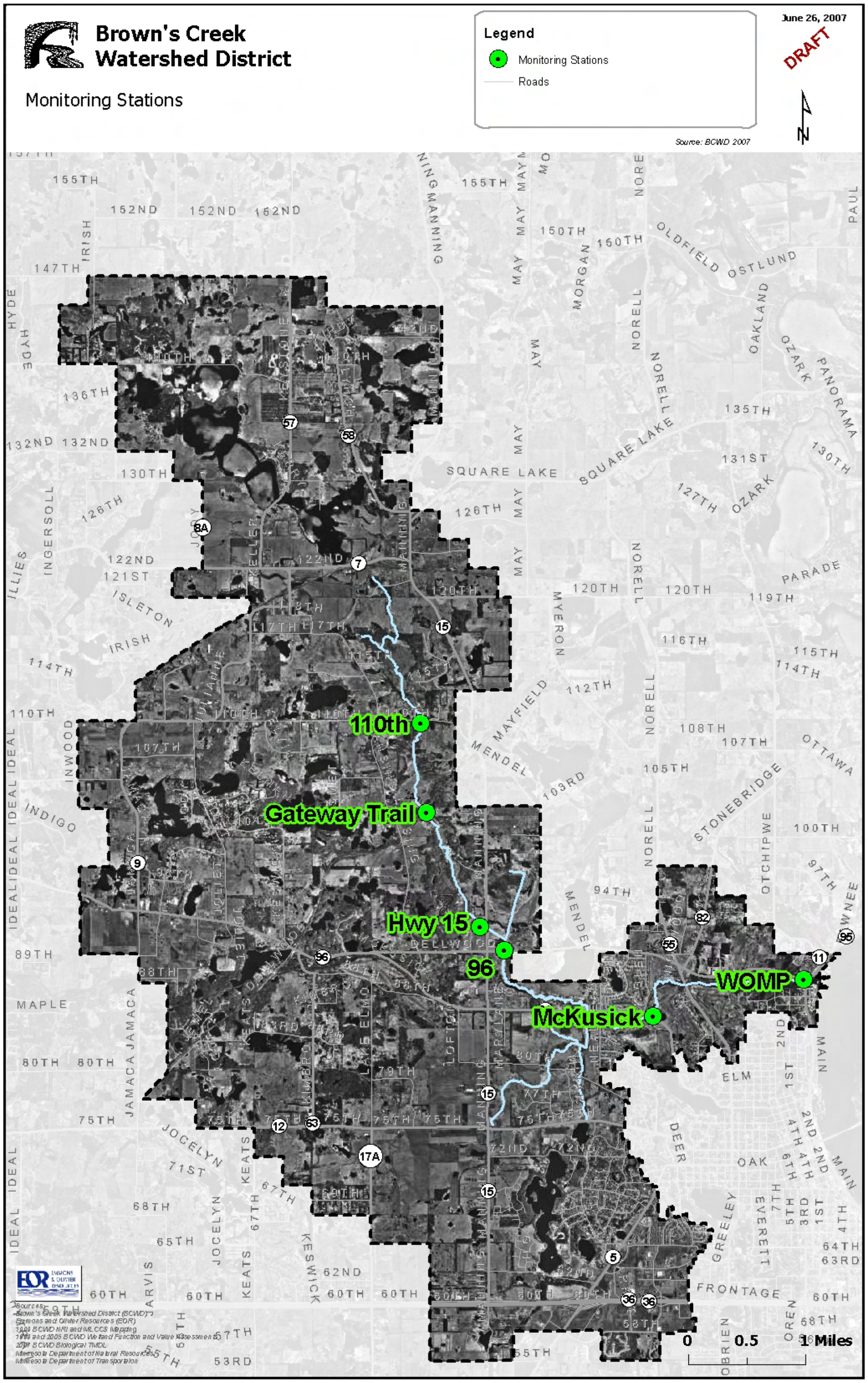
Data began being collected in February 2007 at Highway 15 and in April 2007 at the Gateway Trail and 110th Street. Water quality samples are being collected through the end of June 2007. Lab analysis has been conducted on samples collected from February 22, 2007 to May 23, 2007. These data were incorporated into the water quality analysis as described below. Additional lab results and associated analysis will be incorporated under the Phase II study of the Brown's Creek Biological TMDL.

Geomorphic Assessment

An extremely important component of stream ecology is establishing relationships among habitat, flows, and channel form and function. A channel geomorphology survey was conducted from 110th Street to the first crossing on McKusick Road North (Figure 1). Channel dimensions and longitudinal profile were surveyed at 11 reaches (Attachment 1). In addition, as part of the survey, stream crossings were evaluated to assess their fundamental interaction with the creek. Collectively, this information was used to estimate the Rosgen stream classification type. The ultimate goal of Level II Rosgen classification is to provide the baseline information needed to address questions of sediment supply, stream sensitivity to disturbance, potential for natural recovery, channel responses to changes in flow regime, and fish habitat potential (Rosgen, 1996).

Of the eleven reaches surveyed, there are two predominate channel types (E, C). The transition between channel types correlates well with the groundwater and riparian areas of the systems. Most notable were the riparian vegetation transitions from alder swamp to a wet meadow. These channel types are very stable in this portion of Brown's Creek. Of the culverts assessed, the culvert at 110th Street serves as a fish barrier under low flow conditions.

Figure 1. Brown's Creek Monitoring Stations



Riparian and Groundwater Dependent Vegetation Assessment

Riparian vegetation is very important in determining the structure and function of stream ecosystems. Most aquatic organisms, including invertebrates and fish, are directly or indirectly dependent on inputs of terrestrial detritus to the stream for their food. Natural changes in riparian vegetation and the biotic processing of detritus, as well as other factors, determine the kinds and abundance of aquatic biota living in streams. As part of the Phase I study, a detailed assessment of the riparian corridor expanding 50 feet on both sides of the creek was conducted. One reason for such a detailed assessment was to also evaluate groundwater dependent vegetation associated with Brown's Creek.

Groundwater seepage to the surface environment provides highly specialized hydrologic conditions that support numerous plant species and natural communities. In the upper and lower watersheds of Brown's Creek, groundwater seepage areas in wetlands create favorable conditions for seepage swamps, fens, and wet meadows. Unique plant species that depend on the integrity of groundwater discharge systems include skunk cabbage and swamp willow. Along the entire stretch of Brown's Creek are specialized natural communities that have developed and are dependent on groundwater seepage. Therefore, maintaining base flow to the upper and lower portions of Brown's Creek also maintains the health of individual rare plants and natural communities that are dependent on groundwater seepage.

The Brown's Creek Watershed District (BWCD) identified a process to evaluate whether a wetland or lake was a groundwater dependent resource. Criteria to identify groundwater dependent wetlands and lakes are described in the BCWD Watershed Management Plan. These criteria were used in this assessment. Field investigations were conducted in May and June 2007 from the second crossing at McKusick north to the headwaters area. Evidence of groundwater inputs were recorded using a Global Positioning System (GPS) with sub-meter accuracy, and divided into springs, seeps, and boils. The information collected on groundwater dependent vegetation provides additional detail to the wetland inventory (Attachment 2).

Groundwater Assessment

A critical component of a TMDL is to identify natural versus anthropogenic sources of pollutants. In the case of Brown's Creek, understanding the relationship between the creek, groundwater, and DO is critical to reviewing the DO standard for Brown's Creek and TMDL regulations in the headwaters area. In order to fully understand this, groundwater flow and chemistry were evaluated from County Road 5 to 121st Avenue with an emphasis on the stretch of Brown's Creek located between Highway 15 and 110th Street (Figure 1).

A high precision stream gauging effort was undertaken on May 4, 2007 to determine base flows in Brown's Creek (Table 2). In addition, water samples for cation/anion chemistry and natural organic material were collected at all gauging stations. Additional fieldwork was then undertaken to locate significant springs on the upper reaches between Highway 15 and 110th Street on June 8 and 18, 2007. Several large springs were located along with numerous small seeps. Twelve water samples for cation/anion chemistry and natural organic material were collected at all the major springs and a selection of the seeps (Attachment 3).

Table 2. Synoptic stream gauging on Brown's Creek May 4, 2007.

Location	g NaCl	Flow (liter/sec)	(ft^3/sec)	change (ft^3/sec)
121st Avenue		no flow		
110th Street	751.8	27.5	0.97	0.97
Gateway Trail	1183.3	65.2	2.30	1.33
Highway 15	1514.4	99.5	3.51	1.21
McKusick Road	1800	115.7	4.08	0.57
County Road 5	2550	157.3	5.79	1.71
S. Branch above confluence	735.4	1.97	0.069	0.069

As shown in Table 1, the largest gains in ground water flow occur between 110th Ave and the Gateway Trail (1.33 cfs) and between the Gateway Trail and Highway 15(1.21 cfs). The large increase between McKusick Road and County Rd 5 is probably associated with the Prairie du Chein bedrock unit. There was minimal ground water input to the South Branch of Brown's Creek.

Preliminary chemistry results show calcium/magnesium carbonate dominated systems as would be expected of upland recharge on Superior Lobe glacial tills. There is minor evidence of contaminants including chloride and nitrate possibly associated with septic systems at one location. Chloride values averaged between 4 and 8 ppm with one sample at 21 ppm. Nitrate-N ranged from 0.01 to 2.5 ppm. However, nutrient and organic loading from septic systems and feedlots do not appear to be a significant contributor for the upper reaches of Brown's Creek based on this preliminary assessment.

Biological Monitoring

Macroinvertebrate and Surface Floating Pupal Exuviae (SFPE) data were collected at three monitoring sites (110th Street, Highway 15, and Highway 96). Dip-net samples were collected on May 5, 2007, and SFPE data was collected on April 15, May 6 and June 9, 2007. Historical dip-net and SFPE data from the lower portion of Brown's Creek was used for comparison purposes.

Based on an interim analysis (Attachment 4), the species richness based on historical dip net data for the site in the lower portion of Brown's Creek is higher than the species richness detected at sites in the upper portion. In addition, diversity index values do not differ substantively among sites, and no pattern can be generalized from them other than that they suggest there is no strong stress response in terms of community structure of invertebrates. However, metrics based on Ephemeroptera, Plecoptera, and Trichoptera (EPT) and Diptera clearly indicate the historical data differs markedly from the data collected in May 2007 from the upstream three sites. Both the number and percent of EPT taxa are lower than indicated in historical data, with percent of EPT decreasing consistently from Hwy 96 north to upstream of 110th Street. The pattern of increasing percent Diptera from downstream to upstream reinforces the trend for EPT. Together, these metrics indicate a response to changing habitat, temperature, dissolved oxygen or a combination of these parameters from downstream to upstream.

In addition to evaluating species richness and diversity, similarity among sampling sites was also evaluated using Jaccard's Coefficient. Jaccard's Coefficient values can range from 1.0 representing complete overlap in community composition to 0.0 indicating no overlap in community composition. When multiplied by 100, the resulting value represents the percent of species shared among the two sample sites being compared. In the upper portion of Brown's Creek, three patterns are apparent from these coefficients. The first pattern is that the 110th Street site is the least similar site to all others. The second conspicuous pattern is that the two most similar sites, Highway 15 and Highway 96, are physically close to each other and have relatively similar substrates, discharge, and flow characteristics. The third pattern is that the community structure of the sample site at Highway 96 is the most similar of the upstream sites to the historical data for the site in the lower portion of the creek. Consequently, it appears the substrate, physical, and/or chemical conditions are most different at the upstream site relative to sites at Highway 15, Highway 96, and in the lower portion of the watershed.

Results of collections of SFPE strongly corroborate the patterns in data for dip-net collections. Species richness of all upstream sites is less than the estimate for April through June in the historical data for the lower segment of the creek. Richness among the upstream sites, however, does not vary substantively and there is no upstream-downstream pattern of increasing or decreasing richness. The upstream-most site, however, clearly shows a depressed diversity index value relative to all other sites, but is still in the range of values generally considered as indicating good to excellent conditions. The richness and percent of Orthocladiinae show a very strong pattern that reinforces the diversity index pattern, with the site upstream of 110th Street showing substantial reductions in Orthocladiinae. The percent Chironominae shows a corresponding and reinforcing pattern of increased percent composition at 110th Street. Consequently these metrics point to reductions in DO and/or increases in temperature as structuring community composition and emergence of Chironomidae from April through June.

Water Quality Analysis

Various pollutants were evaluated in an attempt to determine their potential to be stressors to the biological community of the creek (Attachment 5). Data were visually examined and means were compared to water quality standards and guidelines for class 2A waters. In addition to the MN standards, data were compared to guidelines based on the 75^{th} percentile of data (1970 through 1992, annual) from minimally impacted streams in the north central hardwood forests ecoregion (McCollor and Heiskary 1993). Flow and load duration curves were also used to see under which flow regimes the standard and guideline exceedences occur.

Nutrients

Phosphorus and nitrogen were evaluated to assess if nutrient impairment is a likely stressor on the biological community in Brown’s Creek. Historical total phosphorus (TP) data collected in 2005 and 2006 indicate that under high flow conditions, the monitoring site at Highway 15 exceeds the water quality guideline for total phosphorus. Historic monitoring sites located in the downstream reach of Brown’s Creek also show TP exceedences under high flow conditions. Data collected during the first part of 2007 shows that there were no TP exceedences.

No historic nitrogen data was available in the upper reach of the creek. Data collected during the first part of 2007 revealed exceedences for both the ammonia standard and the nitrate + nitrite-nitrogen (NO_x) guideline. Preliminary results from the groundwater assessment indicate nitrate may be naturally higher than the guideline. Both NO_x and ammonia will be more closely evaluated during the Phase II study.

Sediment

Total suspended sediment (TSS) data was evaluated to assess if sedimentation is a likely stressor on the biological community in Brown's Creek. TSS data show a pattern similar to that of TP: data from the downstream reaches exceeded both the turbidity standard and the guideline and exceedences occurred mainly under high flow conditions.

VSS:TSS was also evaluated and is higher in the upstream sites as compared to the lower stream sites, indicating that organic matter represents a larger fraction of the suspended solids.
Storm events in the lower portion of Brown's Creek have a lower VSS:TSS than baseflow; the mineral component of TSS is larger in storm events, possibly due to changes in watershed runoff or streambed and streambank erosion.

Metals
Of the metals evaluated, copper was indicated as a potential stressor. While most of the observed concentrations are well below the chronic standard, there are observations that exceed this standard, three above the maximum standard, and one observation that is above the acute standard.

Dissolved Oxygen (DO)
Dissolved oxygen data was evaluated for the three sites of the upper reach of the creek: 110th Street, Gateway Trail, and Highway 15 using a continuous YSI probe. Data collected and evaluated from April 16, 2007 to May 11, 2007 show that DO at the Gateway Trail and 110th Street sites fell below the water quality standard.. Based on the groundwater analysis and the biological analysis also done at these sites, it is hypothesized at this time that the low DO in this portion of the creek is naturally occurring. This will be further evaluated in the Phase II study.

Temperature
Data collected from April 16 to May 11 at 110th Street, Gateway Trail, and Highway 15 shows that the stream is approximately 1 degree warmer at the upstream site compared to the downstream site and the water temperature did not exceed either the critical or threat temperature during this time period. However, additional observation of historic data from 2005 and 2006 reveals that the maximum daily in-stream water temperatures for the Highway 15 and McKusick Road sites exceeded the critical temperature several times.

*Chloride*The chloride concentrations in Brown's Creek are all well below the standard of 230 mg/L and none of the individual values exceed the final acute value of 1720 mg/L

Conclusion

Due to the change of scope of this project, a complete stressor identification of Brown's Creek has not been completed However, based on the data collected and analysis to date, we can conclude that the following candidate causes are potentially impacting the aquatic life in Brown's Creek. Conceptual models of these potential stressors can be found in Attachment 6.

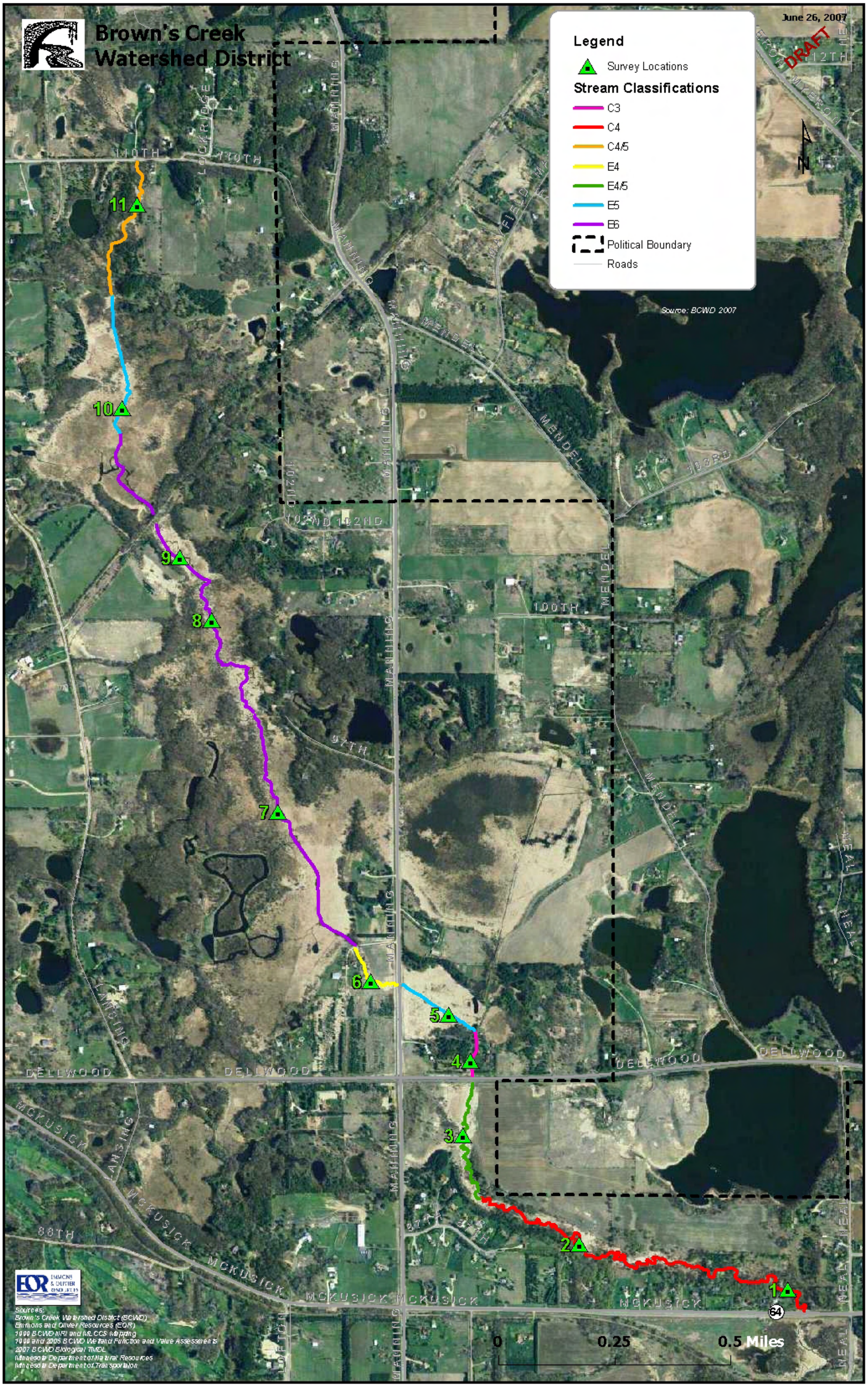
- Sedimentation
- Low dissolved oxygen
- Nutrient enrichment
- Ammonia toxicity
- Copper toxicity
- High temperature

In addition, of the data evaluated to date, the following have been excluded as being a candidate cause based on monitoring data showing no exceedences of the standards or guidelines.

- Chloride
- Lead (Pb)
- Nickel (Ni)
- Zinc (Zn)
- Cadmium (Cd)
- Chromium (Cr)

Attachment 1

Geomorphic Analysis



Brown's Creek Watershed District
June 26, 2007
DRAFT
Legend
Survey Locations
Stream Classifications
C3
C4
C4/5
E4
E4/5
E5
E6
Political Boundary
Roads
Source: BCWD 2007
110TH
LOCKRIDGE
MANNING
MENDEL
102ND
103RD
100TH
97TH
DELLWOOD
LANSING
MCKUSICK
88TH
64
1
2
3
4
5
6
7
8
9
10
11
0
0.25
0.5 Miles
Sources:
Brown's Creek Watershed District (BCWD)
Emmons and Olivier Resources (EOR)
2007 BCWD Biological TMDL
Minnesota Department of Natural Resources
Minnesota Department of Transportation

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 500 river feet upstream of McKusick Rd N*
DATE	*5/22/2007*
FIELD ID	*Site #1*

BANKFULL ELEVATION (ft)		866.1
CHANNEL DIMENSIONS	W_{bkf} (ft)	*11.00*
	D_{mean} (ft)	*0.84*
	W/D	*13.10*
	D_{max}(ft)	*1.17*
	2 x D_{max}(ft)	*2.35*
	CSA (ft^2)	*9.23*
	W_{flp} (ft)	*17.00*
	E	*1.55*
CHANNEL MATERIAL (D50)		*Gravel*
SINUOSITY		*1.5*
SLOPE		*0.004*
ROSGEN LEVEL II STREAM CLASSIFICATION		***C4***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- The deepest pool (3.75' @ bankfull) across all surveyed reaches was found within this section.
- Strong groundwater contribution throughout
- Hardwood and Alder overstory

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 2600 river feet downstream of Hwy 96*
DATE	*5/22/2007*
FIELD ID	*Site #2*

BANKFULL ELEVATION (ft)		879.4
CHANNEL DIMENSIONS	W_{bkf} (ft)	*11.70*
	D_{mean} (ft)	*0.93*
	W/D	*12.57*
	D_{max}(ft)	*1.03*
	2 x D_{max}(ft)	*2.06*
	CSA (ft^2)	*10.89*
	W_{flp} (ft)	*34.00*
	E	*2.91*
CHANNEL MATERIAL (D50)		*Gravel*
SINUOSITY		*1.27*
SLOPE		*0.003*
ROSGEN LEVEL II STREAM CLASSIFICATION		***C4***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- Strong groundwater contribution throughout
- Hardwood & Alder overstory

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 400 river feet downstream of Hwy 96*
DATE	*5/22/2007*
FIELD ID	*Site #3*

BANKFULL ELEVATION (ft)		890.49
CHANNEL DIMENSIONS	W_{bkf} (ft)	*8.00*
	D_{mean} (ft)	*1.43*
	W/D	*5.59*
	D_{max}(ft)	*1.67*
	2 x D_{max}(ft)	*3.33*
	CSA (ft^2)	*11.46*
	W_{flp} (ft)	*80.00*
	E	*10.00*
CHANNEL MATERIAL (D50)		*Gravel/Sand*
SINUOSITY		*1.29*
SLOPE		*0.0048*
ROSGEN LEVEL II STREAM CLASSIFICATION		***E4/5***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable
- One of the steepest gradients
- Reed Canary Grass dominated cover

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 300 river feet upstream of Hwy 96*
DATE	*5/22/2007*
FIELD ID	*Site #4*

BANKFULL ELEVATION (ft)	893.9

CHANNEL DIMENSIONS	W_{bkf} (ft)	*14.00*
	D_{mean} (ft)	*1.11*
	W/D	*12.66*
	D_{max}(ft)	*1.60*
	2 x D_{max}(ft)	*3.20*
	CSA (ft^2)	*15.48*
	W_{flp} (ft)	*29.00*
	E	*2.07*

CHANNEL MATERIAL (D50)	*Cobble*

SINUOSITY	*1.02*

SLOPE	*0.004*

ROSGEN LEVEL II STREAM CLASSIFICATION	***C3***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks generally stable
- Cross-section and profile rip-rapped.
- Only section with significant cobble (likely artificial)
- Highly manicured buffer

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 500 river feetdownstream of Hwy 15*
DATE	*5/22/2007*
FIELD ID	*Site #5*

BANKFULL ELEVATION (ft)	894.77

CHANNEL DIMENSIONS		
	W_{bkf} (ft)	*7.50*
	D_{mean} (ft)	*1.88*
	W/D	*3.99*
	D_{max}(ft)	*1.69*
	2 x D_{max}(ft)	*3.39*
	CSA (ft^2)	*14.10*
	W_{flp} (ft)	*150.00*
	E	*20.00*

CHANNEL MATERIAL (D50)	*Sand*
SINUOSITY	*1.01*
SLOPE	*0.0001*
ROSGEN LEVEL II STREAM CLASSIFICATION	***E5***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- Reed Canary Grass dominated cover
- Channel material tapers from gravel in the upstream reaches to sand & organics in the downstream portion of this reach
- Historic ditching is apparent
- Poorest habitat of all reaches

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 300 river feet upstream of Hwy 15*
DATE	*5/22/2007*
FIELD ID	*Site #6*

BANKFULL ELEVATION (ft)		897
CHANNEL DIMENSIONS	W_{bkf} (ft)	*10.00*
	D_{mean} (ft)	*1.31*
	W/D	*7.65*
	D_{max}(ft)	*1.38*
	2 x D_{max}(ft)	*2.77*
	CSA (ft^2)	*13.06*
	W_{flp} (ft)	*65.00*
	E	*6.50*
CHANNEL MATERIAL (D50)		*Gravel*
SINUOSITY		*1.08*
SLOPE		*0.006*
ROSGEN LEVEL II STREAM CLASSIFICATION		***E4***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- Steep gradient
- Some of the best potential habitat surveyed

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 2725 river feet upstream of Hwy 15*
DATE	*5/22/2007*
FIELD ID	*Site #7*

BANKFULL ELEVATION (ft)		899.5
CHANNEL DIMENSIONS	W_{bkf} (ft)	*11.00*
	D_{mean} (ft)	*1.12*
	W/D	*9.86*
	D_{max}(ft)	*1.38*
	2 x D_{max}(ft)	*2.76*
	CSA (ft^2)	*12.27*
	W_{flp} (ft)	*180.00*
	E	*16.36*
CHANNEL MATERIAL (D50)		*Organics**
SINUOSITY		*1.09*
SLOPE		*0.0003*
ROSGEN LEVEL II STREAM CLASSIFICATION		***E6***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- Strong groundwater contribution throughout
- Bed material consists of consolidated and unconsolidated organic material. Limited sand was found well beneath the organics in some areas
- Very low gradient

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 1670 river feet downstream of the Gateway Trail*
DATE	*5/22/2007*
FIELD ID	*Site #8*

BANKFULL ELEVATION (ft)		902.3
CHANNEL DIMENSIONS	W_{bkf} (ft)	*12.10*
	D_{mean} (ft)	*1.47*
	W/D	*8.22*
	D_{max}(ft)	*1.81*
	2 x D_{max}(ft)	*3.62*
	CSA (ft^2)	*17.81*
	W_{flp} (ft)	*200.00*
	E	*16.53*
CHANNEL MATERIAL (D50)		*Organics**
SINUOSITY		*1.09*
SLOPE		*0.0002*
ROSGEN LEVEL II STREAM CLASSIFICATION		***E6***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- Strong groundwater contribution throughout
- Alder overstory
- Bed material consists of consolidated and unconsolidated organic material. Limited sand was found well beneath the organics in some areas
- Very low gradient

Note: Survey may have been distorted by an active beaver dam present 300+/- downstream of surveyed reach

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 890 river feet downstream of the Gateway Trail*
DATE	*5/22/2007*
FIELD ID	*Site #9*

BANKFULL ELEVATION (ft)	902.9

CHANNEL DIMENSIONS		
	W_{bkf} (ft)	*10.00*
	D_{mean} (ft)	*1.79*
	W/D	*5.58*
	D_{max}(ft)	*1.88*
	2 x D_{max}(ft)	*3.77*
	CSA (ft^2)	*17.94*
	W_{flp} (ft)	*205.00*
	E	*20.50*

CHANNEL MATERIAL (D50)	*Organics**
SINUOSITY	*1.16*
SLOPE	*0.001*
ROSGEN LEVEL II STREAM CLASSIFICATION	***E6***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- Cattail dominated cover
- Bed material consists of consolidated and unconsolidated organic material. Limited sand was found well beneath the organics in some areas
- Very low gradient

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 1850 river feet upstream of the Gateway Trail*
DATE	*6/20/2007*
FIELD ID	*Site #10*

BANKFULL ELEVATION (ft)		905.55
CHANNEL DIMENSIONS	W_{bkf} (ft)	*4.00*
	D_{mean} (ft)	*1.21*
	W/D	*3.32*
	D_{max}(ft)	*1.64*
	2 x D_{max}(ft)	*3.29*
	CSA (ft^2)	*4.82*
	W_{flp} (ft)	*200.00*
	E	*50.00*
CHANNEL MATERIAL (D50)		*Sand*
SINUOSITY		*1.1*
SLOPE		*0.003*
ROSGEN LEVEL II STREAM CLASSIFICATION		***E5***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are very stable
- Bankfull width and cross-sectional area are significantly less than downstream reaches
- Significant groundwater contributions throughout
- Areas of high flora quality

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 375 river feet downstrem of 110th Street*
DATE	*6/20/2007*
FIELD ID	*Site #11*

BANKFULL ELEVATION (ft)	917.3

CHANNEL DIMENSIONS	W_{bkf} (ft)	*15.00*
	D_{mean} (ft)	*0.51*
	W/D	*29.16*
	D_{max}(ft)	*1.50*
	2 x D_{max}(ft)	*2.99*
	CSA (ft^2)	*7.72*
	W_{flp} (ft)	*82.00*
	E	*5.47*

CHANNEL MATERIAL (D50)	*Gravel*

SINUOSITY	*1.28*

SLOPE	*0.0062*

ROSGEN LEVEL II STREAM CLASSIFICATION	***C4***

GENERAL COMMENTS & CONCLUSIONS:

- Most significant bank instabilities can be found in this reach, although streambanks are still very stable in relative comparison
- Hardwood and Alder dominated overstory
- Bankfull width increases dramatically with the short breaks in the canopy (reaches dominated by herbaceous cover).

Note: The new culvert at 110th street may be an impediment to fish migration. The downstream invert is elevated above the water surface during normal to low flows conditions.

Attachment 2

Riparian and Groundwater Dependent Vegetation Maps

Brown's Creek Watershed District

June 26, 2007

DRAFT

Riparian and Groundwater Dependent
Vegetation Assessment
Upper Brown's Creek

Legend

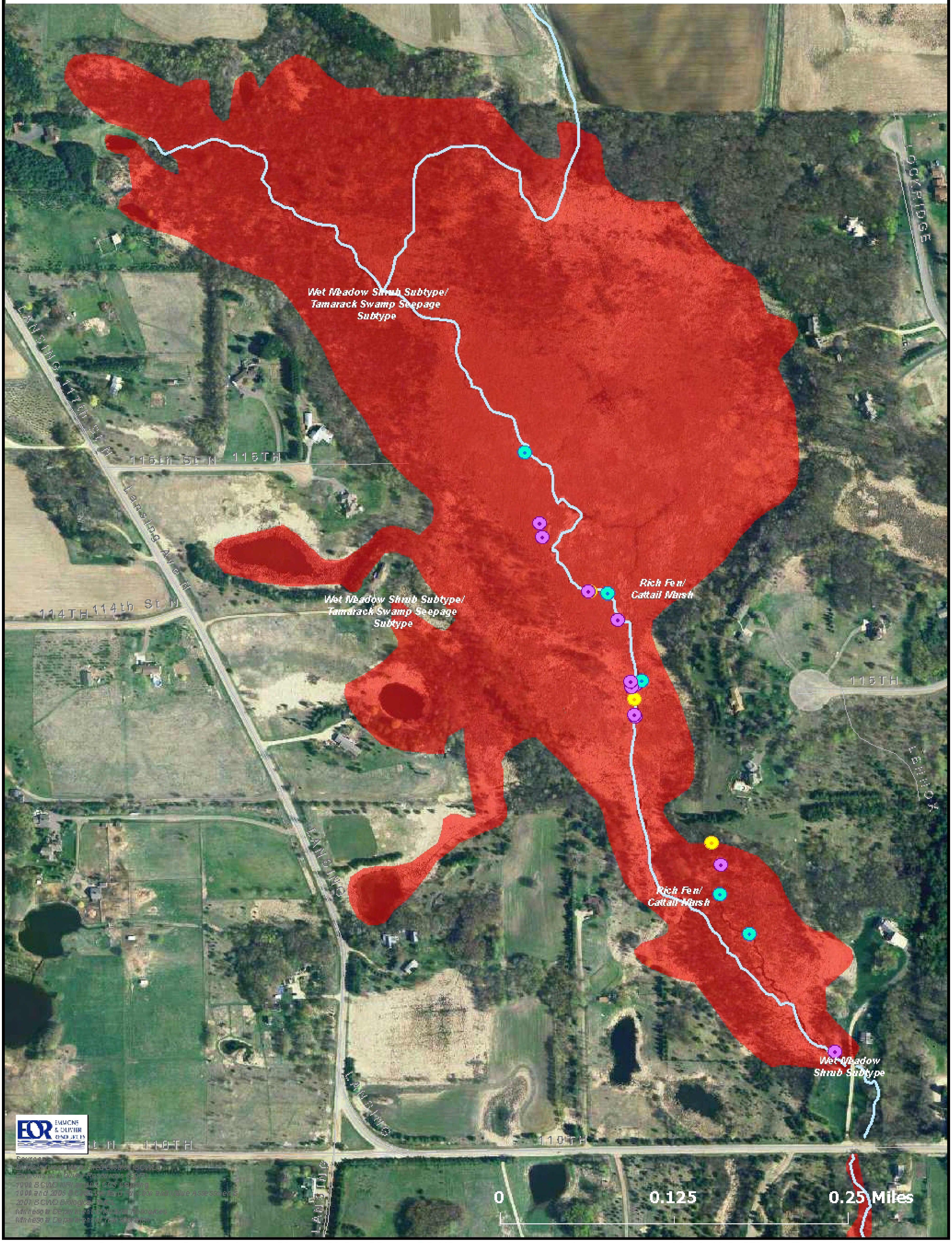
Field Collected Groundwater Indicators

- seep
- spring
- stream
- boil

Groundwater Dependent Wetlands

- Based on BCWD WFVA/Plant Community Type
- Based on Adjacent to GW Dependent
- Based on Additional Groundwater Studies
- Roads

Source: BCWD 2007



Brown's Creek Watershed District

Riparian and Groundwater Dependent Vegetation Assessment
Middle Brown's Creek
Reaches 4 and 5

June 26, 2007

DRAFT

Legend

Field Collected Groundwater Indicators

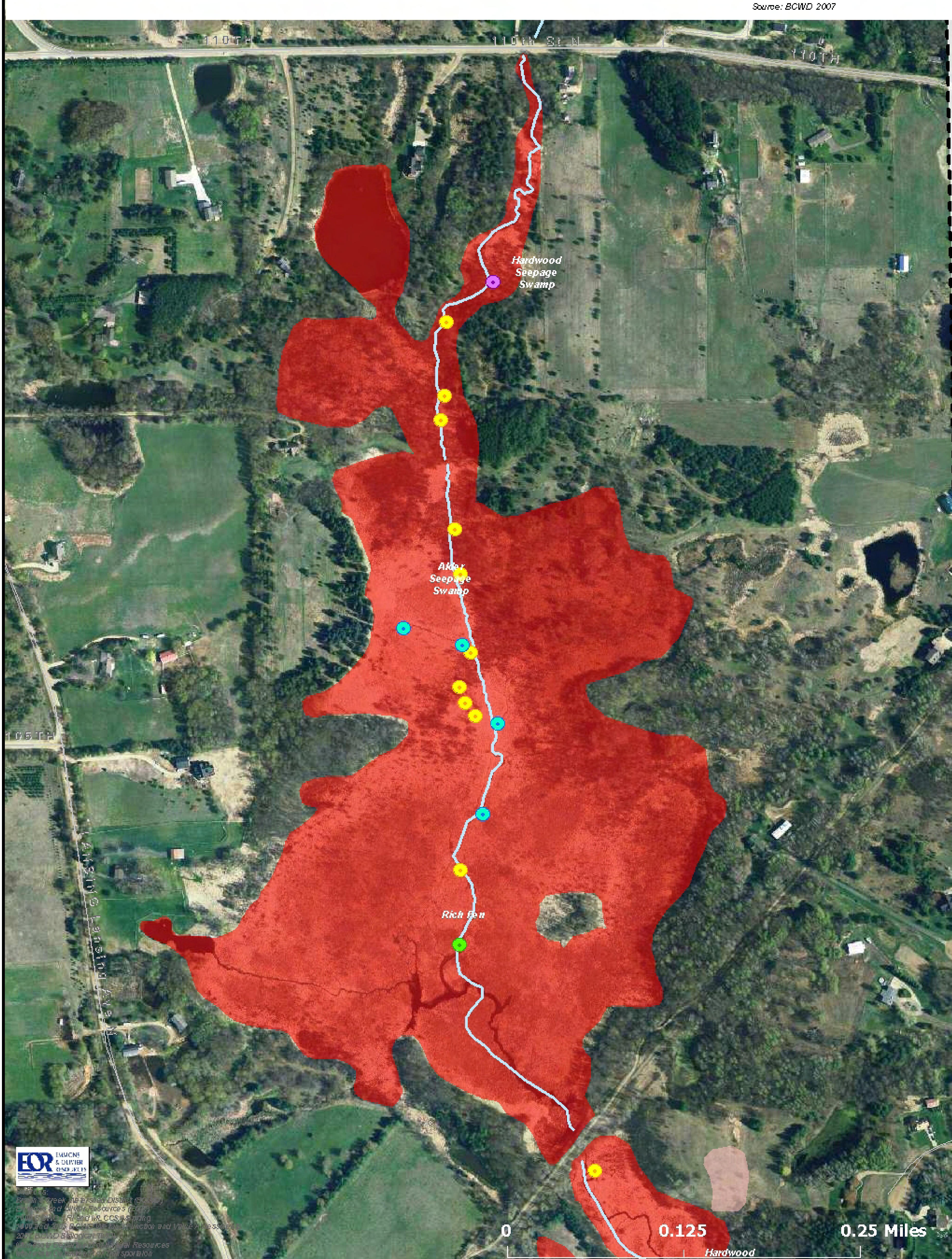
- seep
- spring
- stream
- boil

Groundwater Dependent Wetlands

- Based on BCWD WFVA/Plant Community Type
- Based on Adjacent to GW Dependent
- Based on Additional Groundwater Studies
- Roads

N

Source: BCWD 2007



June 26, 2007

DRAFT

Brown's Creek Watershed District

Riparian and Groundwater Dependent Vegetation Assessment
Middle Brown's Creek
Reaches 1, 2 and 3

Legend

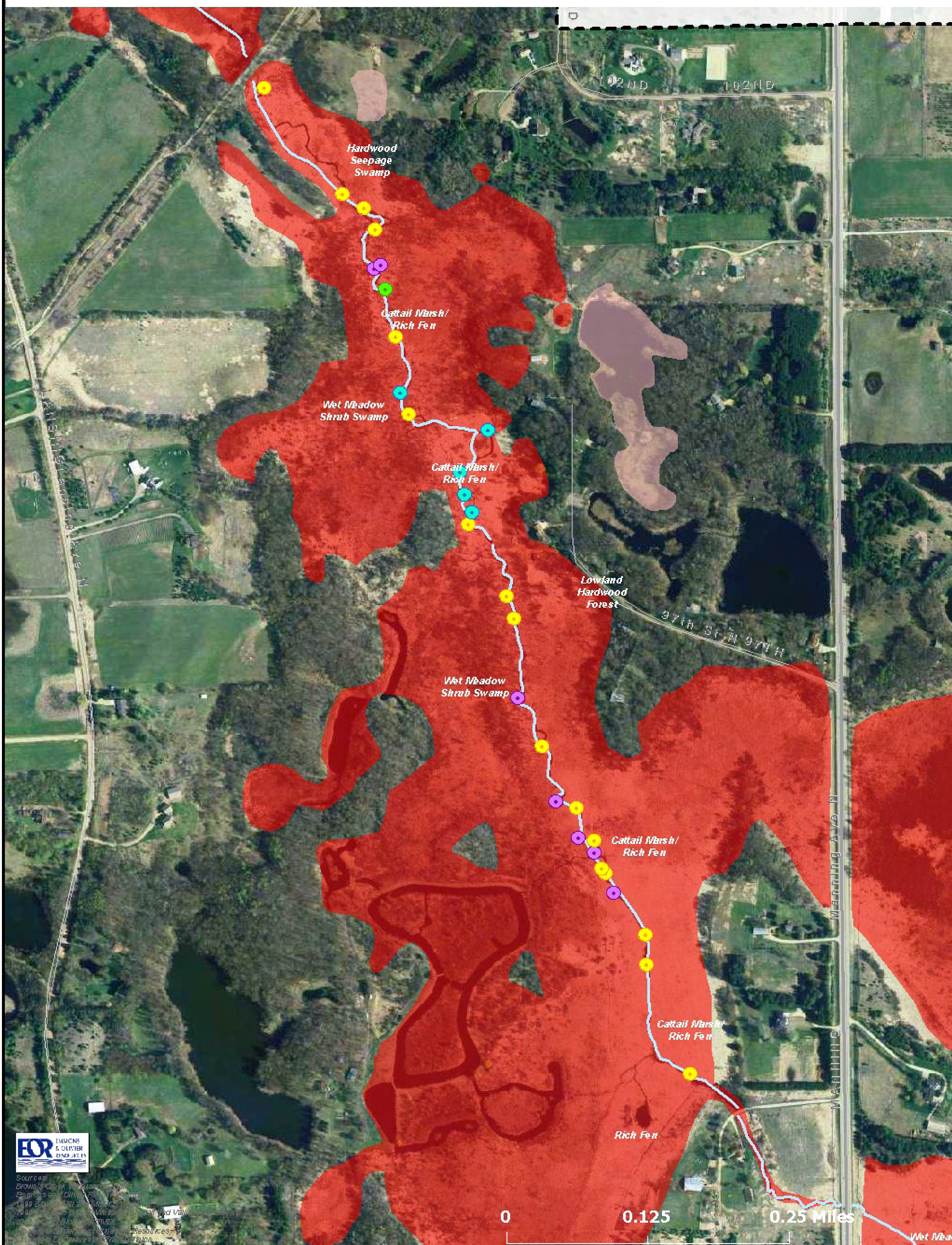
Field Collected Groundwater Indicators

- seep
- spring
- stream
- boil

Groundwater Dependent Wetlands

- Based on BCWD WFVA/Plant Community Type
- Based on Adjacent to GW Dependent
- Based on Additional Groundwater Studies
- Roads

Source: BCWD 2007



Brown's Creek Watershed District

Riparian and Groundwater Dependent Vegetation Assessment
Middle Brown's Creek - Manning Reach
Lower Brown's Creek - McKusick Reach (west)

Legend

Field Collected Groundwater Indicators

- seep
- spring
- stream
- boil

Groundwater Dependent Wetlands

- Based on BCWD WFVA/Plant Community Type
- Based on Adjacent to GW Dependent
- Based on Additional Groundwater Studies
- Roads

June 26, 2007

DRAFT

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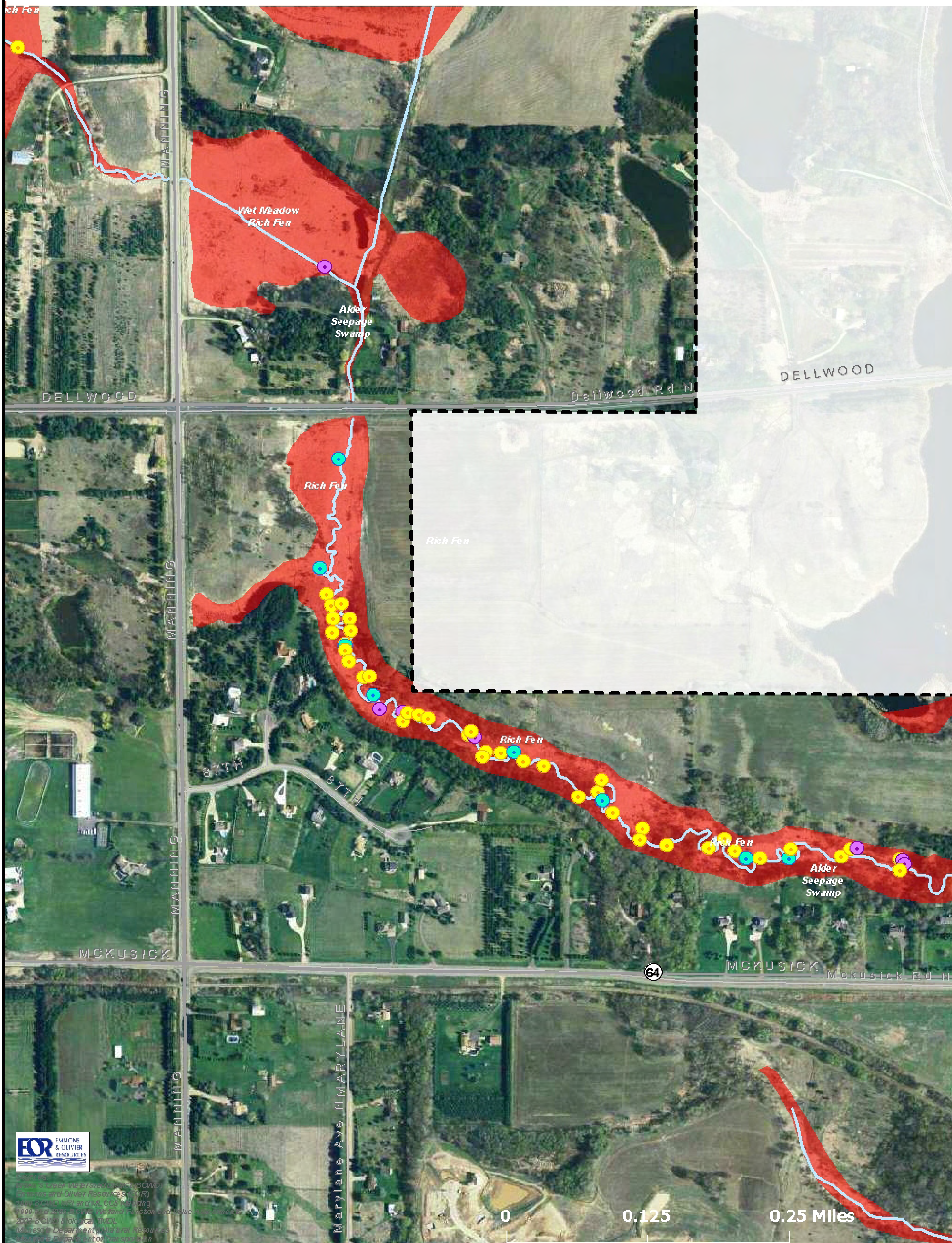
Source: BCWD 2007



Brown's Creek Watershed District

June 26, 2007

DRAFT

Riparian and Groundwater Dependent Vegetation Assessment
Lower Brown's Creek - McKusick Reach (east)
Lower Brown's Creek - DNR Reach 9

Legend

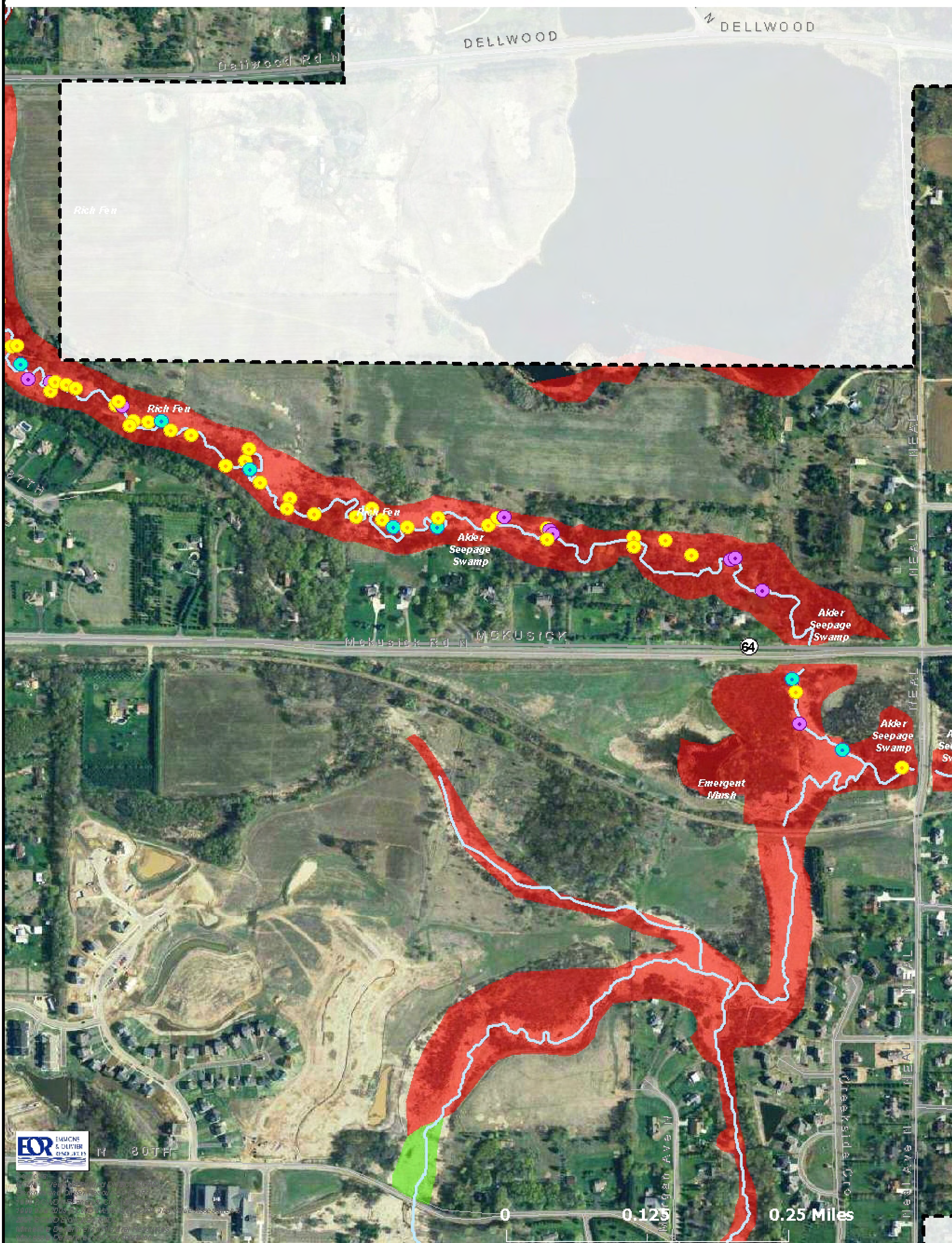
Field Collected Groundwater Indicators

- seep
- spring
- stream
- boil

Groundwater Dependent Wetlands

- Based on BCWD WFVA/Plant Community Type
- Based on Adjacent to GW Dependent
- Based on Additional Groundwater Studies
- Roads

Source: BCWD 2007



Brown's Creek Watershed District

June 26, 2007

DRAFT

Riparian and Groundwater Dependent Vegetation Assessment
Lower Brown's Creek

Legend

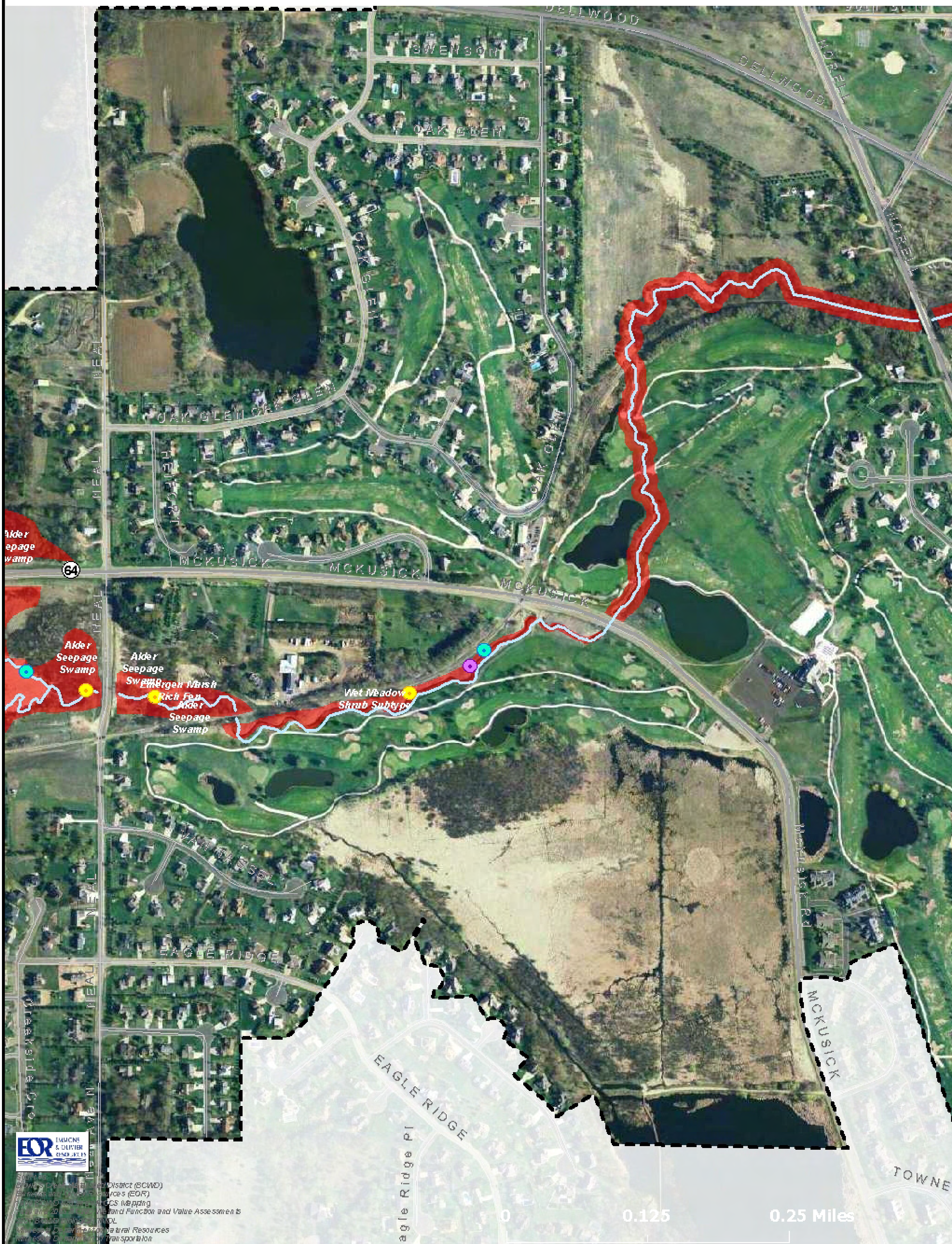
Field Collected Groundwater Indicators

- seep
- spring
- stream
- boil

Groundwater Dependent Wetlands

- Based on BCWD WFVA/Plant Community Type
- Based on Adjacent to GW Dependent
- Based on Additional Groundwater Studies
- Roads

Source: BCWD 2007



Attachment 3

Interim Groundwater Report

Brown's Creek Ground Water Hydrology Report - Manning to 110th Reach
Preliminary Report

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At the request of the Washington Conservation District and the Brown's Creek Watershed District work was undertaken to investigate the influence of ground water on the upper reaches of Brown's Creek. Analyses that were conducted included refinement of a water table aquifer map, review of existing chemistry and isotope studies, synoptic high precision stream gauging and collection of new water chemistry samples from stream and springs.

The water table mapping built off maps from the Square Lake Clean Water Partnership (2002), Carnelian-Marine Watershed District Ground Water Study (2001), Marine Watershed Management Organization St. Croix Spring Creeks Stewardship Plan (2001) and Science Museum of Minnesota St. Croix Watershed Research Station LCMR report on Monitoring and Modeling Valley Creek Watershed (1999). Specific improvements included extending mapped coverage to include all of Brown's Creek above the Paleozoic bedrock and refinement of twenty-five foot contours down to ten-foot contours. The new water table map is presented as Figure 1.

A high precision stream gauging effort was undertaken on May 4th, 2007 with the assistance on John Barry of Emmons & Olivier Resources. This date was several days removed from the most recent rainfall event. Gauging was conducted with a salt dilution method. A known quantity of salt, ranging from 735 to 2,500 grams of NaCl, was injected at a point a few hundred feet upstream of the monitoring point. At the monitoring point conductance was recorded at one-second intervals using a Campbell CR-10 datalogger and model 247 temperature/conductance probe. The sample probe was calibrated at each gauging station with four NaCl standards of 0.00 g/l, 0.05 g/l, 0.50 g/l and 5.00 g/l after allowing the standards to equilibrate to the stream temperatures. By performing an isothermal calibration at each station the final results are automatically reported in grams per liter of NaCl. The value for stream flow is then found by dividing the mass of NaCl in grams by the area of the conductance curve in gram seconds per liter to produce flow rate in liters per second. Results can be found in Table 1.

Table 1. Synoptic stream gauging on Brown's Creek May 4, 2007.

Location	g NaCl	Flow (liter/sec)	(ft^3/sec)	change (ft^3/sec)
121st Ave		no flow		
110th Ave	751.8	27.5	0.97	0.97
Gateway Trail	1183.3	65.2	2.30	1.33
Manning	1514.4	99.5	3.51	1.21
McKusick Rd	1800	115.7	4.08	0.57

County Rd 5	2550	157.3	5.79	1.71
S. Branch above confluence	735.4	1.97	0.069	0.069

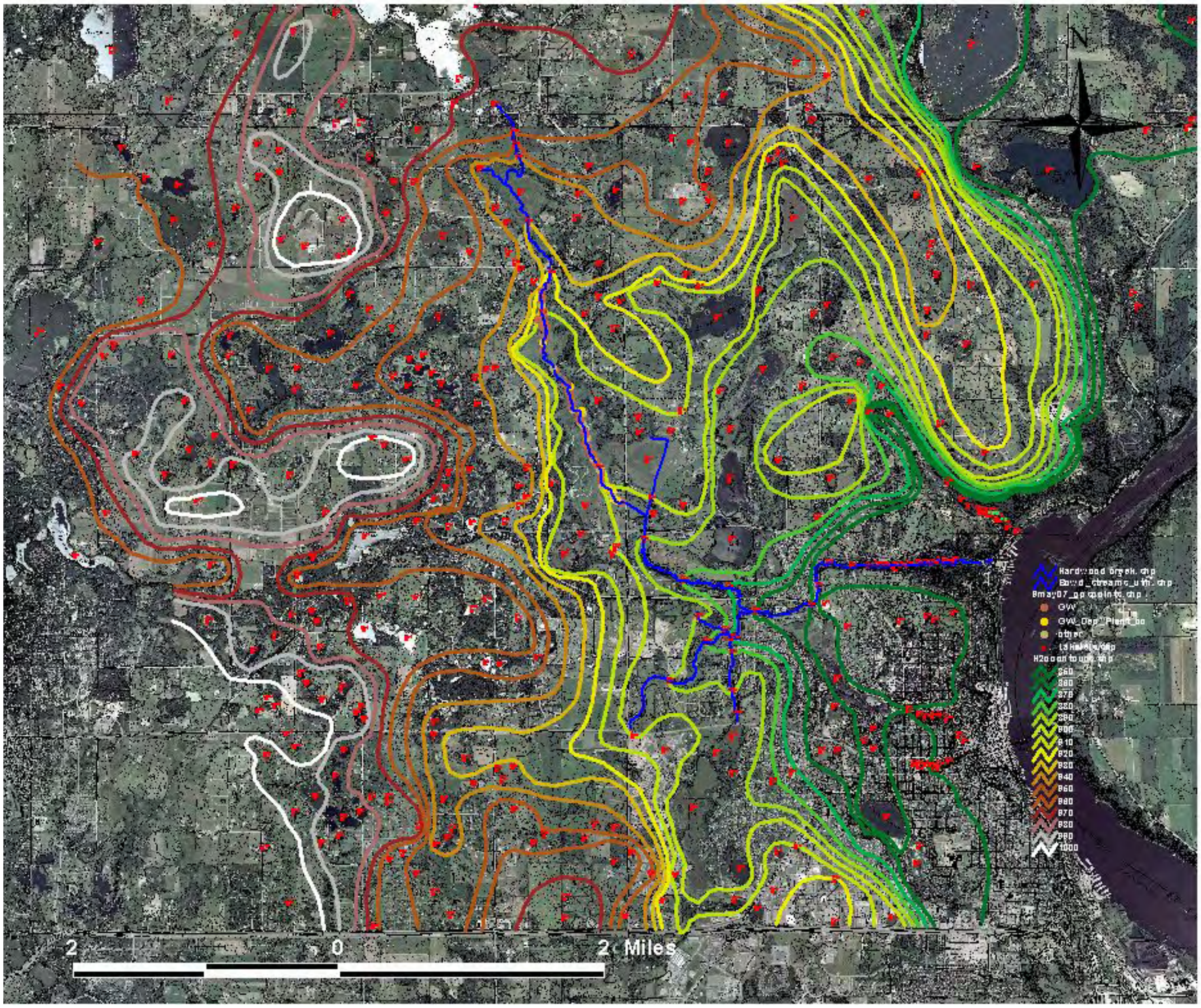

Figure 1. Water table potentiometric surface for the Brown's Creek Watershed (10 foot contours).

The largest gains in ground water flow occur between 110th Ave and the Gateway (1.33 cfs) and between the Gateway and Manning Ave (1.21 cfs). The large increase between McKusick Road and County Rd 5 is probably associated with the Prairie du Chein bedrock unit. There was minimal ground water input to the South Branch of Brown's Creek. In addition, water samples for cation/anion chemistry and natural organic material were collected at all six gauging stations.

Additional fieldwork was then undertaken to locate significant springs on the upper reaches between Manning and 110th Avenue on June 8th and 18th. Several large springs were located along with numerous small seeps. Twelve water samples for cation/anion chemistry and natural organic material were collected at all the major springs and a selection of the seeps. The locations of sampling points are shown in Figures 2 and 3.

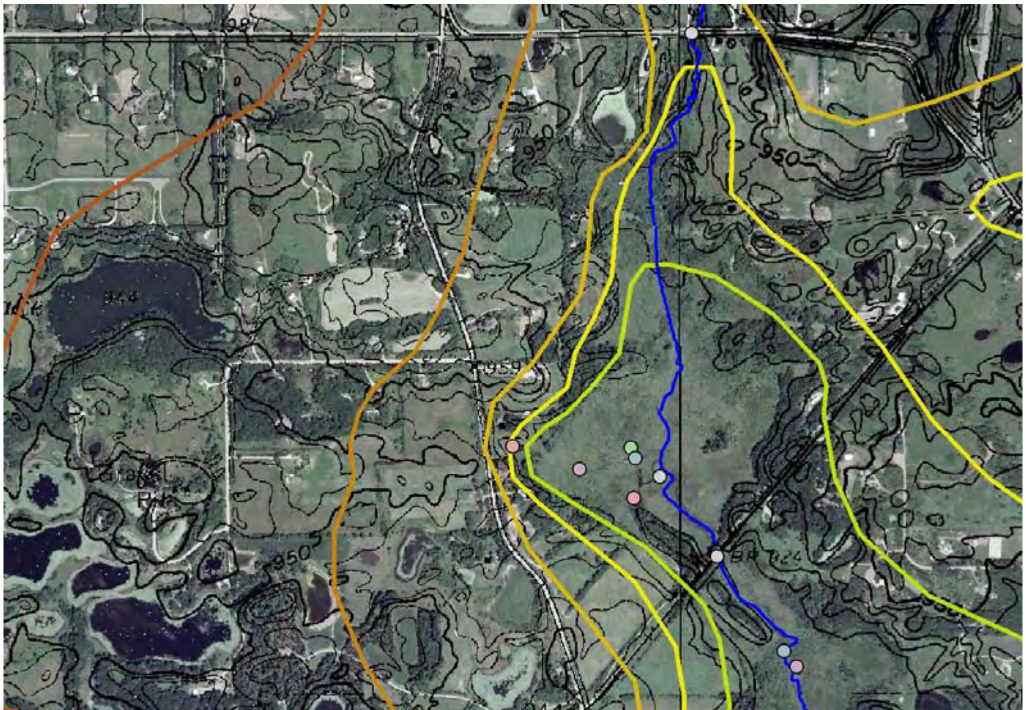

Figure 2. Brown's Creek sampling locations: 110th Avenue to Gateway Trail.

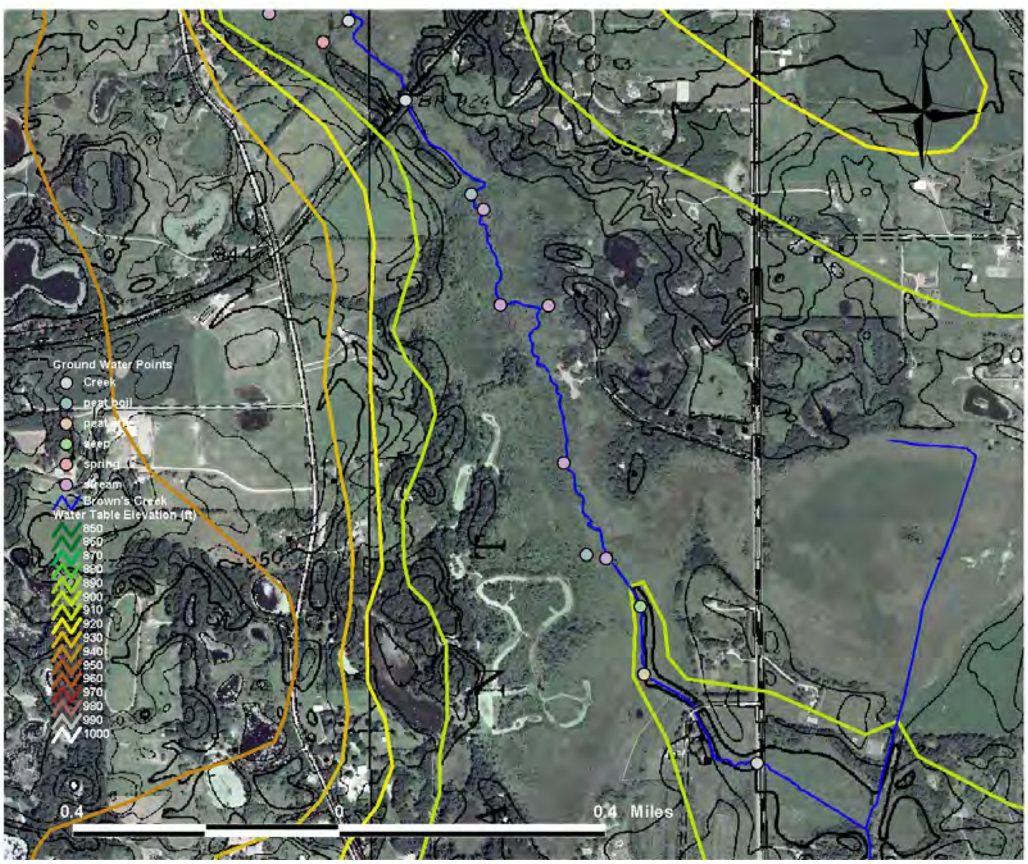

Figure 3. Brown's Creek sampling locations: Gateway Trail to Manning Avenue.

The larger springs in the upper reaches of Brown's Creek appear to be associated with the large, peat-filled basins that occur above Manning Avenue. Less ground water inflow is associated with stream sections located directly on glacial drift materials. Examination of the water table potentiometric map (Figure 1) shows a concentration of potential lines along the western margins of the peat basins. These narrowly spaced lines imply a steep hydraulic gradient and the increased likelihood of springs. Some of the springs are located along the basin margins while several springs emerge well out into the peat basin. Two springs, on either side of the Gateway Trail are directly associated with an esker that is perpendicular to the trail (linear ridge to the west of Brown's Creek crossing the Gateway).

There are numerous seeps that have lower electrical conductances (<0.6 mS) and higher water temperatures (>15°C). These seeps may be representative of meteoric waters moving within the peatland systems. The deeper ground water springs are larger (0.2 to 1 cfs), have cooler water (down to 8°C) and have slightly elevated conductivities (>0.75 mS).

Preliminary chemistry results show calcium/magnesium carbonate dominated systems as would be expected of upland recharge on Superior Lobe glacial tills. There is minor evidence of contaminants including chloride and nitrate possibly associated with septic systems at one location. Chloride values averaged between 4 and 8 ppm with one sample at 21 ppm as noted above. Nitrate-N ranged from 0.01 to 2.5 ppm. Nutrient and organic load from septic systems, feedlots, etc. do not appear to be a significant contributor for the upper reaches of Brown's Creek.

Attachment 4

Interim Biological Monitoring Report

INTERIM REPORT

Bioassessment of Macroinvertebrates at Three Sites on Brown's Creek Near Stillwater, Minnesota

by

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Introduction

In this document the community structure of macroinvertebrates is summarized for three sample sites in Brown's Creek. Data for this study were generated using (1) a standard dip-net sampling approach according to a protocol by the Minnesota Pollution Control Agency (Anonymous, available on-line) and (2) an innovative, rapid bioassessment field methodology using collections of surface-floating pupal exuviae (SFPE) to assess Chironomidae emerging from Brown's Creek. This innovative method is fully described and citations are included to provide necessary background and context. Detailed explanations are also provided of metrics that are calculated from data derived from each type of sample.

This report summarizes interim results for dip-net samples collected 5 May 2007, and collections of surface-floating pupal exuviae on 15 April, 6 May and 9 June 2007. Raw data by sample site and sample date are available by request in digital form.

Locations of Sample Sites

The locations of the sites sampled with dip-nets and for SFPE during this project were selected to coincide with (1) the locations of sites for which historical data exist for fish community structure and (2) places that are being monitored for physical and chemical parameters. The uppermost site is located just upstream of Hwy 110. The middle site is located just upstream of Hwy 15 and the lower site is located just upstream of Hwy 96. Historical data were obtained from the Metropolitan Council for macroinvertebrates collected in Fall of 2004 and 2005 with dip-nets in the lower section of Brown's Creek near the site where data are collected by Citizen Volunteers. In addition, data from a one-year study of Chironomidae emergence using collections of SFPE were reviewed. These two sets of data allow for comparisons of the three sample sites in this study to data generated during April, May, and June for the lower section of the stream in which trout populations occur.

Methods

Dip-net Samples

Dip-net samples were collected according to the SOP provided on-line by the Minnesota Pollution Control Agency. Samples were also preserved, sorted and processed according to guidelines developed by MPCA.

Collections of Surface-Floating Pupal Exuviae of Chironomidae (SFPE)

Chironomidae were evaluated using collections of pupal exuviae that are left behind on the water surface after adults emerge from the water. This method is relatively cost efficient and has been used successfully in other studies of Chironomidae throughout the world (Ferrington *et al.* 1991).

However, it is not routinely employed in the United States for water quality assessments and therefore needs to be explained in detail.

Although not widely used in water quality investigations in the United States, collecting SFPE is not a new approach for gathering information about Chironomidae communities. It was first suggested by Thienemann (1910), but only occasionally used in taxonomic and biogeographic studies (Thienemann 1954, Brundin 1966) or ecological studies (Humphries 1938) until more recently. During the last 45 years, however, there has been increasing use of pupal exuviae collections. Reiss (1968) and Lehmann (1971) used collections of SFPE to supplement larval collections when investigating Chironomidae community composition. In Western Europe and England collections of SFPE have been used extensively for surface water quality monitoring (McGill *et al*. 1979, Ruse 1995a, b; Ruse & Wilson 1984, Wilson 1977, 1980, 1987, 1989; Wilson & Bright 1973, Wilson & McGill 1977, Wilson & Wilson 1983). In North America the methodology has been successfully used in studies of phenology (Coffman 1973, Wartinbee & Coffman 1976), diel emergence patterns (Coffman 1974), ecology and community composition (Blackwood *et al*. 1995, Chou *et al*. 1999, Ferrington 1998, 2000, Ferrington *et al*. 1995, Kavanaugh 1988), microbial decomposition (Kavanaugh 1988), assessment of effects of point sources of enrichment (Coler 1984, Ferrington & Crisp 1989), and effects of agricultural practices (Barton *et al*. 1995). In England and the United States SFPE collections have been used to study water and sediment quality (Ruse & Wilson 1984, Ruse *et al*. 2000, Ferrington 1993b), and were used in Australia for measuring the effects of stream acidification on Chironomidae (Cranston *et al*. 1997). The following paragraphs briefly describe aspects of the methodology common to most of the above applications.

Chironomid larvae live in soft sediments or on rocks and interstitial materials in stream beds, where they can often attain densities of 1,000 or more larvae per square meter in healthy stream systems (Coffman & Ferrington 1996), and often more than 30,000 larvae per square meter in organically enriched streams (Ferrington 1990). Upon completion of the larval life they attach themselves with silken secretions to the surrounding substrates and pupation occurs. When the developing adult matures the pupa frees itself from the silken chamber and swims to the surface of the water where the adult emerges from within the pupal skin (or exuvia). The exuvia fills with air and by virtue of an outer waxy layer of the cuticle (which has non-wettable properties) it remains floating on the water surface until bacteria begin to decompose the wax layer. Floating exuviae are concentrated by stream currents into eddy areas or into regions such as slack water areas downstream of rocks or points where riparian vegetation or fallen trees contact the water surface. By collecting exuviae from these "natural" collection points, one can rapidly evaluate the emergence of Chironomidae from a broad spectrum of microhabitats in the stream. Emergence frequencies are then calculated for all species in the sample.

Field collection of SFPE is accomplished by dipping an enameled pan into the water downstream of areas where pupal exuviae accumulate. Water, detritus and floating pupal exuviae flow in as one edge of the pan is dipped beneath the surface of the water. After the pan has filled with water, the contents are passed through a U.S. Standard Testing Sieve with aperture of 125 microns. Detritus and exuviae are retained by the sieve. The entire procedure of dipping and sieving is repeated until a large amount of detritus and exuviae is accumulated in the sieve. Contents of the sieve are then transferred to a sample jar and field preserved with 80% ethanol, and labeled. Exuviae are sorted from detritus in the laboratory under 12X magnification to insure all specimens are found and removed. It has been my experience that 10 minutes of collecting provides sufficient sample size for impact assessments in streams moderately to severely impacted by organic enrichment in eastern Kansas, with samples often containing several hundred to a thousand or more exuviae. The protocol is accepted as a Standard Operating Procedure for water quality investigations by the U.S. EPA (Ferrington 1987).

The above methodology is slightly different from a more common approach of suspending a net at the water surface to intercept floating exuviae and emerging adults used by Brundin (1966) and others. However, the methodology that is being used in this research is more effective in that it does not require the investigator to spend a long time at one site, or return to retrieve the net at some future date. It also circumvents the need to be concerned about diel differences in emergence affecting the catch, as was shown to occur when the net is left in place for shorter periods (Hardwick *et al*. 1995).

One reason why the SFPE method has not been widely used in the United States until recently was due to the difficulty accumulating the widely published literature in which pupal stages were described. This problem has been largely corrected by publications of Coffman and Ferrington (1984, 1996) and Wiederholm (1986) in which pupal keys to genus are presented. In Europe keys by Wilson & McGill (1982) for England and Langton (1991) for the West Palaearctic have facilitated more extensive use of the method.

Metrics Calculated

The following metrics were calculated for dip-net samples from each of the sites investigated in this project: (1) cumulative species richness by sample site; (2) Brillouin's Diversity Index (based on cumulative totals of all samples per site); (3) number of EPT taxa; (4) percent of EPT; (5) number of Diptera taxa; and (6) percent Diptera. Metrics 1 and 2 also were calculated for SFPE samples. Four additional metrics are calculated from SFPE samples: (1) number of Orthocladiinae species; (2) percent Orthocladiinae; (3) number of Chironominae species and (4) percent Chironominae. Orthocladiinae typically are more cold-adapted and require greater dissolved Oxygen than Chironominae. Consequently, this metric can be used to help interpret responses to temperature and/or DO.

Species Diversity- Species diversity indices were calculated from the cumulative data available for each sample site. The indices were calculated using ECOMEAS© software developed by the Water Quality & Freshwater Ecology Program at the Kansas Biological Survey of the University of Kansas. This software calculates ten of the more commonly used diversity indices and, when appropriate, their associated Evenness and Equitability values. Copies of the print outs for each composited sample will be available on request.

Brillouin's Index of Diversity will be used in this interim report to document patterns of diversity among sites. This index is considered most appropriate to quantify the diversity content of samples when not all taxa in the sample area can be expected to be represented in random samples taken from the site (Magurran 1998). Results of the other commonly reported indices such as the Shannon Index or Margelef's Index are not discussed but can be provided for persons that are more familiar with, or prefer to use, these two other indices.

For purposes of interpretation, empirical results from numerous studies using collections of SFPE (mostly in Kansas, and dealing primarily with organic loading in urban streams) have shown that index values of 2.000 nats or greater are typical for collections of SFPE from streams with excellent to very good water quality. Values of less than 1.000 nats generally occur only when very significant alterations of Chironomidae communities have occurred as a consequence of pollutant-related stresses. Values between 1.500 nats and 2.000 nats are cautiously interpreted as a sign of either response to pollutant stress or reduced habitat heterogeneity. Values between 1.000 nats and 1.500 nats are confidently interpreted as a response to pollutant stress, since reduced habitat heterogeneity alone generally does not result in index values this low.

Analysis of Faunal Similarities Among Sample Sites

A numerical analysis of the similarities of (1) all macroinvertebrates collected in dip-nets samples and (2) Chironomidae composition as determined from SFPE samples across all sites has been calculated using the Community Similarity option in the ECOMEAS© software developed by the Water Quality & Freshwater Ecology Program at the Kansas Biological Survey of the University of Kansas. The Community Similarity option in the software calculates 16 of the more commonly used coefficients of community similarity. Copies of the print outs for each pair of sample sites can be made available on request. Jaccard's Coefficient of community similarity will be used in this interim report to document patterns of similarity among pairs of sample sites. Jaccard's Coefficient is considered appropriate to quantify the similarity of two communities based on presence/absence data (Magurran 1998), and it is commonly reported in other studies (e. g., Blackwood *et al.* 1995). Results of other commonly reported coefficients such as the Sorensen's or Ochiai's Coefficient will not be discussed but the index values can be obtained by persons that are more familiar with, or prefer to use, these other coefficients.

Jaccard's Coefficient is calculated as the formula a/(a + b + c) where a is the number of species in common among two sample sites, b is the number of species present only in the first of the two sample sites being compared and c is the number of species present only in the second of the two sample sites being compared. With 3 different sample sites and the historical data collected in the lower portions of the stream, the number of two-site comparisons is calculated as N*(N-1)/2 where N is the number of sample sites. Thus, in this study there are 6 unique comparisons of sample sites taken two at a time.

Results and Discusion

Results of dip-net samples are shown in Table 1. The SOP for sorting samples stipulates that subsamples of 300 organisms will be identified and quantified. The SOP also requires that the remainder of the sample be scanned and that representative specimens of all taxa be removed in order to include rare species in the species richness estimate. This scan is completed after the 300 organism subsample is obtained. Consequently, the final specimen count exceeds 300 organisms. The total number of specimens processed per sample is indicated in Table 1.

Table 1: Summary of metrics for collections of dip-nets.

Sample Site	Numbers of Specimens Processed	Cumulative Species Richness	Brillouin's Diversity Index (nats)	# EPT	% EPT	# Diptera	% Diptera
Site Upstream of Hwy 110	**345**	**46**	**2.756**	**5**	**4.6%**	**24**	**55.9%**
Site Upstream of Hwy 15	**345**	**42**	**2.727**	**4**	**7.5%**	**23**	**50.1%**
Site Upstream of Hwy 96	**350**	**49**	**2.479**	**9**	**14.0%**	**26**	**35.1%**
Historical Data	**1141**	**54**	**2.473**	**11**	**62.8%**	**26**	**13.1%**

The species richness based on historical data for the site in the lower portion of Brown's Creek is higher than the species richnesses detected at sites in the upper portion. Diversity Index values do not differ substantively among sites, and no pattern can be generalized from them other than that they suggest there is no strong stress response in terms of community structure of invertebrates. However, metrics based on EPT and Diptera clearly indicate the historical data differs markedly from the data collected in May of 2007 from the upstream three sites. Both the number and percent of EPT taxa are lower than indicated in historical data, with percent of EPT decreasing consistently from Hwy 96 to upstream of Hwy 110. The pattern of increasing percent Diptera from downstream to upstream reinforces the trend for EPT and, together, these three metrics indicate response to changing habitat, temperature, dissolved Oxygen or a combination of these parameters from downstream to upstream.

Results of the numerical analysis of the similarities of macroinvertebrate composition across all four sample sites based on Jaccard's Coefficient are presented in Table 2. Values below the diagonal represent the raw coefficient scores. Numbers above the diagonal indicate the rank similarities among pairs of sample sites.

Table 2: Similarity of taxonomic composition among pairs of sample sites based on Jaccard's Coefficient of Similarity

Sample Sites	Hwy 110	Hwy 15	Hwy 96	Historical
Hwy 110	-----	**4**	**5**	**6**
Hwy 15	**0.294**	-----	**1**	**3**
Hwy 96	**0.203**	**0.542**	-----	**2**
Historical	**0.190**	**0.371**	**0.431**	-----

Jaccard's Coefficient values can range from 1.0 representing complete overlap in community composition to 0.0 indicating no overlap in community composition. When multiplied by 100 the resulting value represent the percent of species shared among the two sample sites being compared. Three patterns are apparent from the coefficients. The first pattern is that the uppermost site upstream of Hwy 110 is the least similar site to all other, being only 29.5% similar to the Site upstream of Hwy 15, 20.3% similar to the site upstream of Hwy 96, and only 19% similar to the historical data for the sample site in the lower portion of the creek.

The second conspicuous pattern in the two most similar sites, Hwy 15 and Hwy 96, are physically close to each other and have relatively similar substrates, discharge and flow characteristics.

It is also important to note that the community structure of the sample site at Hwy 96 is the most similar of the upstream sites to the historical data for the site in the lower portion of the creek. Consequently, it appears the substrate, physical and/or chemical conditions are most different at the upstream site relative to sites at Hwy 15, Hwy 96, and in the lower portion of the catchment.

Results of collections of SFPE strongly corroborate the patterns in data for dip-net collections. Table 3 provides summary metrics, and Table 4 presents the results of analysis of similarity.

Sample Site	**Numbers of Specimens Processed**	**Cumulative Species Richness**	**Brillouin's Diversity Index (nats)**	**# ORTH**	**% ORTH**	**# CHIR**	**% CHIR**
Site Upstream of Hwy 110	**307**	**24**	**2.008**	**12**	**70.0%**	**7**	**24.8%**
Site Upstream of Hwy 15	**629**	**27**	**3.343**	**18**	**94.9%**	**5**	**3.5%**
Site Upstream of Hwy 96	**543**	**24**	**3.236**	**17**	**91.3%**	**4**	**2.8%**
Historical Data (April-June)	**940**	**33**	**3.388**	**28**	**91.2%**	**6**	**2.6%**

Species richness of all upstream sites is less than the estimate for April through June in the historical data for the lower segment of the creek. Richness among the upstream sites, however, does not vary substantively and there is no upstream-downstream pattern of increasing or decreasing richness. The upstream-most site, however, clearly shows a depressed diversity index value relative to all other sites, but is still in the range of values generally considered as indicating good to excellent conditions. The richness and percent of Orthocladiinae show a very strong pattern that reinforces the diversity index pattern, with the site upstream of Hwy 110 showing substantial reductions in Orthocladiinae. The percent Chironominae shows a corresponding and reinforcing pattern of increased percent composition at Hwy 110. Consequently these metrics point to reductions in DO and/or increases in temperature as structuring community composition and emergence of Chironomidae from April through June.

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Attachment 5

Water Quality Evaluation

Water Quality Analysis Summary

The following narrative summarizes the water quality analysis that has been conducted to date for the Brown's Creek TMDL. Various pollutants were evaluated in an attempt to determine their potential to be stressors to the biological community of the creek.

APPROACH

Water quality data from five monitoring sites were used in the analysis. Monitoring data from 2005 and 2006 were available from the three downstream sites, and data from 2007 were available from the three upstream sites (Table 1).

Table 1. Available monitoring data

Site	2005 - 2006	2007 (through May)
110th St.		x
Gateway		x
Highway 15	x	x
McKusick	x	x
WOMP	x	x

Data were visually examined and means were compared to water quality standards and guidelines (Table 2). Brown's Creek is classified as a Class 2A water. In addition to the MN standards, data were compared to guidelines based on the 75th percentile of data (1970 through 1992, annual) from minimally impacted streams in the north central hardwood forests ecoregion (McCollor and Heiskary 1993).

Table 2. Water quality standards and guidelines

Parameter	Standard	Guideline*
Total Phosphorus		0.15 mg/l
Total Suspended Solids	45 mg/l (derived from turbidity standard)	16 mg/l
Turbidity	25 NTU	
Fecal Coliform	200 organisms/100ml	
Chloride	230 mg/l	
Ammonia Nitrogen	0.016 mg/l	
Nitrate + Nitrite Nitrogen		0.26 mg/l
Copper	Variable with total hardness, see narrative below.	

*75th percentile of data (1970 through 1992, annual) from minimally impacted streams in the north central hardwood forests ecoregion (McCollor and Heiskary 1993)

Flow and load duration curves were used to see under which flow regimes the standard and guideline exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis.

Load duration curves take the flow distribution information constructed for the stream and factor in pollutant loading to the analysis. The curve is built by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The curve represents the pollutant load that can be in the stream at a particular flow without exceeding the standard for that pollutant. Monitored loads of pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

RESULTS

Flow duration curves

Flow duration curves, based on 2005 and 2006 data, were constructed for the Highway 15, McKusick Road and WOMP/Highway 96 monitoring sites. This time period was chosen because the original analysis was being conducted on the Highway 15 monitoring site and the reach of stream above. The data for the Highway 15 site is limited to 2005-2006. To compare the lower sites to the Highway 15 data, the same time period was used despite the fact that additional data is available for these sites. Further analysis of the complete data set for the McKusick and WOMP sites will be conducted in a future phase of the project.

In addition to the individual flow duration curves, a composite flow duration chart showing all three sites was constructed (Figure 1). All but the very highest flows are very similar for the McKusick and Highway 15 sites but the WOMP site has 3 to 6 cfs more flow. The maximum flows are higher for the McKusick Road (~75cfs) site than the Highway 15 site (~40cfs).

Total Phosphorus (TP)

Total phosphorus means at the three downstream sites (Highway 15, McKusick, and WOMP) exceeded the water quality guideline of 0.15 mg/L in 2005 and 2006 (Figure 2). The means from 2007 did not exceed the guideline. During the first part of 2007, TP was lowest at the most upstream site and increased downstream.

At the three downstream sites, the guideline is exceeded under high flow conditions at all of the sites (Figures 3 through 5).

Turbidity and Total Suspended Solids (TSS)

Since there are limited turbidity data for Brown's Creek, TSS was used as a surrogate for turbidity. The turbidity standard is 25 NTU. Using a relationship between TSS and turbidity derived from a set of Minnesota rivers (Heiskary and Markus 2001), an equivalent of 45 mg/L TSS was used to represent 25 NTU turbidity. Monitored TSS values were plotted in relation to both the 16 mg/l guideline and the 45 mg/l concentration derived from the turbidity standard.

TSS data show a pattern similar to that of TP: data from the downstream reaches exceeded both the standard and the guideline (Figure 6), and exceedances occurred mainly under high flow conditions (Figures 7 through 9), with some exceedances at 4 to 5 times the standard.

Fecal Coliform
Fecal coliform concentrations exceed the chronic standard at the Highway 15 site and are borderline at the McKusick site (Figure 10). The exceedances all occurred under dry conditions (Figures 11-13). However, fecal coliform monitoring was not conducted during storm events, so the fecal coliform monitoring data do not adequately represent the entire range of flows. The elevated fecal coliform concentrations in the upper reach of the stream could potentially be attributed to the larger number of animals, particularly deer and horses, that are present in the upper watershed. Fecal coliform was evaluated but is not expected to be a stressor to the biological community within the creek.

Chloride
The chloride concentrations in Brown's Creek are all well below the standard of 230 mg/L (Figure 14), and none of the individual values exceed the final acute value of 1720 mg/L.

Ammonia Nitrogen
Average ammonia concentrations exceeded the standard at all monitoring sites for which data are available (Figure 15). Exceedances at the WOMP site occurred under all flow conditions (Figure 16).

Nitrate + Nitrite-Nitrogen
Nitrate+nitrite-N was high relative to the guideline at all sites (Figure 17) and under all flow regimes (Figure 18).

Copper
High levels of copper are found at the McKusick and WOMP sites (Figure 19). The standard for copper and other metals is dependant upon the hardness of the water. Hardness data were only available for the WOMP site; therefore only these data were explored further.

There are three standards for copper based on toxicity. The chronic standard (CS) refers to the highest water concentration of a toxicant to which organisms can be exposed indefinitely without causing chronic toxicity. The maximum standard (MS) refers to the highest concentration of a toxicant in water to which aquatic organisms can be exposed for a brief time with zero to slight mortality. The MS equals the FAV divided by two. The final acute value (FAV) refers to an estimate of the concentration of a pollutant corresponding to the cumulative probability of 0.05 in the distribution of all the acute toxicity values for the genera or species from the acceptable acute toxicity tests conducted on a pollutant.

The copper chart displays each of the copper concentration standards over a range of total hardness (TH) values and plots monitored copper concentrations also in terms of the observed hardness (Figure 20). While most of the observed concentrations are well below the chronic standard, there are observations that exceed this standard, three above the maximum standard, and one observation is above the final acute value.

Copper can become harmful to aquatic biota and is one of the most toxic heavy metals (Hall *et al*. 1988, 1997; Hellawell 1988). Copper is known to suppress resistance of fish to bacterial diseases and it adversely affects fish behavior, growth (Hodson *et al*. 1979), and reproduction success (Ellenberger *et al.* 1994).

Volatile Suspended Solids:Total Suspended Solids (VSS/TSS)
VSS:TSS is higher in the upstream sites, indicating that organic matter represents a larger fraction of the suspended solids (Figure 21). At the Highway 15 site, VSS:TSS does not vary by flow condition (Figure 22).

Storm events have a lower VSS:TSS than baseflow (Figure 23); the mineral component of TSS is larger in storm events, possibly due to changes in watershed runoff or streambed and streambank erosion.

Dissolved Phosphorus:Total Phosphorus (DP:TP)
The ratio of dissolved phosphorus to total phosphorus decreases as one moves downstream (Figure 24).

At Highway 15, the DP:TP appears slightly lower under high flow conditions than under low flow conditions, indicating a larger proportion of particulate phosphorus under the high flow conditions (Figure 25).

Dissolved Oxygen (DO)
Dissolved oxygen data was evaluated for the three sites of the upper reach of the creek: 110th Street, Gateway Trail, and Highway 15 for the data collected from April 16, 2007 to May 11, 2007 (Figure 26). Other DO data have been collected at the McKusick Road site but the data are of questionable quality and were not evaluated.

Minimum daily dissolved oxygen concentrations are generally highest at the downstream Highway 15 site and are lower and slightly more variable at the middle site (Gateway Trail). The upper site, 110th Street, shows a large increase in minimum daily DO concentration around the 20th to 22nd of April followed by a substantial decrease. After the decrease, the 110th Street DO data fluctuate similarly to the Highway 15 site data but approximately 2.5 mg/l lower. The data are also plotted against the DO standard of 7.0 mg/l. The chart shows that DO at the Gateway Trail and 110th Street sites fell below the standard.

Temperature
Two separate analyses were performed related to stream temperature. The first analysis compares the maximum daily in-stream water temperatures for the Highway 15, McKusick Road, and WOMP sites for 2005 and 2006 separately (Figures 27 and 28). This information is plotted against the critical temperature for brown trout, 75^{o} F, and the threat temperature for brown trout, 65^{o} F. Temperature at the WOMP site was below the

critical temperature throughout the two years, but the McKusick and Highway 15 sites exceeded that temperature at several times, mostly in July. Generally the creek is approximately 3 degrees cooler at each of the monitoring stations heading downstream.

The second temperature analysis evaluated the 2007 data collected from April 16, 2007 to May 11, 2007 at the three sites of the upper reach of the creek: 110th Avenue, Gateway Trail, and Highway 15 (Figure 28). The data generally show that the stream is approximately 1 degree warmer at the upstream site compared to the downstream site. The temperature did not exceed either the critical or threat temperature during this time period.

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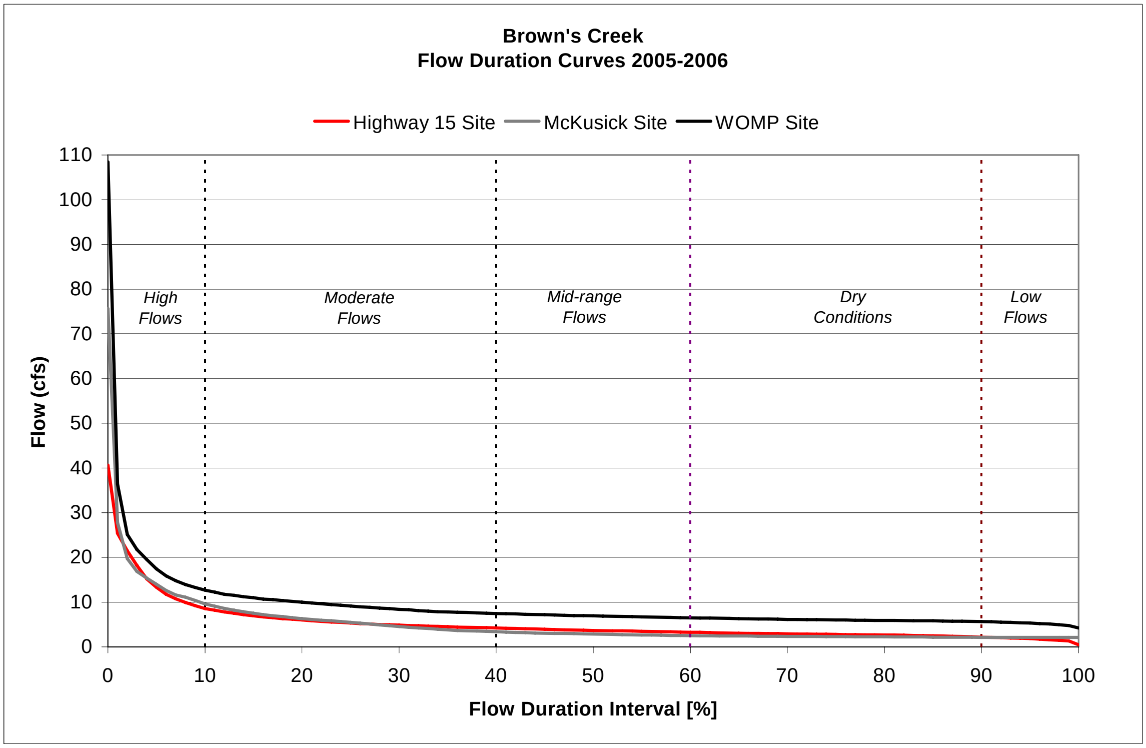
Brown's Creek Water Quality Evaluation
Figures

Figure 1



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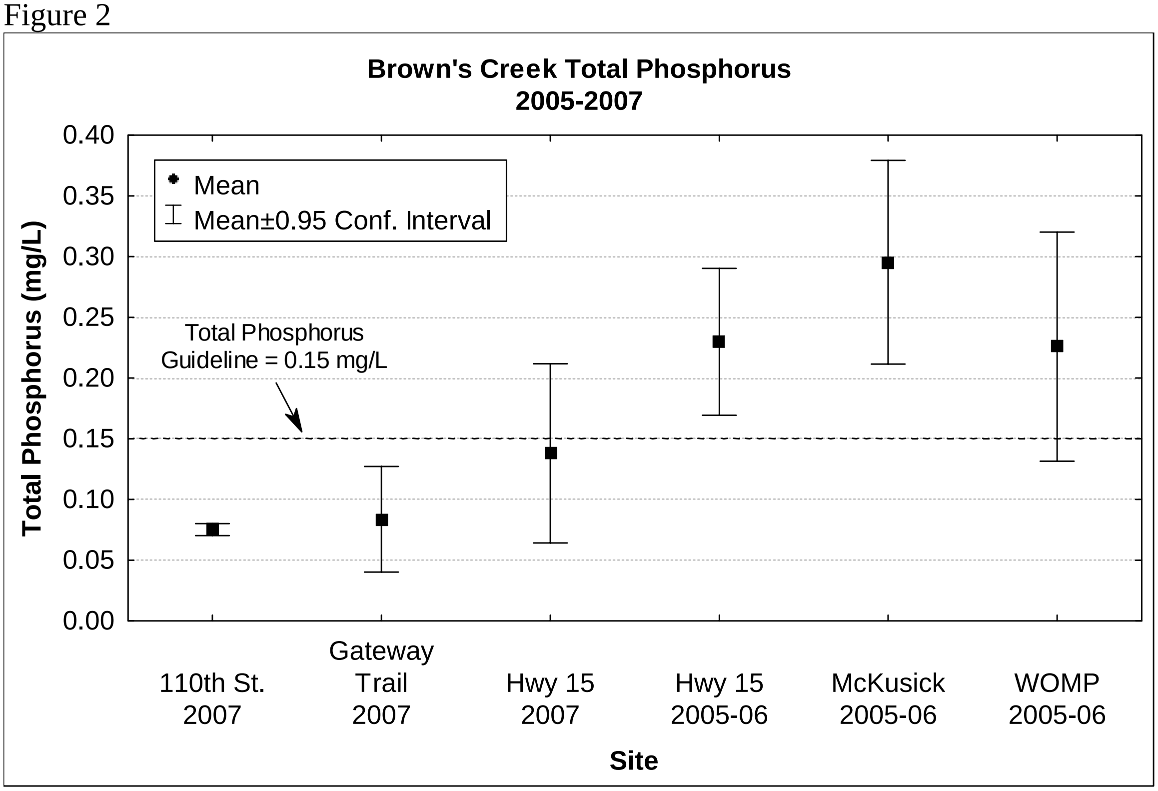

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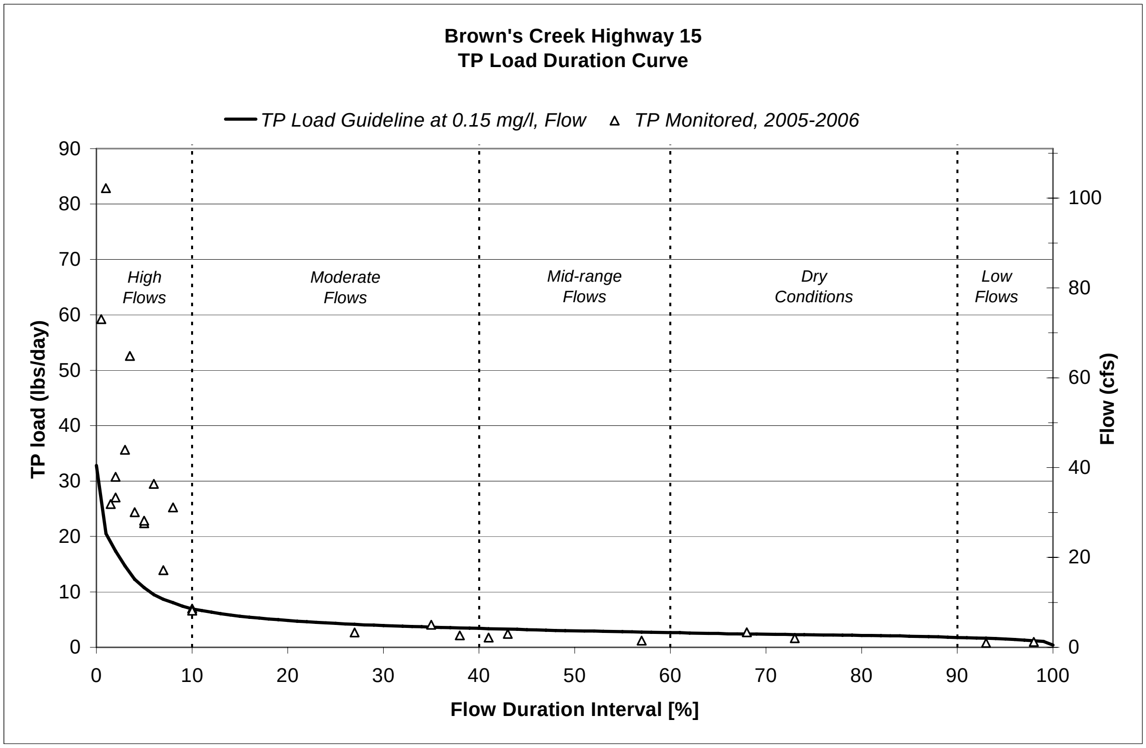

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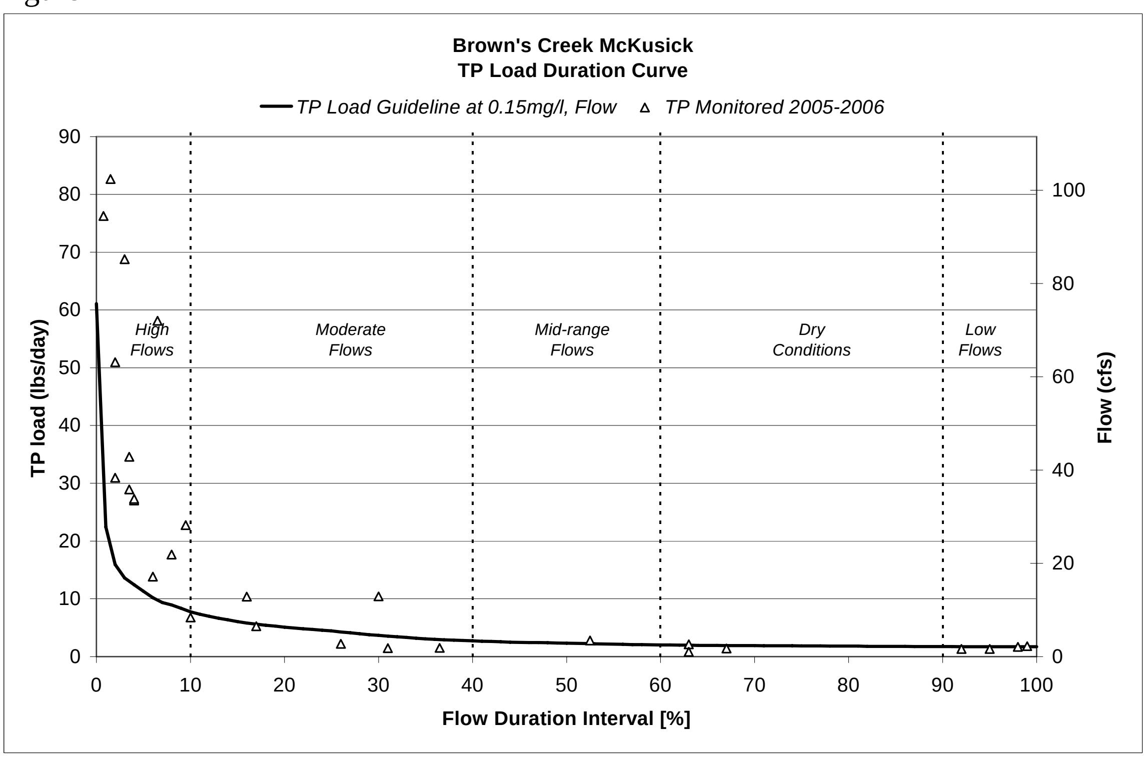

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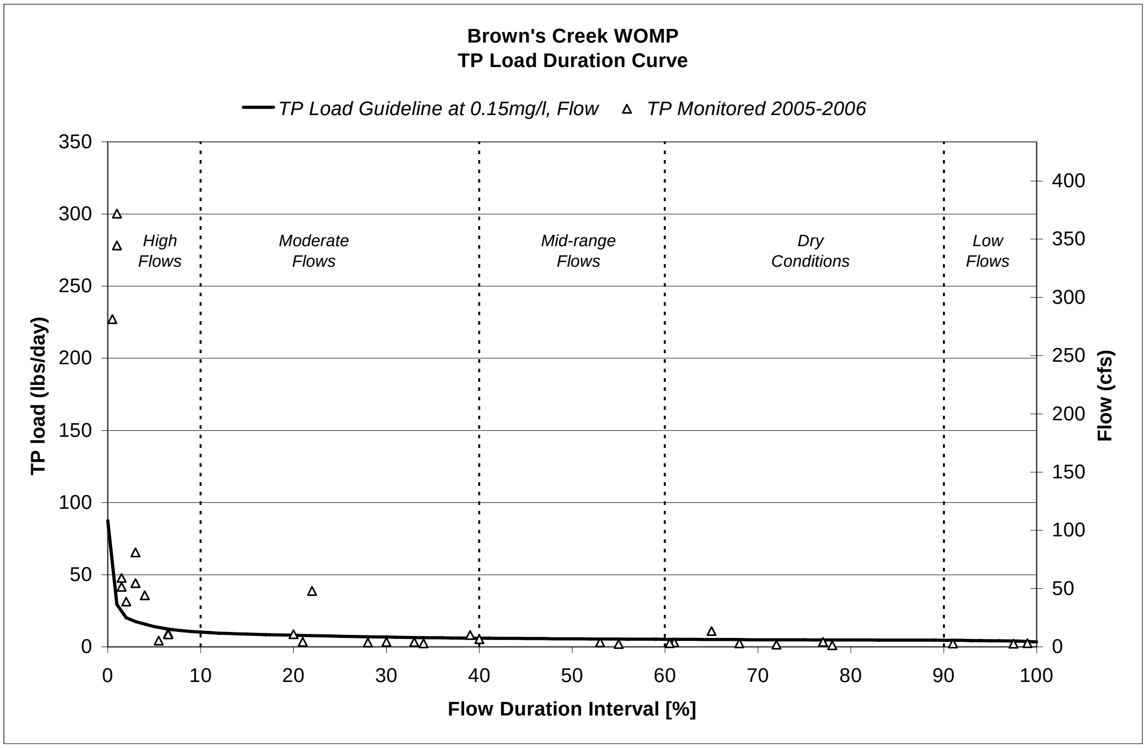

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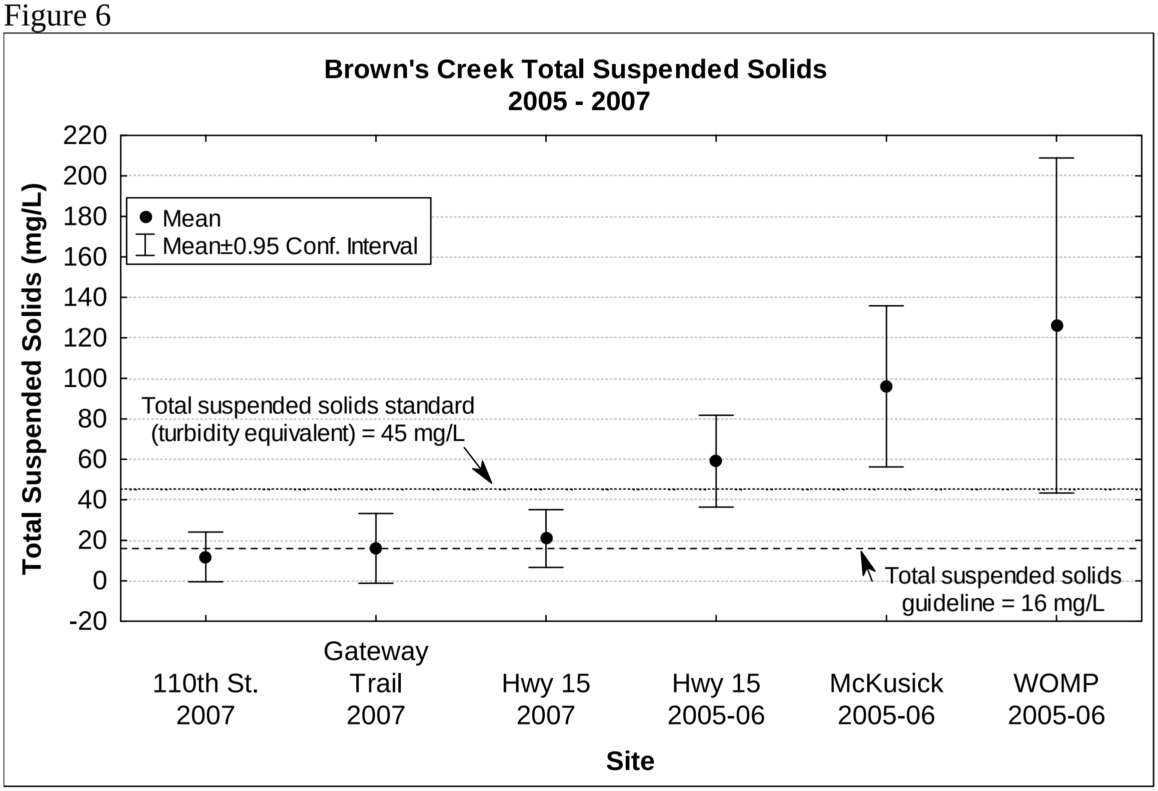

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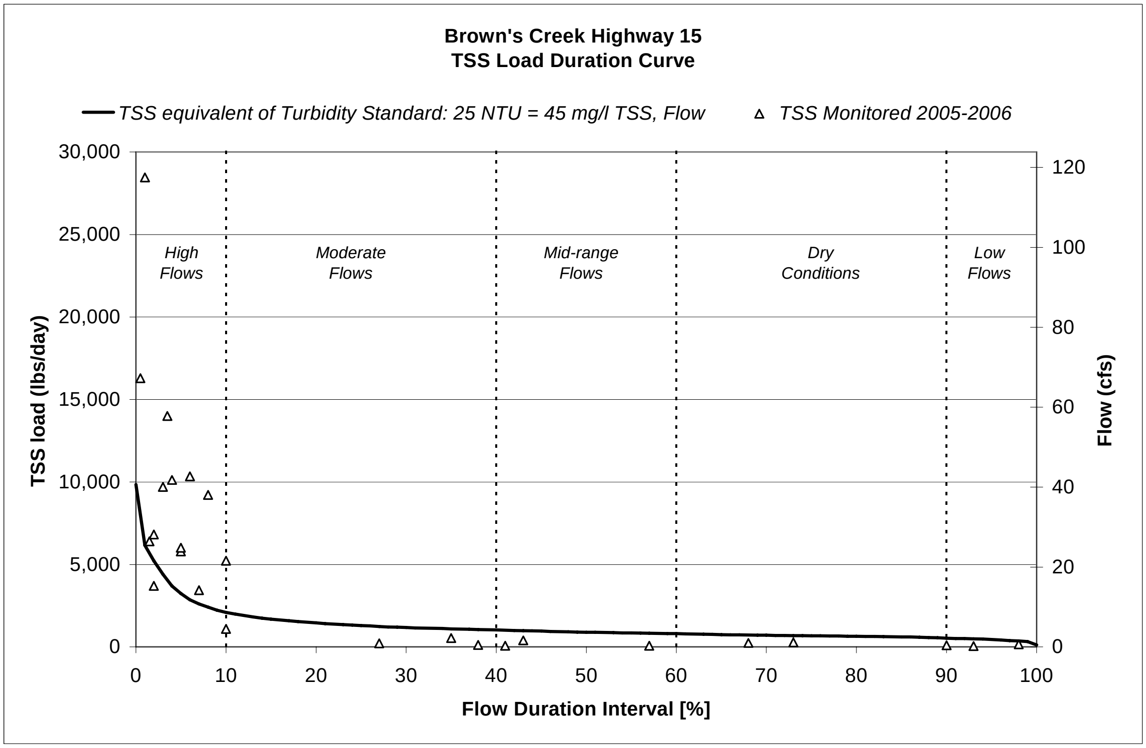

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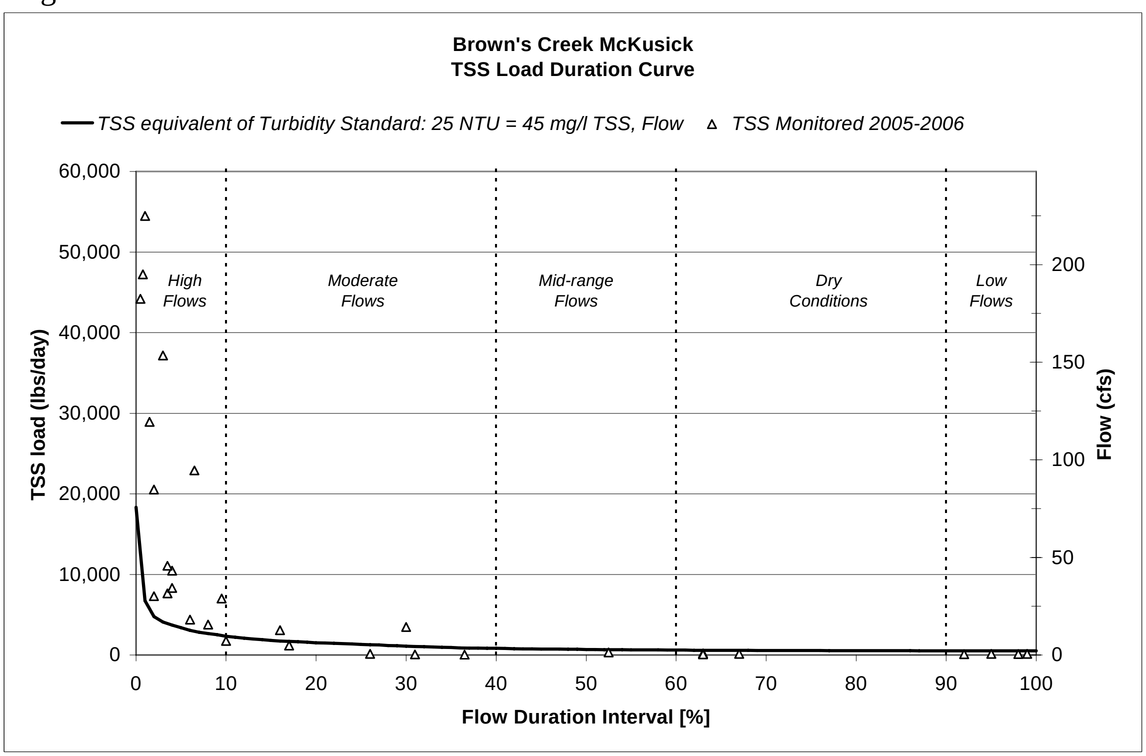

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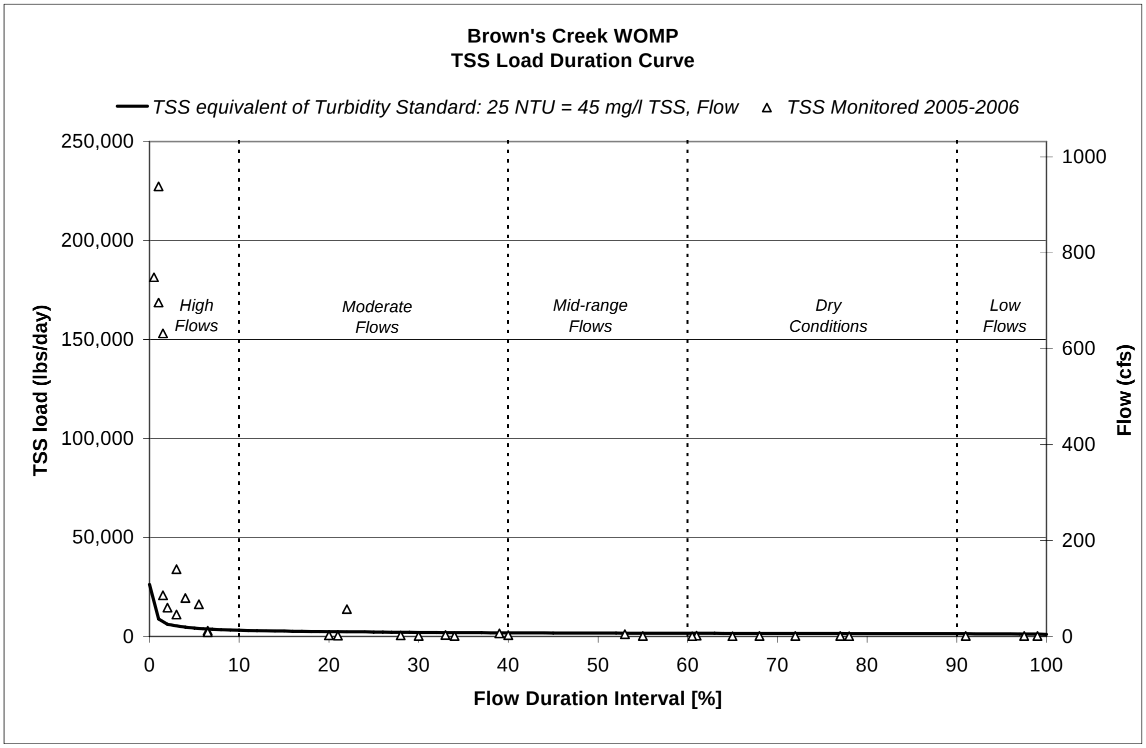

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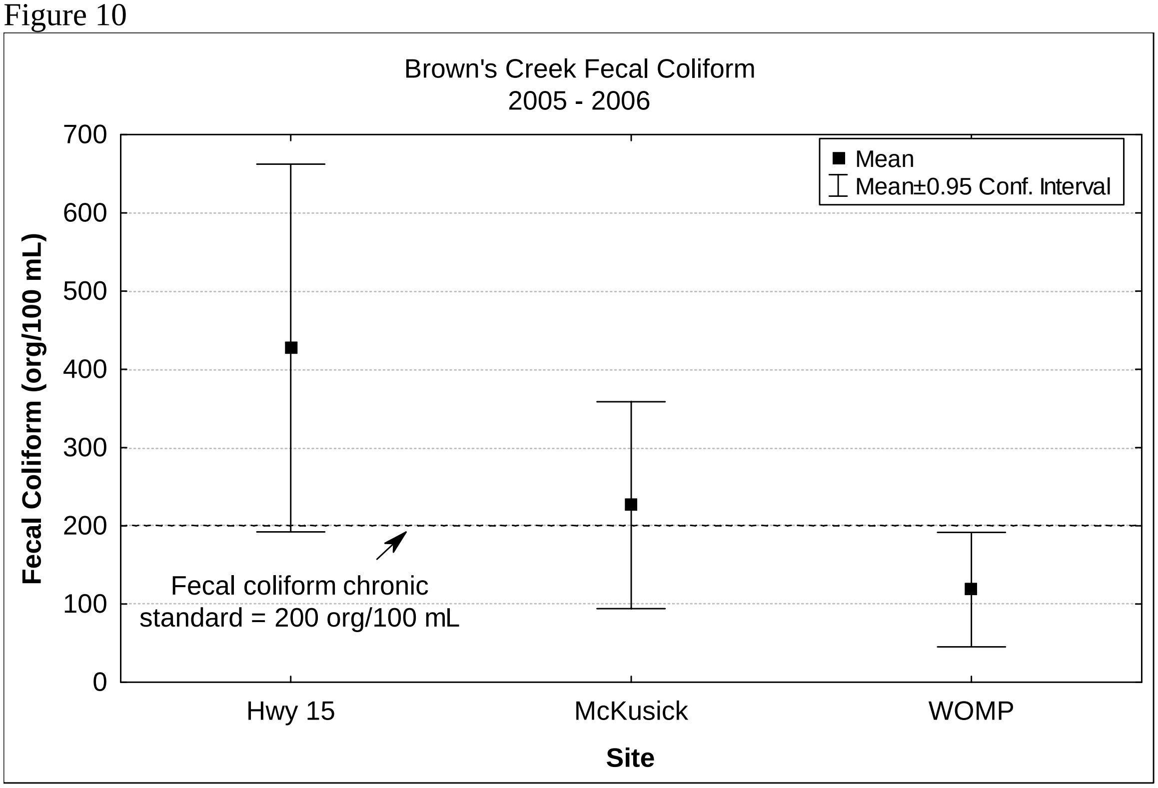

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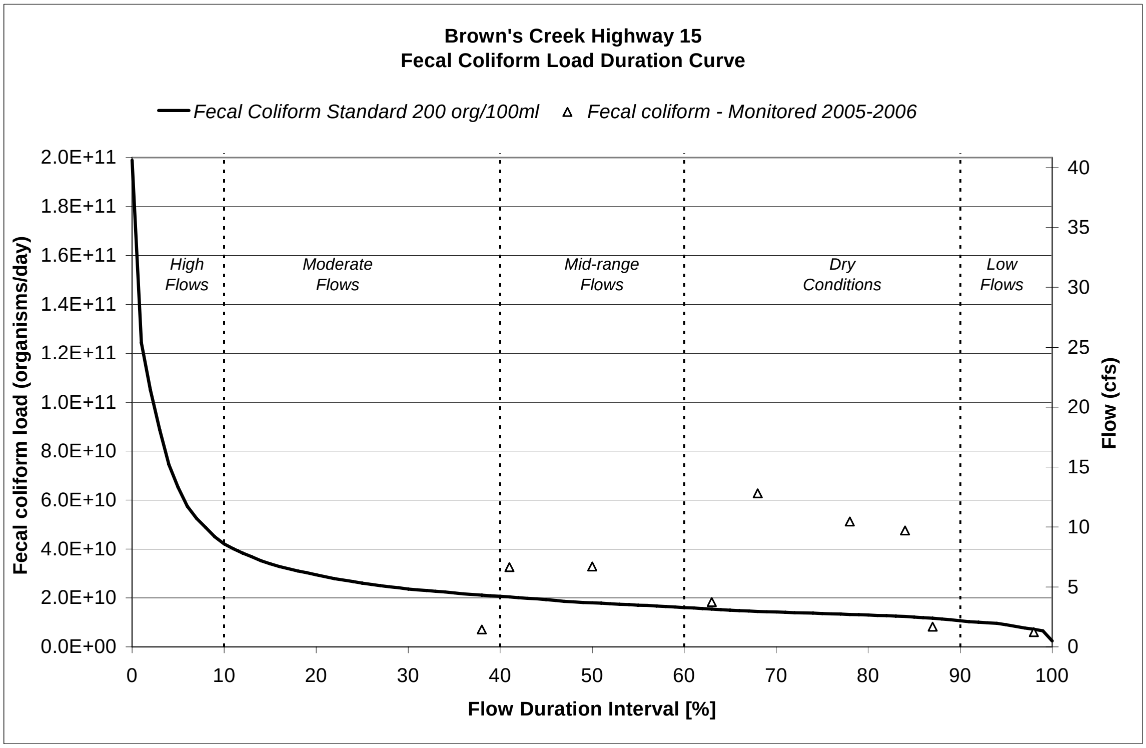

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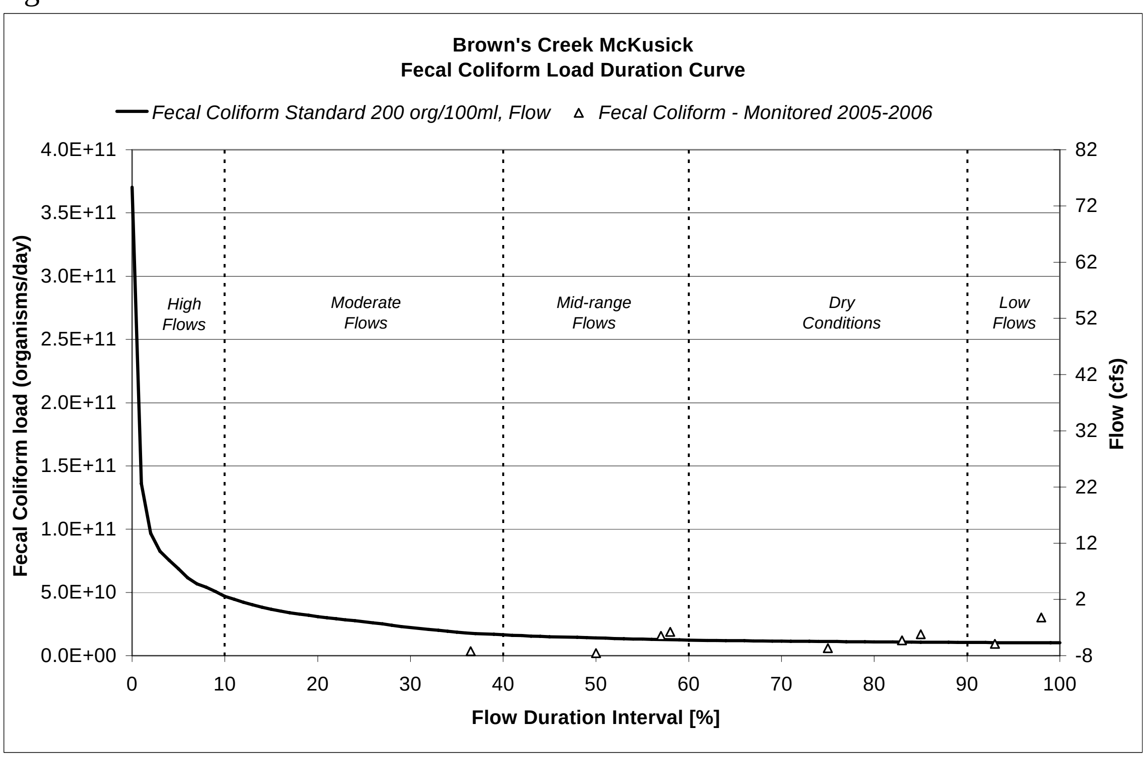

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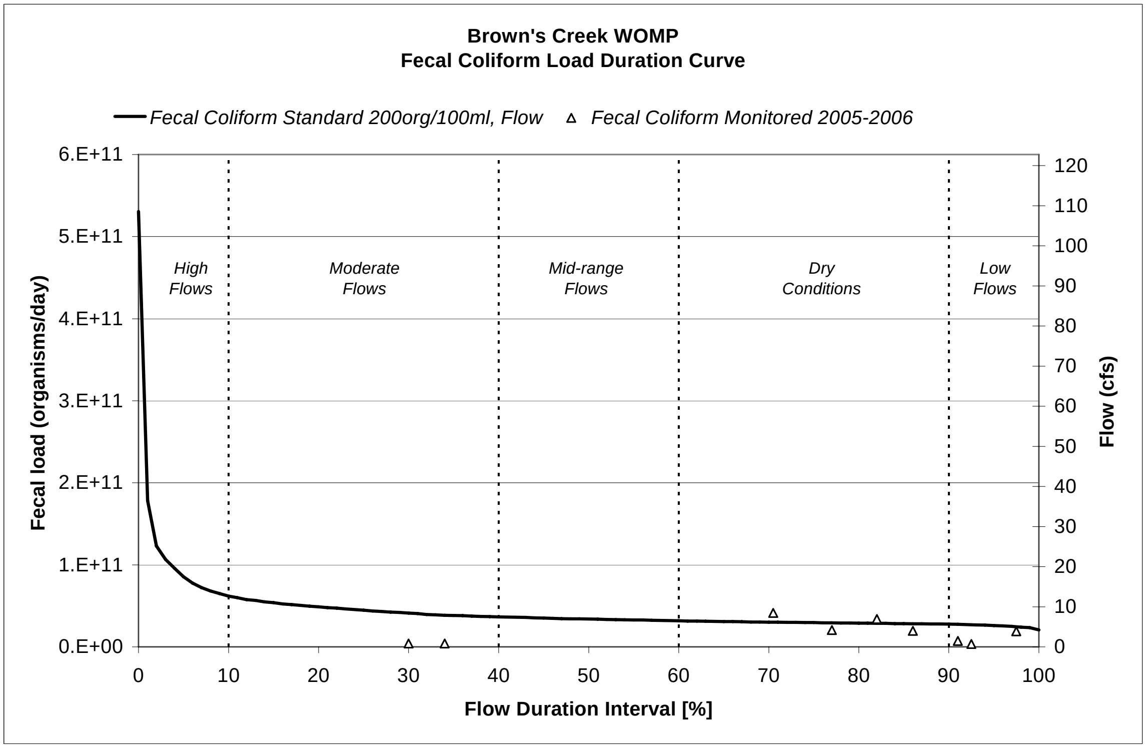

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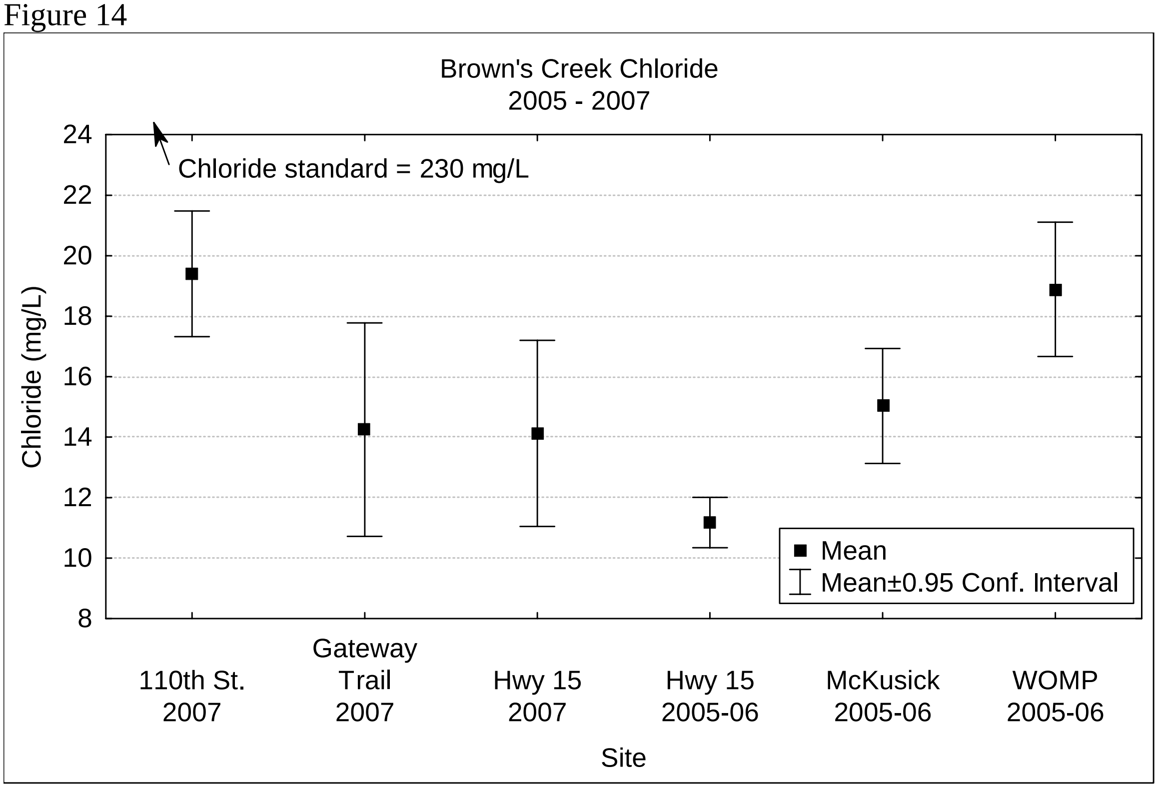

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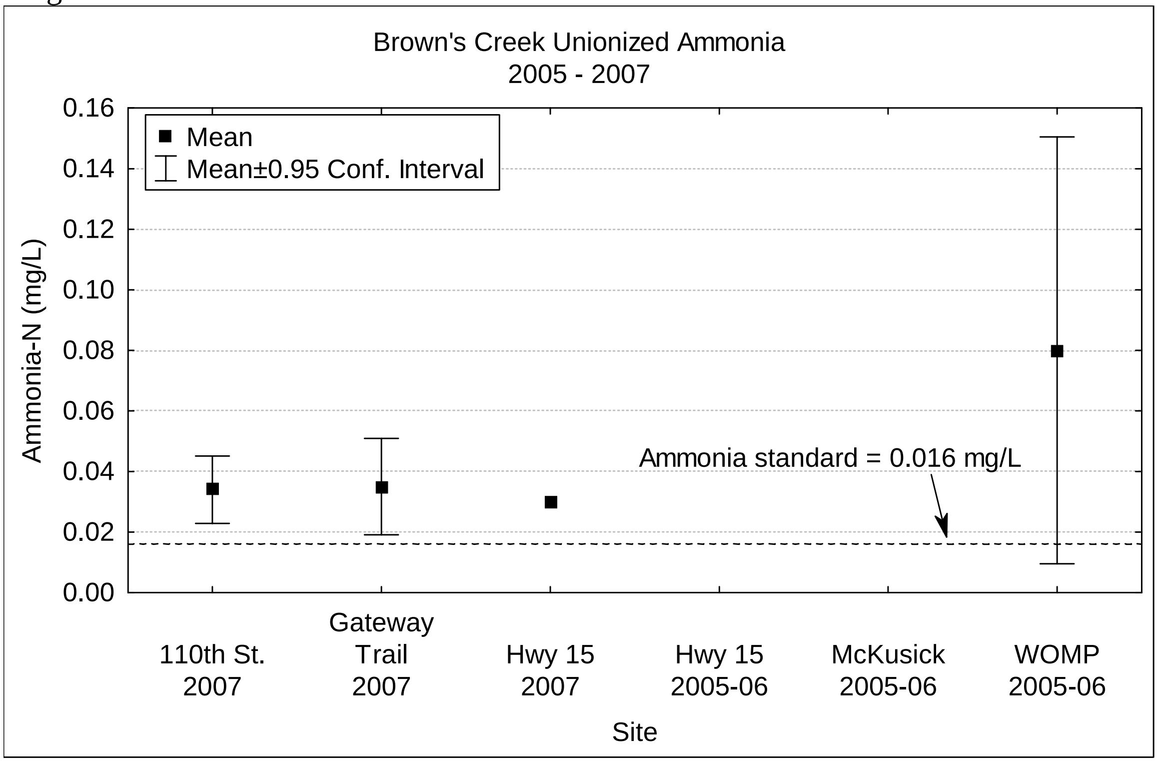

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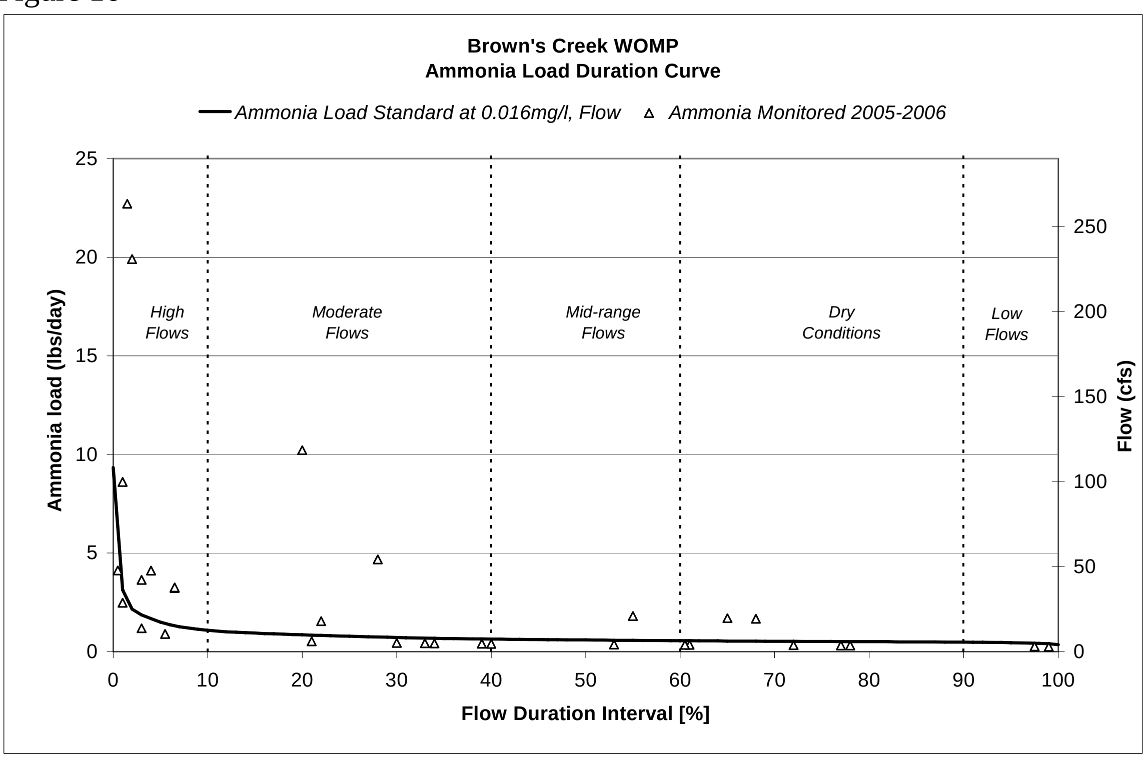

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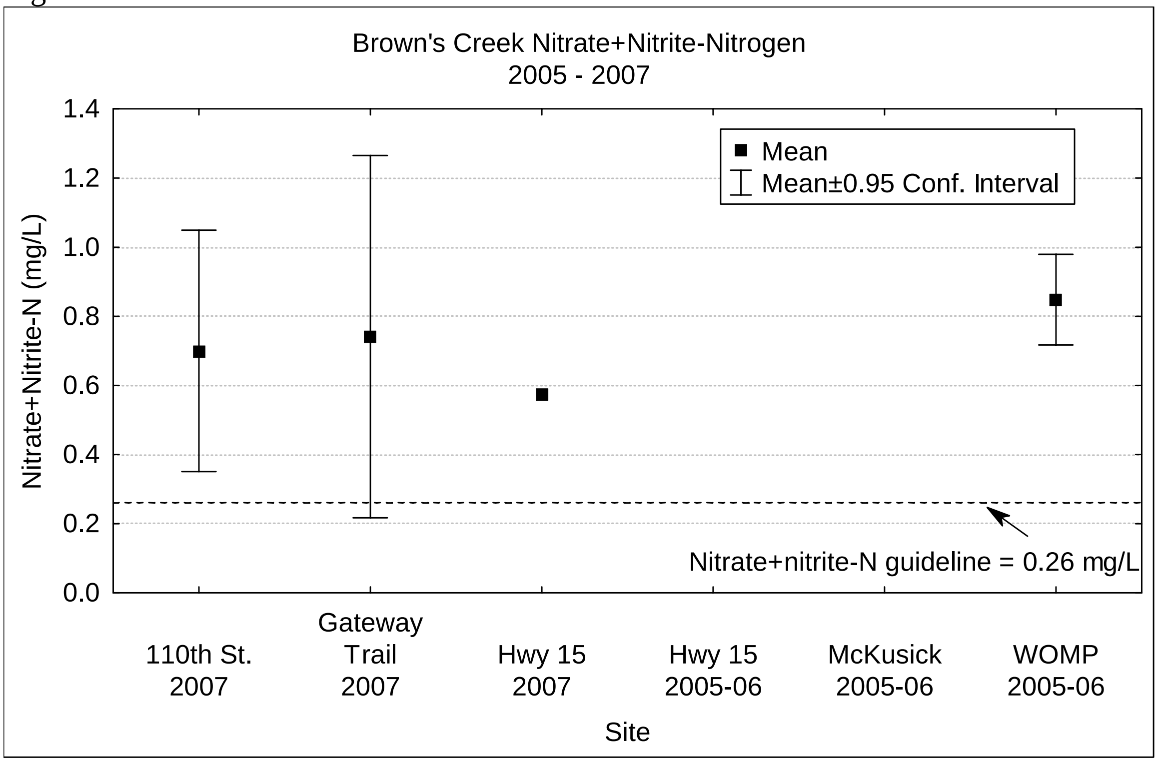

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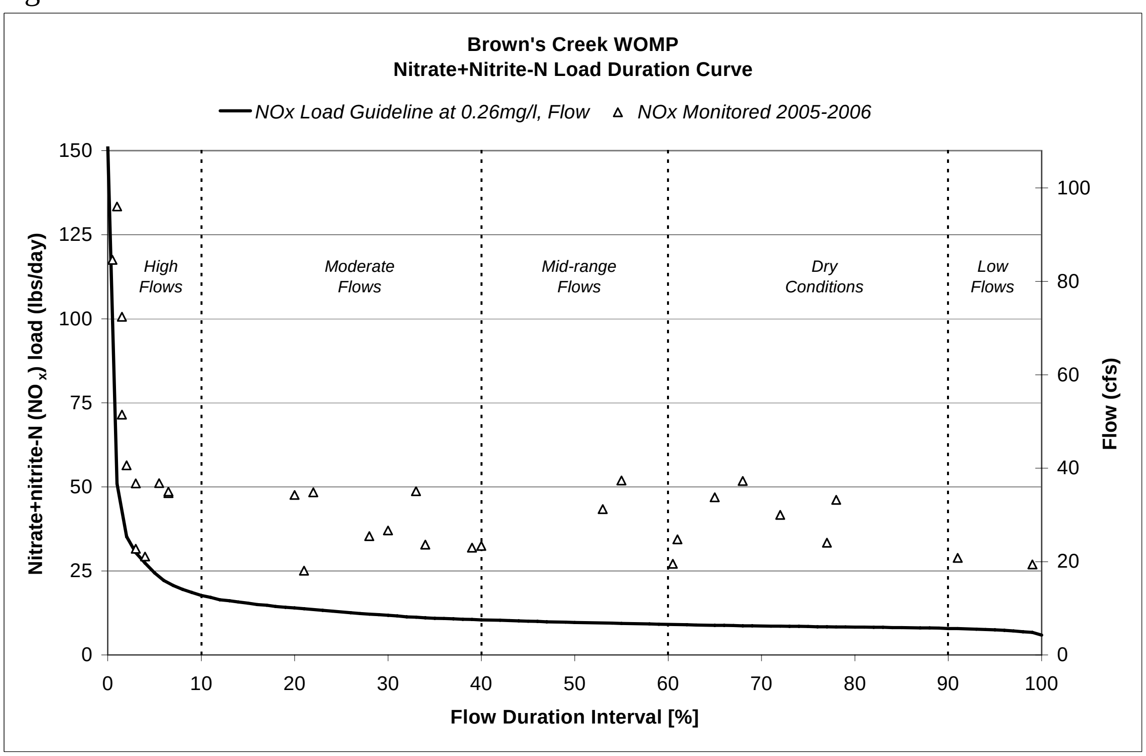

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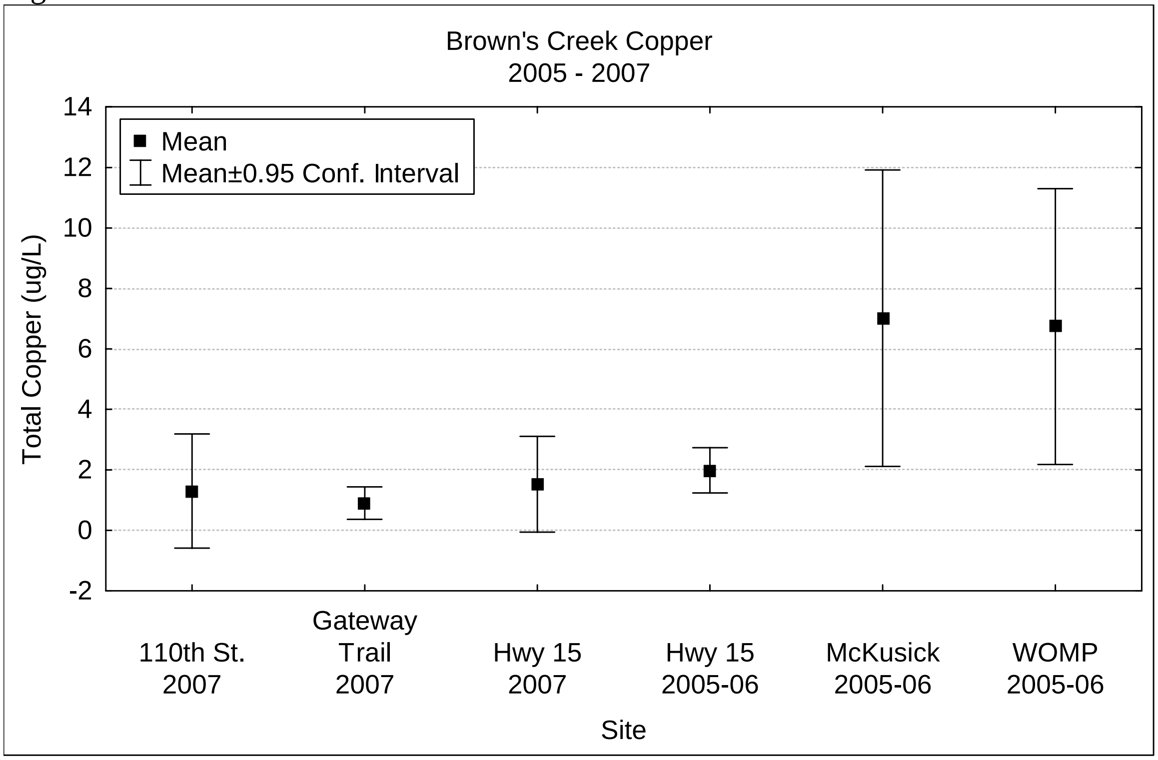

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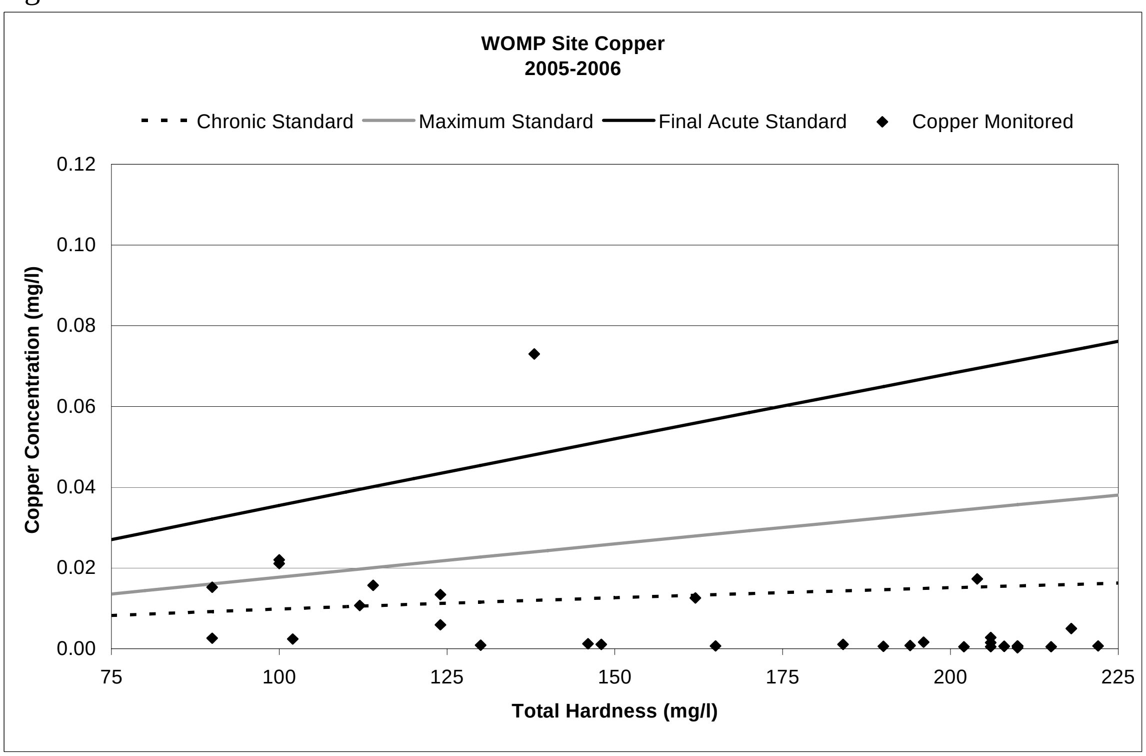

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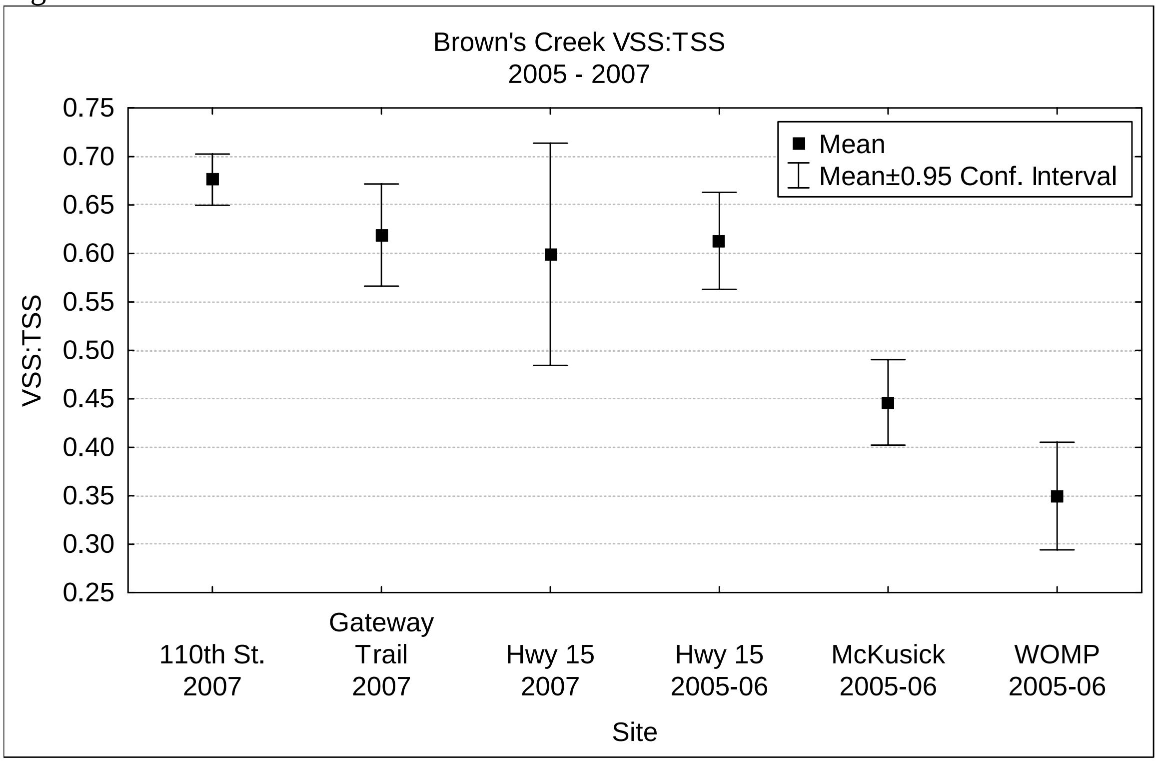

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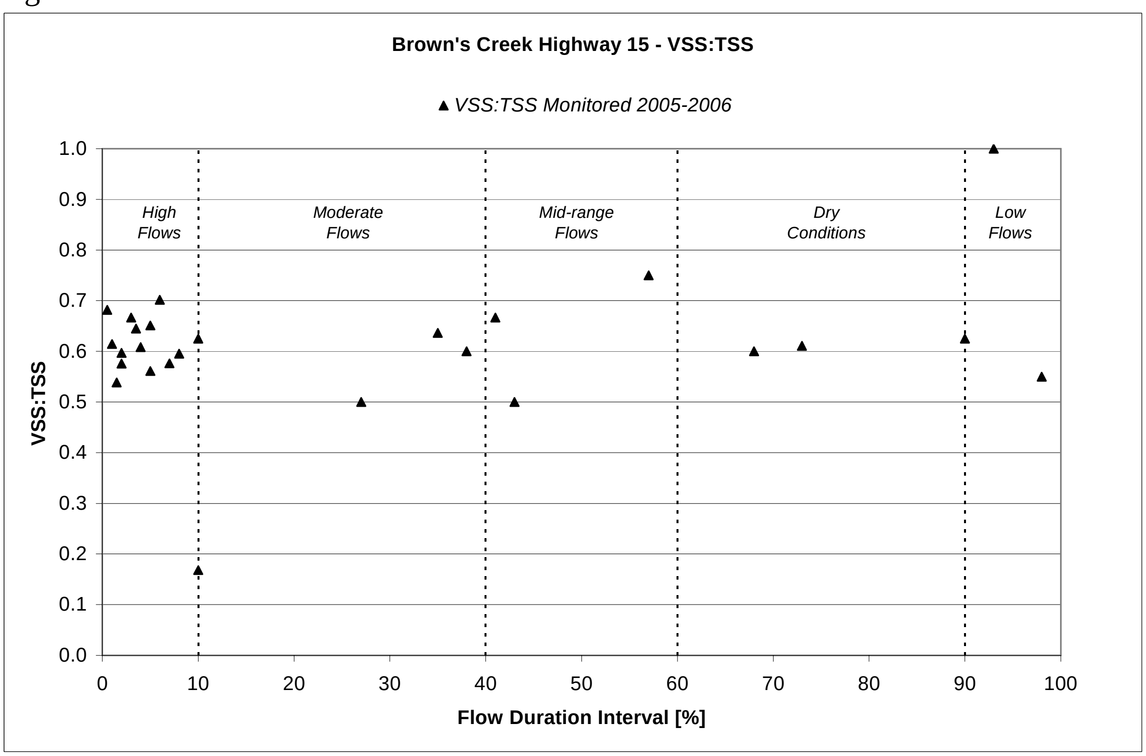

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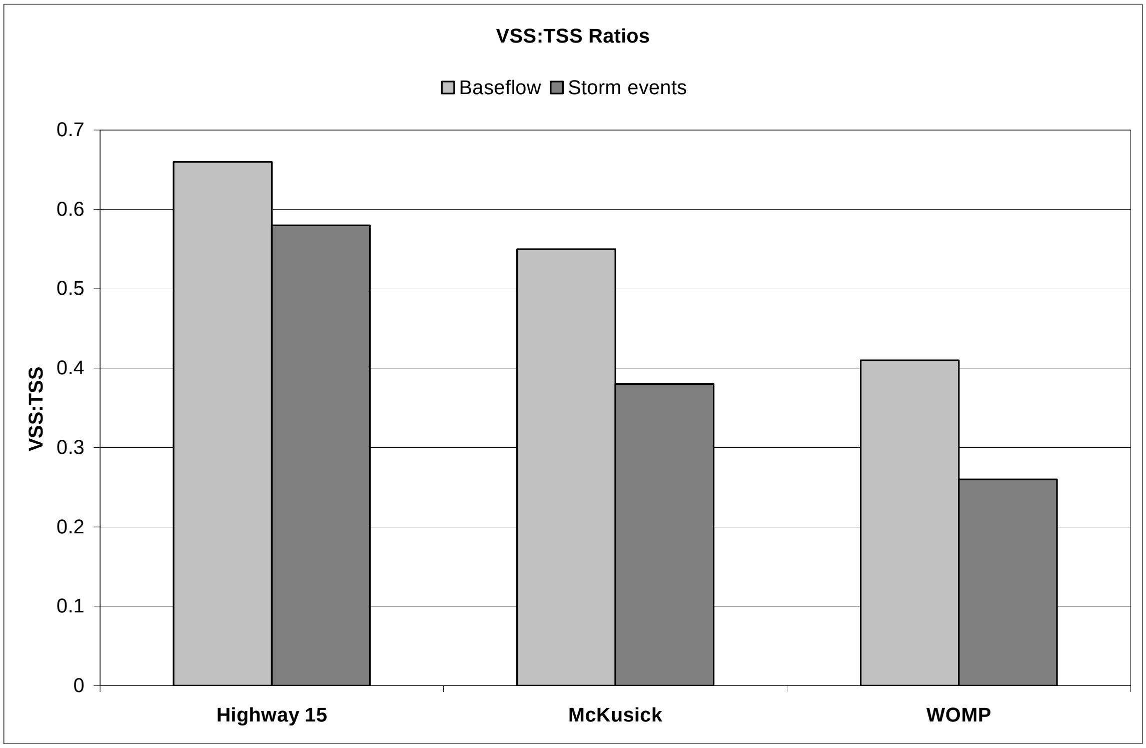

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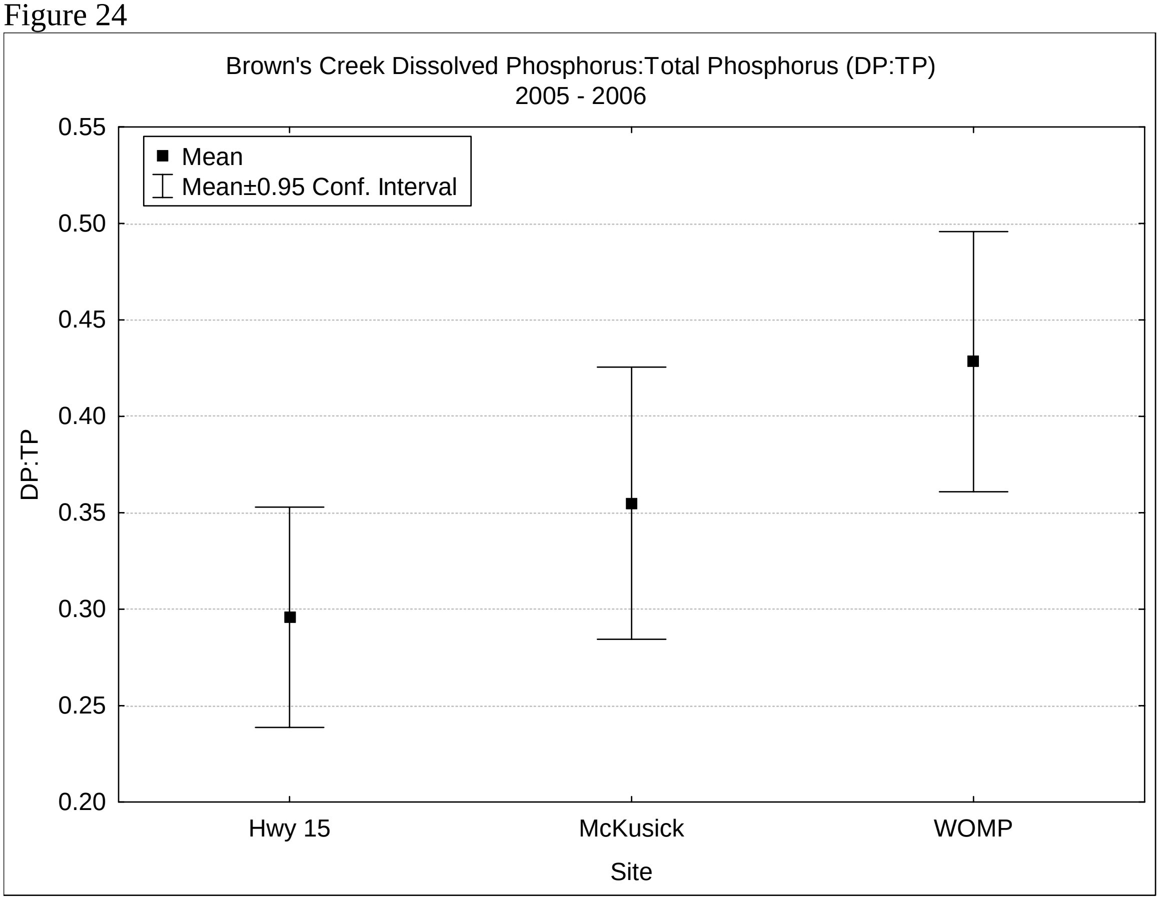

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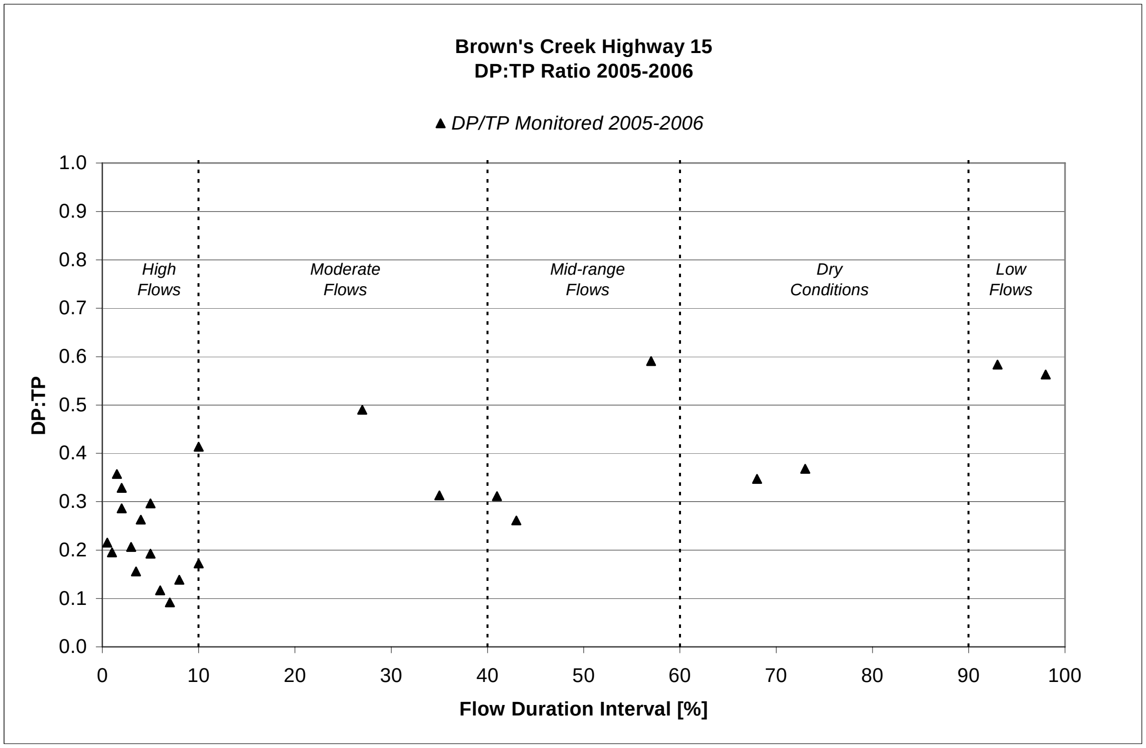

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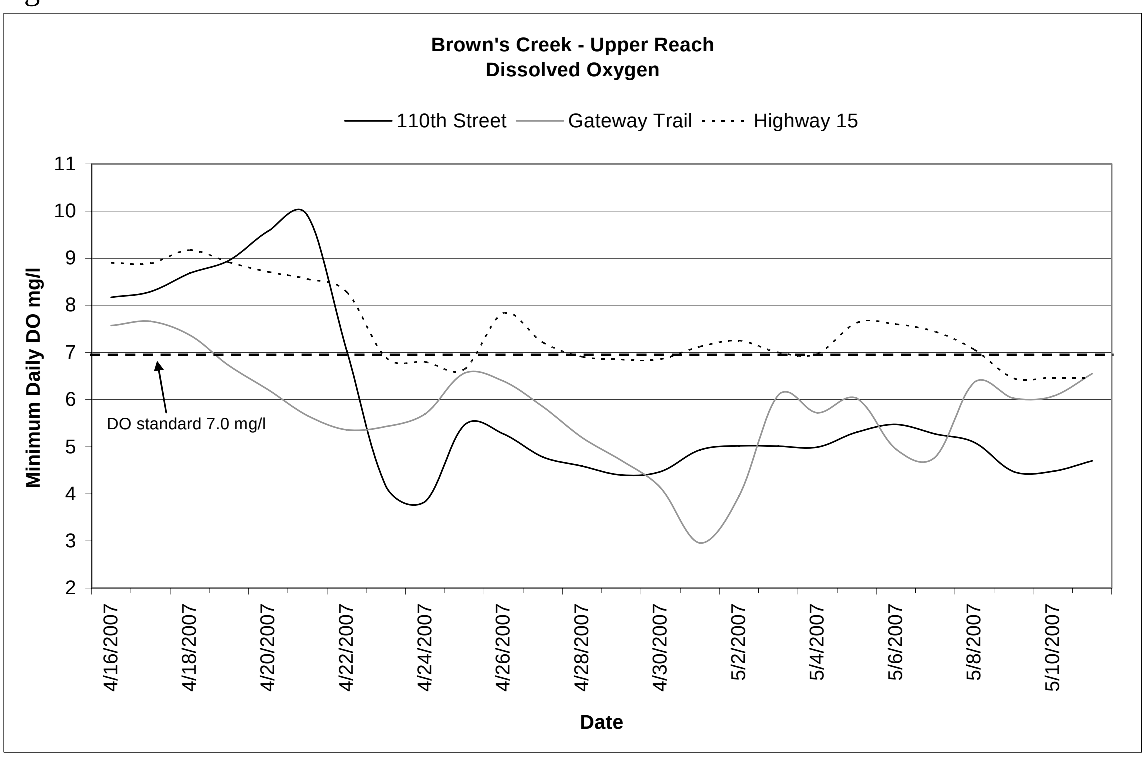

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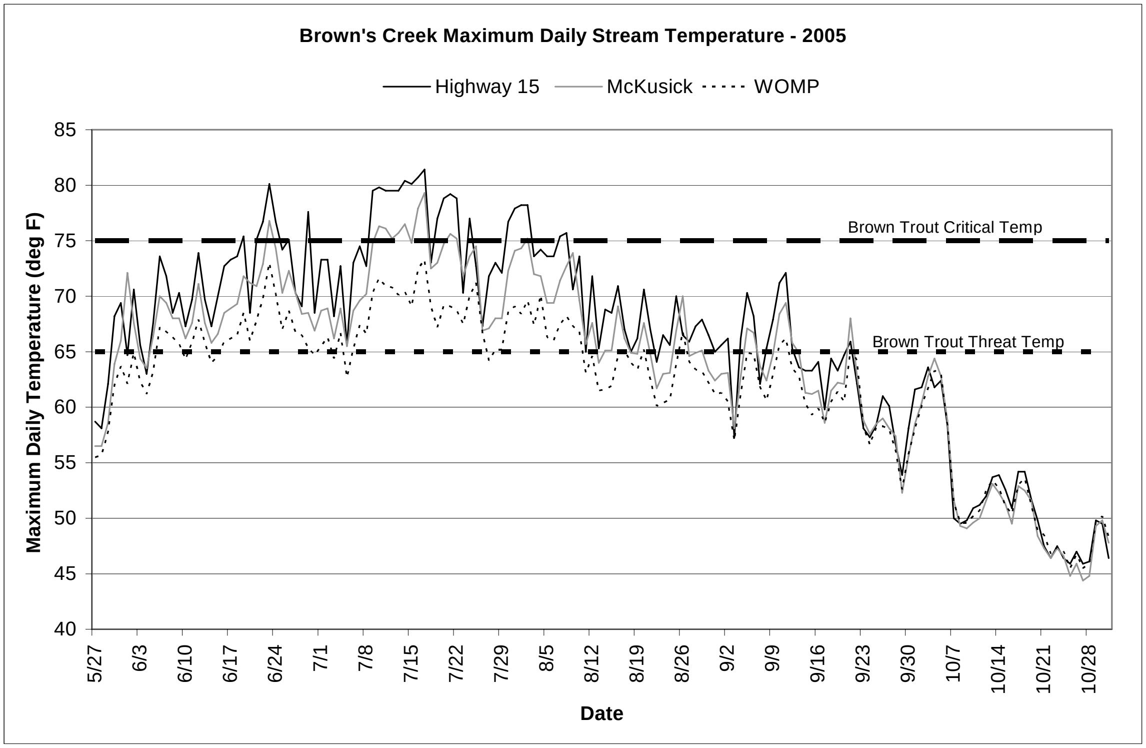

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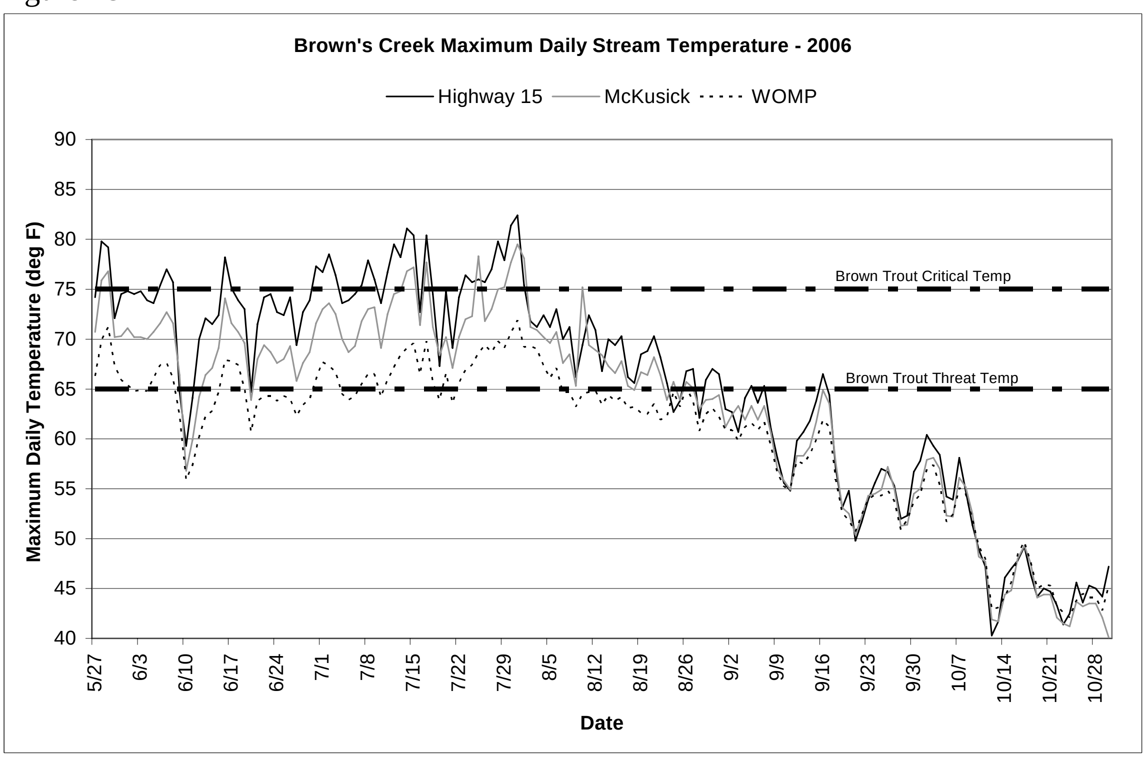

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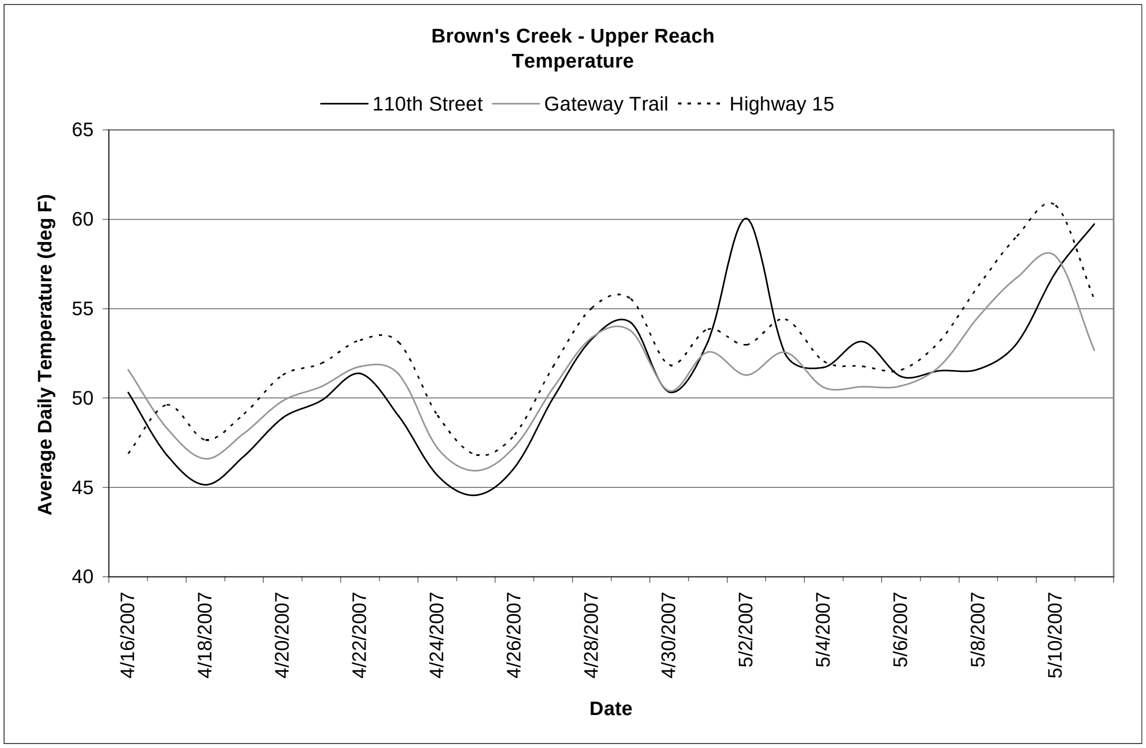
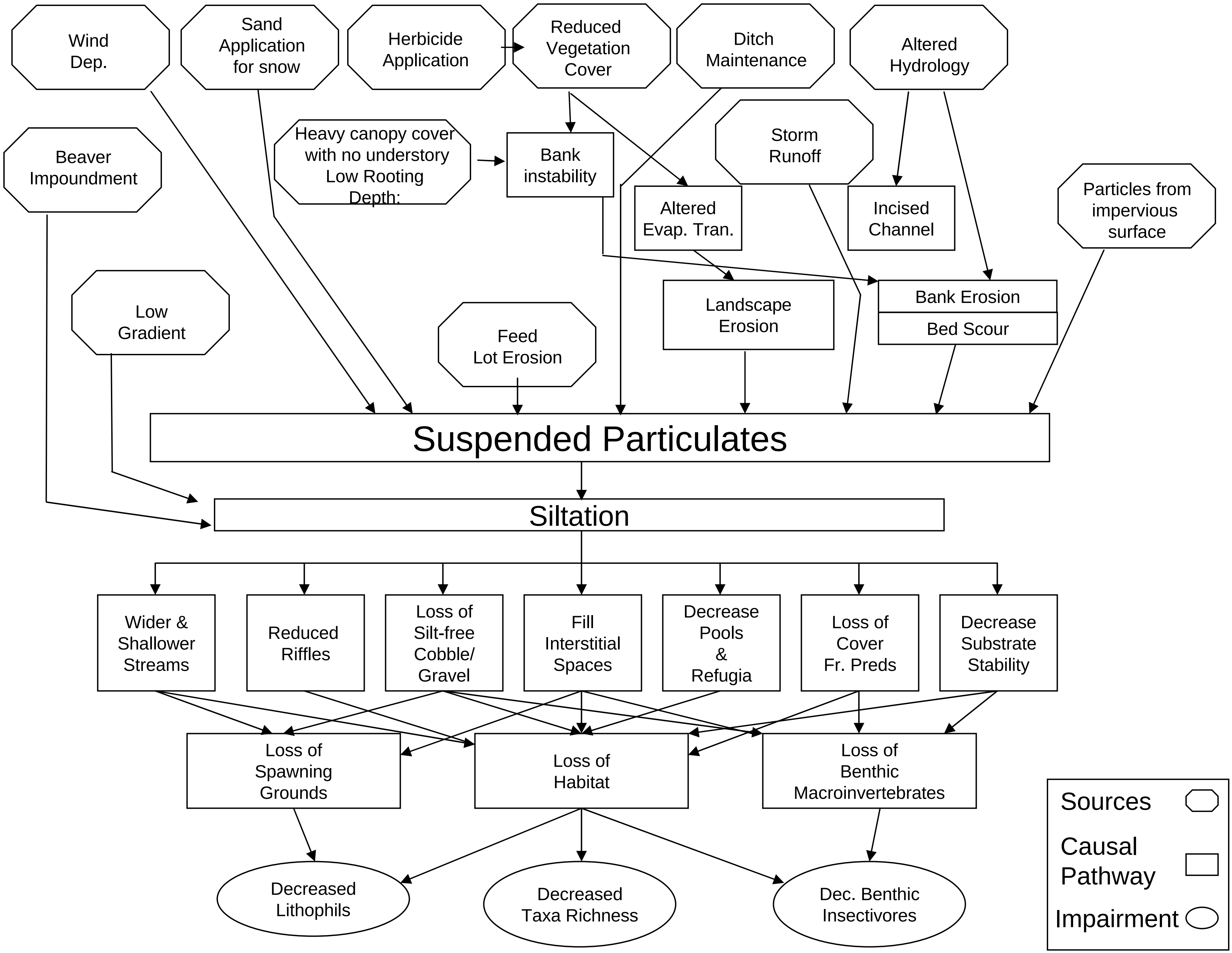
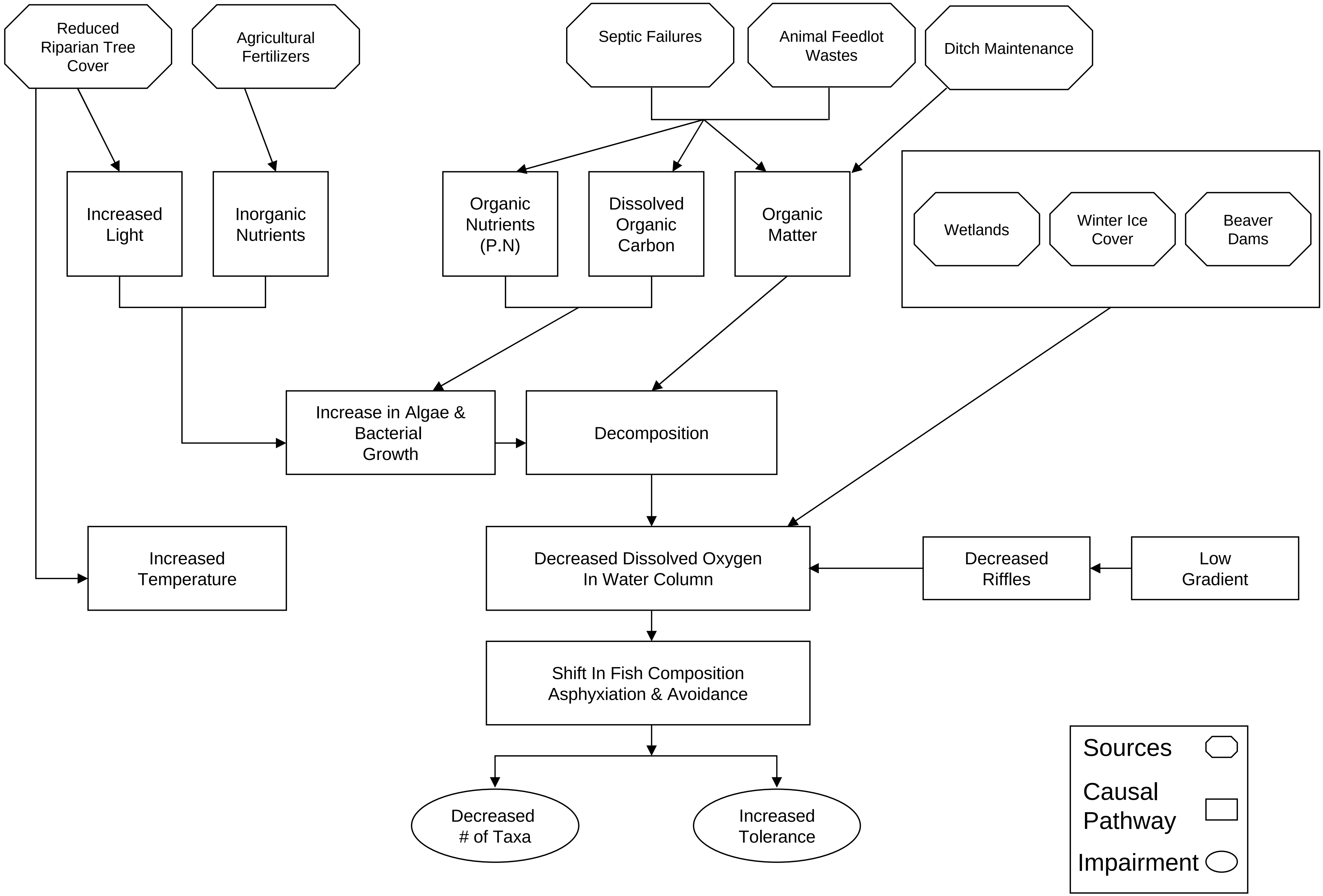


Brown's Creek - Upper Reach
Temperature
110th Street
Gateway Trail
Highway 15
Average Daily Temperature (deg F)
65
60
55
50
45
40
4/16/2007
4/18/2007
4/20/2007
4/22/2007
4/24/2007
4/26/2007
4/28/2007
4/30/2007
5/2/2007
5/4/2007
5/6/2007
5/8/2007
5/10/2007
Date

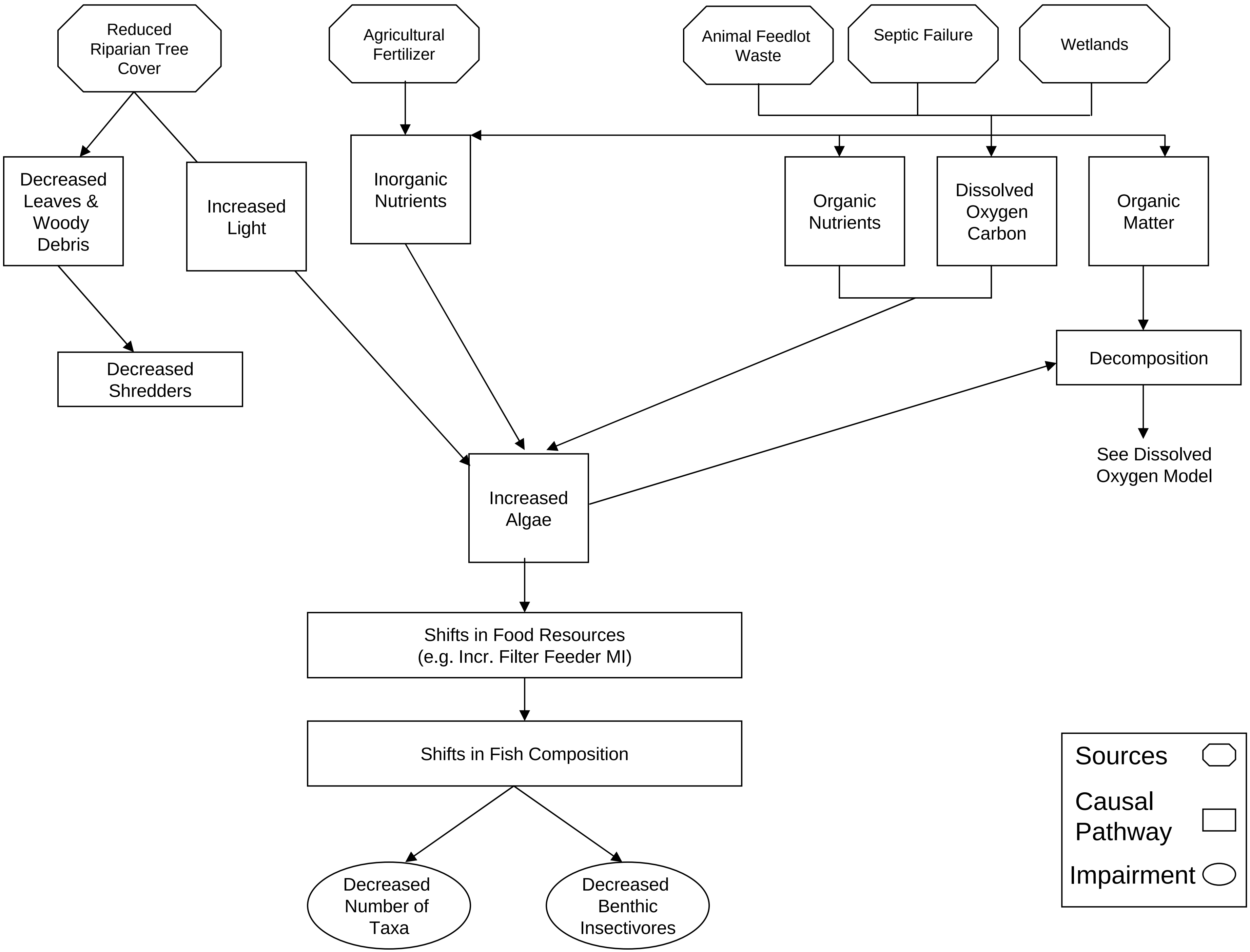
Attachment 6
Conceptual models



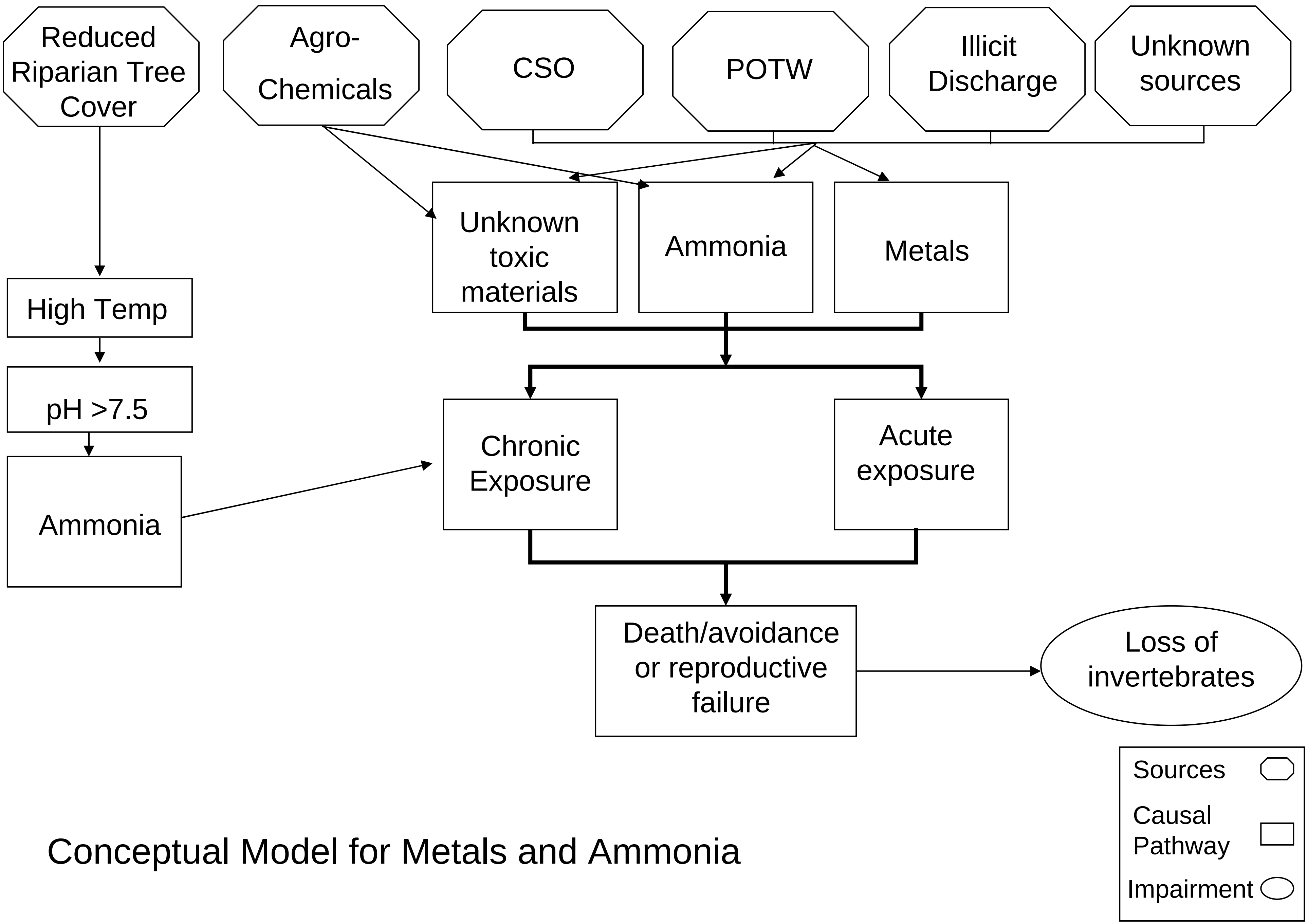
Conceptual Model for Sediment



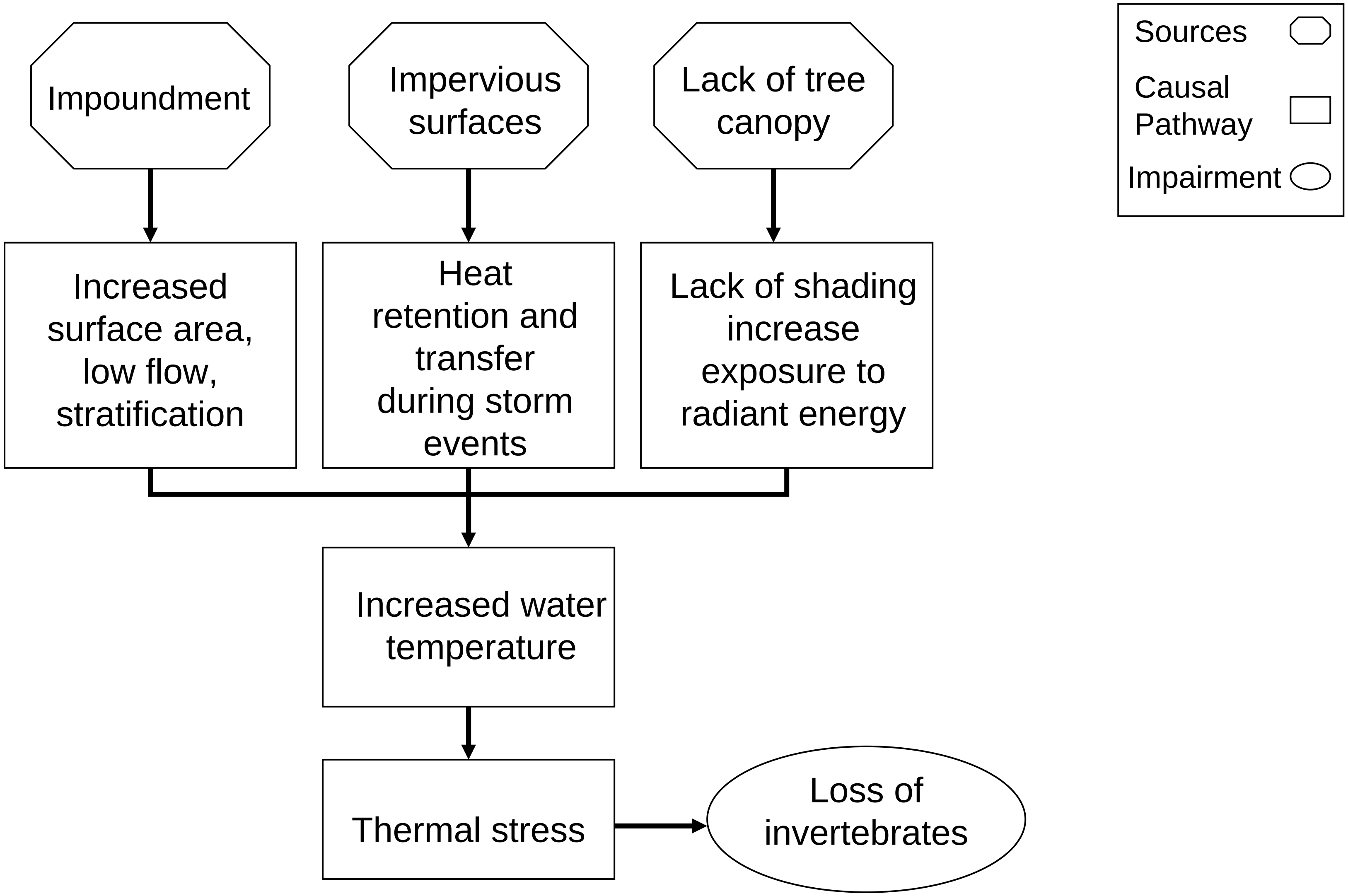
Conceptual Model for Dissolved Oxygen



Conceptual Model for Nutrients



Conceptual Model for Metals and Ammonia



Conceptual Model for Temperature

Attachment B. History of Brown's Creek Impairment Listing by the MPCA.

May 7, 2007 – from Jeff Jasperson

Regarding the justification for re-listing 07030005-587 Browns Creek:

The fish community at Browns Creek (96SC066) is characterized by a prevalence of highly tolerant warmwater species, no intolerant species, and complete absence of species indicative of coldwater habitats. These fish community attributes along with others at 96SC066 suggests a lack of a coldwater assemblage.

The macroinvertebrate community at 96SC066 is impaired due to a macroinvertebrate index of biological integrity (MIBI) score below the regional threshold for impairment.

Regarding the justification for listing 07030005-520 Browns Creek:

The fish community at Browns Creek (06SC055) is characterized by a prevalence of highly tolerant warmwater species, no intolerant species, and poor representation of species indicative of coldwater habitats. These fish community attributes along with others at 06SC055 suggests a lack of a coldwater assemblage.

History of assessment:

Segment 07030005-512 was placed on the 2002 TMDL list due to a biological (fish) impairment as indicated by a poor warmwater fish IBI score at site 96SC066. At that time it was understood that the warmwater use designation (2B) was applicable. In June of 2002, the segment 07030005-512 was split into two segments: 07030005-519 (Brown's Creek headwaters to trout stream portion – unlisted 2B) and 07030005-520 (Brown's Creek trout stream portion – 2A). Station 96SC066 fell on the new 07030005-519. During the 2004 assessment cycle, the biological (fish) impairment listing for 07030005-512 was transferred to 070030005-519. A new listing of biological (invertebrate) impairment was added to 07030005-519 based on a poor invertebrate IBI score for 96SC066.

A review of the use classification layer for the 2006 assessment cycle identified a typographical error found in Minnesota Rules 7050.0470 that described the length of the trout stream segment for Brown's Creek as being shorter than the Minnesota Department of Natural Resources had designated in Minnesota Rules 6264.0050. The trout stream segment should have extended to T30 R21W S12, north line. Therefore, 07030005-519 was retired and split into 07030005-586 (Brown's Creek headwaters to T30 R21W S1, south line – unlisted 2B) and 07030005-587 (Brown's Creek. T30 R21W S12, north line to T30 R21W S13, east line – 2A). Because of 96SC066's geographic location, the biological impairments based on the fish and invertebrates IBI scores were then assigned to 07030005-587 for the 2006 TMDL list.

The correct classification of 07030005-587 as 2A required a reevaluation of the tools used to assess the biology of 96SC066 for the 2008 assessment cycle. The MPCA does not have a tool available for assessing fish in coldwater streams; but the data from the 96SC0066 station do indicate impairment. While the distinction between warm and coldwater fish communities has been well documented, there do not exist clear distinctions between warm and coldwater aquatic marcroinvertebrate communities. Due to the proximity of 96SC066 to the warmwater segment of Brown's Creek, the MPCA decided to apply the macroinvertebrate IBI (MIBI) developed for warmwater streams of the St. Croix Basin.

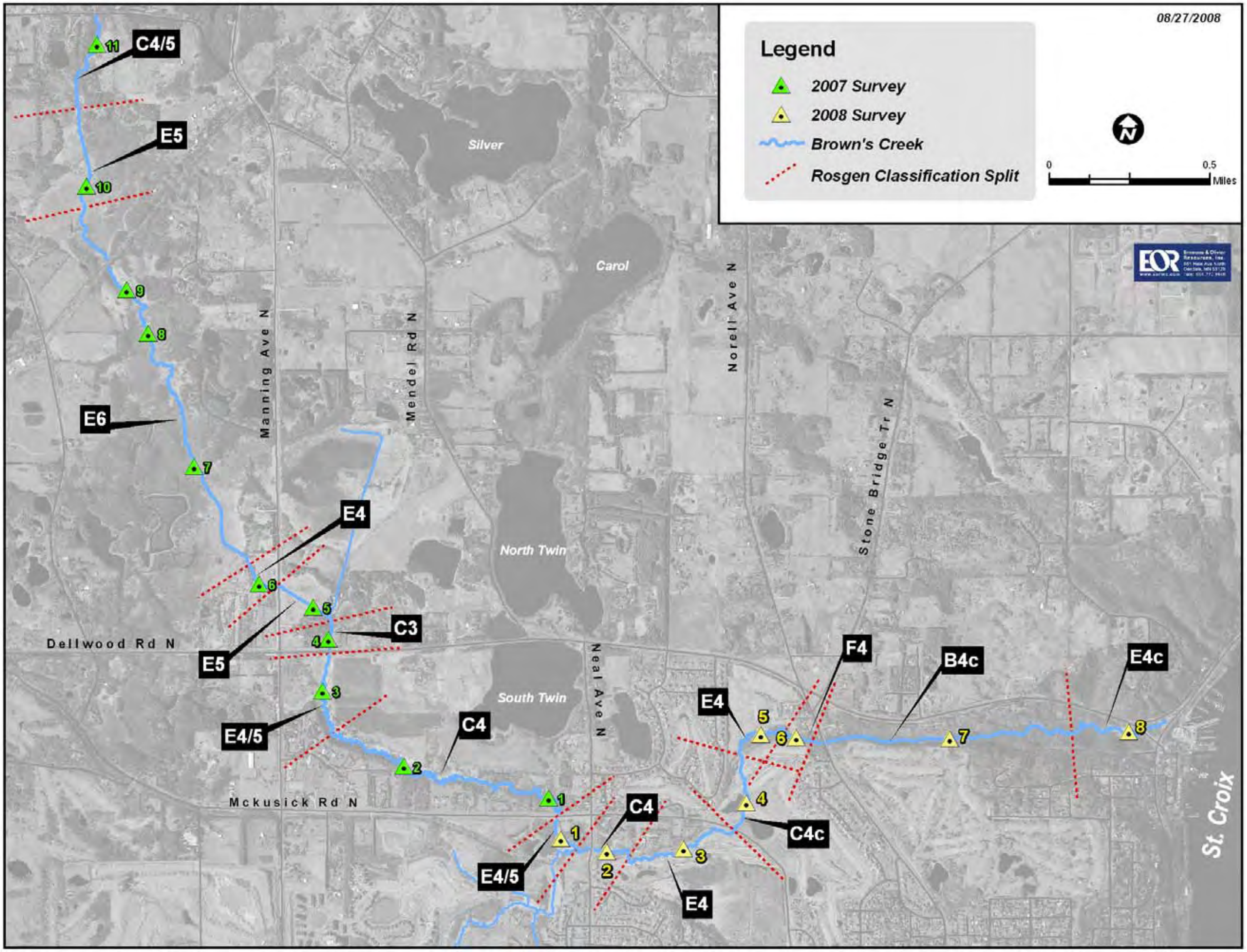
The 'Best Professional Judgment' (BPJ) group decided that 96SC066 will be assessed as impaired using a narrative interpretation of Minnesota Rules 7050.0150 as a class 2A waterbody and 07030005-587 will be placed on the 2008 TMDL list as biologically impaired for fish (lack of coldwater assemblage) and invertebrates (Invertebrate IBI). The BPJ also recognizes that 07030005-520 and 07030005-587 will most likely be combined in the future. In anticipation of having a single 2A use class segment and in support of the current listing of impairment based on the 96SC066 data, the BPJ decided to also assess data from 06SC055 and place 07030005-520 on the 2008 TMDL list as biologically impaired for fish (lack of coldwater assemblage) using a narrative interpretation of Minnesota Rule 7050.0150.

Attachment C. Geomorphic Analysis of Brown's Creek.

Map of Survey Sites

2007 Geomorphic Survey and Analysis – 110th Street North Crossing to Upper McKusick Road Crossing

2008 Geomorphic Survey and Analysis – Upper McKusick Road Crossing to State Hwy 96 Crossing



08/27/2008
Legend
2007 Survey
2008 Survey
Brown's Creek
Rosgen Classification Split
0
0.5
Miles
Silver
Carol
North Twin
South Twin
St. Croix
Manning Ave N
Mendel Rd N
Norell Ave N
Stone Bridge Tr N
Dellwood Rd N
Neal Ave N
Mckusick Rd N
C4/5
E5
E6
E4
E5
C3
E4/5
C4
E4/5
C4
E4
C4c
E4
F4
B4c
E4c

Brown’s Creek Stream Classification

2007 Geomorphic Survey and Analysis
110th Street North Crossing to Upper McKusick Road Crossing

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Downstream of 110th Street*
DATE	*6/20/2007*
FIELD ID	*Site #11 (Data collected ~375' downstream of 110th St.)*

BANKFULL ELEVATION (ft)	917.3

CHANNEL DIMENSIONS		
	W_{bkf} (ft)	*15.00*
	D_{mean} (ft)	*0.51*
	W/D	*29.16*
	D_{max}(ft)	*1.50*
	2 x D_{max}(ft)	*2.99*
	CSA (ft^2)	*7.72*
	W_{flp} (ft)	*82.00*
	E	*5.47*

CHANNEL MATERIAL (D50)	*Gravel*
SINUOSITY	*1.28*
SLOPE	*0.0062*
ROSGEN LEVEL II STREAM CLASSIFICATION	***C4***

GENERAL COMMENTS & CONCLUSIONS:

- Most significant bank instabilities can be found in this reach, although streambanks are still very stable in relative comparison
- Hardwood and Alder dominated overstory
- Bankfull width increases dramatically with the short breaks in the canopy (reaches dominated by herbaceous cover).

Note: The new culvert at 110th street may be an impediment to fish migration. The downstream invert is elevated above the water surface during normal to low flows conditions.

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 1850 river feet upstream of the Gateway Trail*
DATE	*6/20/2007*
FIELD ID	*Site #10*

BANKFULL ELEVATION (ft)	905.55

CHANNEL DIMENSIONS	W_{bkf} (ft)	*4.00*
	D_{mean} (ft)	*1.21*
	W/D	*3.32*
	D_{max}(ft)	*1.64*
	2 x D_{max}(ft)	*3.29*
	CSA (ft^2)	*4.82*
	W_{flp} (ft)	*200.00*
	E	*50.00*

CHANNEL MATERIAL (D50)	*Sand*
SINUOSITY	*1.1*
SLOPE	*0.003*
ROSGEN LEVEL II STREAM CLASSIFICATION	***E5***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are very stable
- Bankfull width and cross-sectional area are significantly less than downstream reaches
- Significant groundwater contributions throughout
- Areas of high flora quality

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 890 river feet downstream of the Gateway Trail*
DATE	*5/22/2007*
FIELD ID	*Site #9*

BANKFULL ELEVATION (ft)	902.9

CHANNEL DIMENSIONS		
	W_{bkf} (ft)	*10.00*
	D_{mean} (ft)	*1.79*
	W/D	*5.58*
	D_{max}(ft)	*1.88*
	2 x D_{max}(ft)	*3.77*
	CSA (ft^2)	*17.94*
	W_{flp} (ft)	*205.00*
	E	*20.50*

CHANNEL MATERIAL (D50)	*Organics**
SINUOSITY	*1.16*
SLOPE	*0.001*
ROSGEN LEVEL II STREAM CLASSIFICATION	***E6***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- Cattail dominated cover
- Bed material consists of consolidated and unconsolidated organic material. Limited sand was found well beneath the organics in some areas
- Very low gradient

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 1670 river feet downstream of the Gateway Trail*
DATE	*5/22/2007*
FIELD ID	*Site #8*

BANKFULL ELEVATION (ft)		902.3
CHANNEL DIMENSIONS	W_{bkf} (ft)	*12.10*
	D_{mean} (ft)	*1.47*
	W/D	*8.22*
	D_{max}(ft)	*1.81*
	2 x D_{max}(ft)	*3.62*
	CSA (ft^2)	*17.81*
	W_{flp} (ft)	*200.00*
	E	*16.53*
CHANNEL MATERIAL (D50)		*Organics**
SINUOSITY		*1.09*
SLOPE		*0.0002*
ROSGEN LEVEL II STREAM CLASSIFICATION		***E6***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- Strong groundwater contribution throughout
- Alder overstory
- Bed material consists of consolidated and unconsolidated organic material. Limited sand was found well beneath the organics in some areas
- Very low gradient

Note: Survey may have been distorted by an active beaver dam present 300+/- downstream of surveyed reach

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 2725 river feet upstream of Hwy 15*
DATE	*5/22/2007*
FIELD ID	*Site #7*

BANKFULL ELEVATION (ft)	899.5

CHANNEL DIMENSIONS		
	W_{bkf} (ft)	*11.00*
	D_{mean} (ft)	*1.12*
	W/D	*9.86*
	D_{max}(ft)	*1.38*
	2 x D_{max}(ft)	*2.76*
	CSA (ft^2)	*12.27*
	W_{flp} (ft)	*180.00*
	E	*16.36*

CHANNEL MATERIAL (D50)	*Organics**
SINUOSITY	*1.09*
SLOPE	*0.0003*
ROSGEN LEVEL II STREAM CLASSIFICATION	***E6***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- Strong groundwater contribution throughout
- Bed material consists of consolidated and unconsolidated organic material. Limited sand was found well beneath the organics in some areas
- Lower gradient

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 300 river feet upstream of Hwy 15*
DATE	*5/22/2007*
FIELD ID	*Site #6*

BANKFULL ELEVATION (ft)	897

CHANNEL DIMENSIONS		
	W_{bkf} (ft)	*10.00*
	D_{mean} (ft)	*1.31*
	W/D	*7.65*
	D_{max}(ft)	*1.38*
	2 x D_{max}(ft)	*2.77*
	CSA (ft^2)	*13.06*
	W_{flp} (ft)	*65.00*
	E	*6.50*

CHANNEL MATERIAL (D50)	*Gravel*
SINUOSITY	*1.08*
SLOPE	*0.006*
ROSGEN LEVEL II STREAM CLASSIFICATION	***E4***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- Steep gradient
- Some of the best potential habitat surveyed

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 500 river feetdownstream of Hwy 15*
DATE	*5/22/2007*
FIELD ID	*Site #5*

BANKFULL ELEVATION (ft)		894.77
CHANNEL DIMENSIONS	W_{bkf} (ft)	*7.50*
	D_{mean} (ft)	*1.88*
	W/D	*3.99*
	D_{max}(ft)	*1.69*
	2 x D_{max}(ft)	*3.39*
	CSA (ft^2)	*14.10*
	W_{flp} (ft)	*150.00*
	E	*20.00*
CHANNEL MATERIAL (D50)		*Sand*
SINUOSITY		*1.01*
SLOPE		*0.0001*
ROSGEN LEVEL II STREAM CLASSIFICATION		***E5***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- Reed Canary Grass dominated cover
- Channel material tapers from gravel in the upstream reaches to sand & organics in the downstream portion of this reach
- Historic ditching is apparent
- Very low habitat
- Good candidate for restoration

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 300 river feet upstream of Hwy 96*
DATE	*5/22/2007*
FIELD ID	*Site #4*

BANKFULL ELEVATION (ft)	893.9

CHANNEL DIMENSIONS		
	W_{bkf} (ft)	*14.00*
	D_{mean} (ft)	*1.11*
	W/D	*12.66*
	D_{max}(ft)	*1.60*
	2 x D_{max}(ft)	*3.20*
	CSA (ft^2)	*15.48*
	W_{flp} (ft)	*29.00*
	E	*2.07*

CHANNEL MATERIAL (D50)	*Cobble*
SINUOSITY	*1.02*
SLOPE	*0.004*
ROSGEN LEVEL II STREAM CLASSIFICATION	***C3***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks generally stable
- Cross-section and profile rip-rapped.
- Only section with significant cobble (likely artificial)
- Highly manicured buffer
- Good restoration site

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 400 river feet downstream of Hwy 96*
DATE	*5/22/2007*
FIELD ID	*Site #3*

BANKFULL ELEVATION (ft)	890.49

CHANNEL DIMENSIONS		
	W_{bkf} (ft)	*8.00*
	D_{mean} (ft)	*1.43*
	W/D	*5.59*
	D_{max}(ft)	*1.67*
	2 x D_{max}(ft)	*3.33*
	CSA (ft^2)	*11.46*
	W_{flp} (ft)	*80.00*
	E	*10.00*

CHANNEL MATERIAL (D50)	*Gravel/Sand*

SINUOSITY	*1.29*

SLOPE	*0.0048*

ROSGEN LEVEL II STREAM CLASSIFICATION	***E4/5***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable
- One of the steepest gradients
- Reed Canary Grass dominated cover

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 2600 river feet downstream of Hwy 96*
DATE	*5/22/2007*
FIELD ID	*Site #2*

BANKFULL ELEVATION (ft)	879.4

CHANNEL DIMENSIONS		
	W_{bkf} (ft)	*11.70*
	D_{mean} (ft)	*0.93*
	W/D	*12.57*
	D_{max}(ft)	*1.03*
	2 x D_{max}(ft)	*2.06*
	CSA (ft^2)	*10.89*
	W_{flp} (ft)	*34.00*
	E	*2.91*

CHANNEL MATERIAL (D50)	*Gravel*
SINUOSITY	*1.27*
SLOPE	*0.003*
ROSGEN LEVEL II STREAM CLASSIFICATION	***C4***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- Strong groundwater contribution throughout
- Hardwood & Alder overstory

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 500 river feet upstream of McKusick Rd N*
DATE	*5/22/2007*
FIELD ID	*Site #1*

BANKFULL ELEVATION (ft)	866.1

CHANNEL DIMENSIONS		
	W_{bkf} (ft)	*11.00*
	D_{mean} (ft)	*0.84*
	W/D	*13.10*
	D_{max}(ft)	*1.17*
	2 x D_{max}(ft)	*2.35*
	CSA (ft^2)	*9.23*
	W_{flp} (ft)	*17.00*
	E	*1.55*

CHANNEL MATERIAL (D50)	*Gravel*
SINUOSITY	*1.5*
SLOPE	*0.004*
ROSGEN LEVEL II STREAM CLASSIFICATION	***C4***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks in this section are generally stable.
- The deepest pool (3.75’ @ bankfull) across all 2007 surveyed reaches was found within this section.
- Strong groundwater contribution throughout
- Hardwood and Alder overstory

Brown’s Creek Stream Classification

2008 Geomorphic Survey and Analysis
Upper McKusick Road Crossing to State Hwy 96 Crossing

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 400 river feet downstream of McKusick Rd N*
DATE	*6/30/2008*
FIELD ID	*Site #1*

BANKFULL ELEVATION (ft)		860.78
CHANNEL DIMENSIONS	W_{bkf} (ft)	*10.00*
	D_{mean} (ft)	*1.75*
	W/D	*5.73*
	D_{max}(ft)	*2.47*
	2 x D_{max}(ft)	*4.94*
	CSA (ft^2)	*17.46*
	W_{flp} (ft)	*58.00*
	E	*5.80*
CHANNEL MATERIAL (D50)		*Medium Gravel*
SINUOSITY		*1.2*
SLOPE		*0.002*
ROSGEN LEVEL II STREAM CLASSIFICATION		***E4/5***

GENERAL COMMENTS & CONCLUSIONS:

- Riparian vegetation dominated by reed canary and stinging nettle ground cover
- Alder present in the overstory along upstream portion of reach
- Creek is down cutting through wetland complex in this reach, banks are composed of peat materials
- Root depth/density is only protecting roughly 1/2 of banks
- The dominant channel material (medium gravel) is likely being transported from upstream reaches
- Channel reference pipes placed in this reach

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 185 river feet downstream of Neal Ave*
DATE	*6/30/2008*
FIELD ID	*Site #2*

BANKFULL ELEVATION (ft)		859
CHANNEL DIMENSIONS	W_{bkf} (ft)	*18.50*
	D_{mean} (ft)	*1.61*
	W/D	*11.49*
	D_{max}(ft)	*2.48*
	2 x D_{max}(ft)	*4.95*
	CSA (ft^2)	*29.78*
	W_{flp} (ft)	*100.00*
	E	*5.41*
CHANNEL MATERIAL (D50)		*Very Fine Gravel*
SINUOSITY		*1.1*
SLOPE		*0.003*
ROSGEN LEVEL II STREAM CLASSIFICATION		***C4***

GENERAL COMMENTS & CONCLUSIONS:

- Riparian vegetation dominated by reed canary and stinging nettle ground cover north of creek and Alder and hardwood overstory south of creek
- Channel material on north side of creek comprised of peat material and south side of creek is predominately mineral soils
- Root depth/density is only protecting roughly 1/2 of northern bank
- Channel blockage from limbs, branches, and small logs occurring.
- Erosion present on upstream portion of reach

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 490 river feet upstream of McKusick Rd at Oak Glen Golf Course on Restored Reach*
DATE	*6/30/2008*
FIELD ID	*Site #3*

BANKFULL ELEVATION (ft)	853.5

CHANNEL DIMENSIONS		
	W_{bkf} (ft)	*14.00*
	D_{mean} (ft)	*2.06*
	W/D	*6.79*
	D_{max}(ft)	*3.22*
	2 x D_{max}(ft)	*6.43*
	CSA (ft^2)	*28.86*
	W_{flp} (ft)	*34.00*
	E	*2.43*

CHANNEL MATERIAL (D50)	*Coarse Gravel*
SINUOSITY	*1.1*
SLOPE	*0.011*
ROSGEN LEVEL II STREAM CLASSIFICATION	***E4***

GENERAL COMMENTS & CONCLUSIONS:

- Restored reach (MNDNR)
- Streambanks in this section are stable
- Heavily vegetated banks consisting of willow and reed canary
- Anthropogenically placed gravel bed
- Riffle-Pool sequences with pools in excess of 2 feet deep
- Willow offer shading/thermal protection

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 265 river feet upstream of Zephyr Railroad Bridge of Oak Glen Golf Course*
DATE	*6/30/2008*
FIELD ID	*Site #4*

BANKFULL ELEVATION (ft)		847.5
CHANNEL DIMENSIONS	W_{bkf} (ft)	*16.00*
	D_{mean} (ft)	*1.48*
	W/D	*10.80*
	D_{max}(ft)	*2.13*
	2 x D_{max}(ft)	*4.27*
	CSA (ft^2)	*23.70*
	W_{flp} (ft)	*43.50*
	E	*2.72*
CHANNEL MATERIAL (D50)		*Very Fine Gravel*
SINUOSITY		*1.1*
SLOPE		*0.0004*
ROSGEN LEVEL II STREAM CLASSIFICATION		***C4c-***

GENERAL COMMENTS & CONCLUSIONS:

- Streambanks generally stable, consisting of highly manicured turf
- Some undercutting present on outside bends
- Reach has very little riparian overstory, limited thermal protection
- Beaver activity present on upstream area of reach
- Good candidate for restoration

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 510 river feet downstream of Zephyr Railroad Bridge located at the Oak Glen Golf Course*
DATE	*6/30/2008*
FIELD ID	*Site #5*

BANKFULL ELEVATION (ft)		842.04
CHANNEL DIMENSIONS	W_{bkf} (ft)	*19.50*
	D_{mean} (ft)	*1.90*
	W/D	*10.29*
	D_{max}(ft)	*2.41*
	2 x D_{max}(ft)	*4.81*
	CSA (ft^2)	*36.97*
	W_{flp} (ft)	*120.00*
	E	*6.15*
CHANNEL MATERIAL (D50)		*Coarse Gravel*
SINUOSITY		*1.6*
SLOPE		*0.0071*
ROSGEN LEVEL II STREAM CLASSIFICATION		***E4***

GENERAL COMMENTS & CONCLUSIONS:

- Riparian vegetation dominated by reed canary and stinging nettle ground cover north of creek and Alder and hardwood overstory south of creek
- Root depth/density is protecting banks
- Reach has some riparian overstory, offering limited thermal protection

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 300 river feet upstream of Hwy 5*
DATE	*6/30/2008*
FIELD ID	*Site #6*

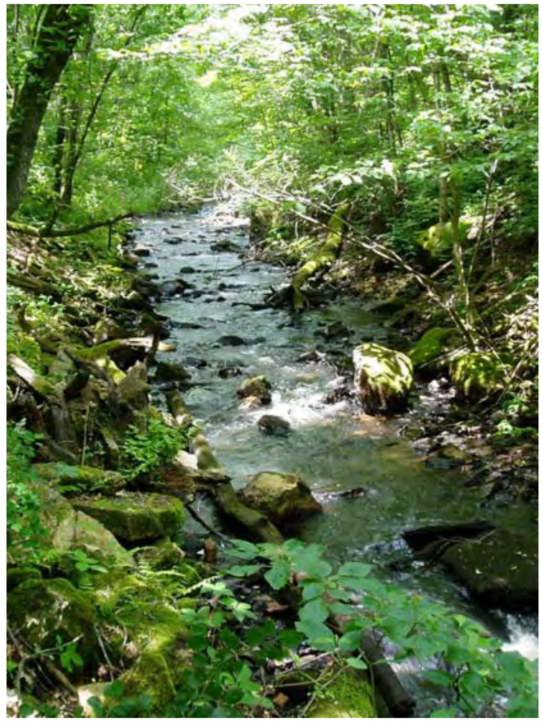
BANKFULL ELEVATION (ft)		834.75
CHANNEL DIMENSIONS	W_{bkf} (ft)	*16.50*
	D_{mean} (ft)	*1.25*
	W/D	*13.18*
	D_{max}(ft)	*1.56*
	2 x D_{max}(ft)	*3.13*
	CSA (ft^2)	*20.65*
	W_{flp} (ft)	*17.90*
	E	*1.08*
CHANNEL MATERIAL (D50)		*Coarse Gravel*
SINUOSITY		*1*
SLOPE		*0.009*
ROSGEN LEVEL II STREAM CLASSIFICATION		***F4***

GENERAL COMMENTS & CONCLUSIONS:

- Straight ditched section parallel to the railroad tracks
- Riparian vegetation dominated by buckthorn and green ash
- Denuded slopes with high erosion
- Root depth/density is inadequately protecting banks
- Moderate channel blockage consisting of limbs, branches, and logs
- Reach has ample riparian overstory, offering thermal protection
- Restoration warranted to restore sinuosity and floodplain

STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 1500 river feet downstream of Hwy 5*
DATE	*6/30/2008*
FIELD ID	*Site #7*

BANKFULL ELEVATION (ft)		790
CHANNEL DIMENSIONS	W_{bkf} (ft)	*15.60*
	D_{mean} (ft)	*1.52*
	W/D	*10.28*
	D_{max}(ft)	*2.22*
	2 x D_{max}(ft)	*4.44*
	CSA (ft^2)	*23.68*
	W_{flp} (ft)	*22.00*
	E	*1.41*
CHANNEL MATERIAL (D50)		*Very Coarse Gravel*
SINUOSITY		*1.1*
SLOPE		*0.0340*
ROSGEN LEVEL II STREAM CLASSIFICATION		***B4c***



GENERAL COMMENTS & CONCLUSIONS:

- Gorge reach, parallel to the railroad tracks
- Riparian vegetation dominated by hardwood overstory and jewel weed /moss understory
- Steep gorge slopes with high erosion potential, erosion at some culvert locations
- Heavy groundwater discharge along reach, especially near the Prairie du Chien -Jordon Sandstone contact
- Moderate channel blockage consisting of boulders, limbs, branches, and logs
- Reach has ample riparian overstory, offering good thermal protection
- Channel reference pipes placed in this reach

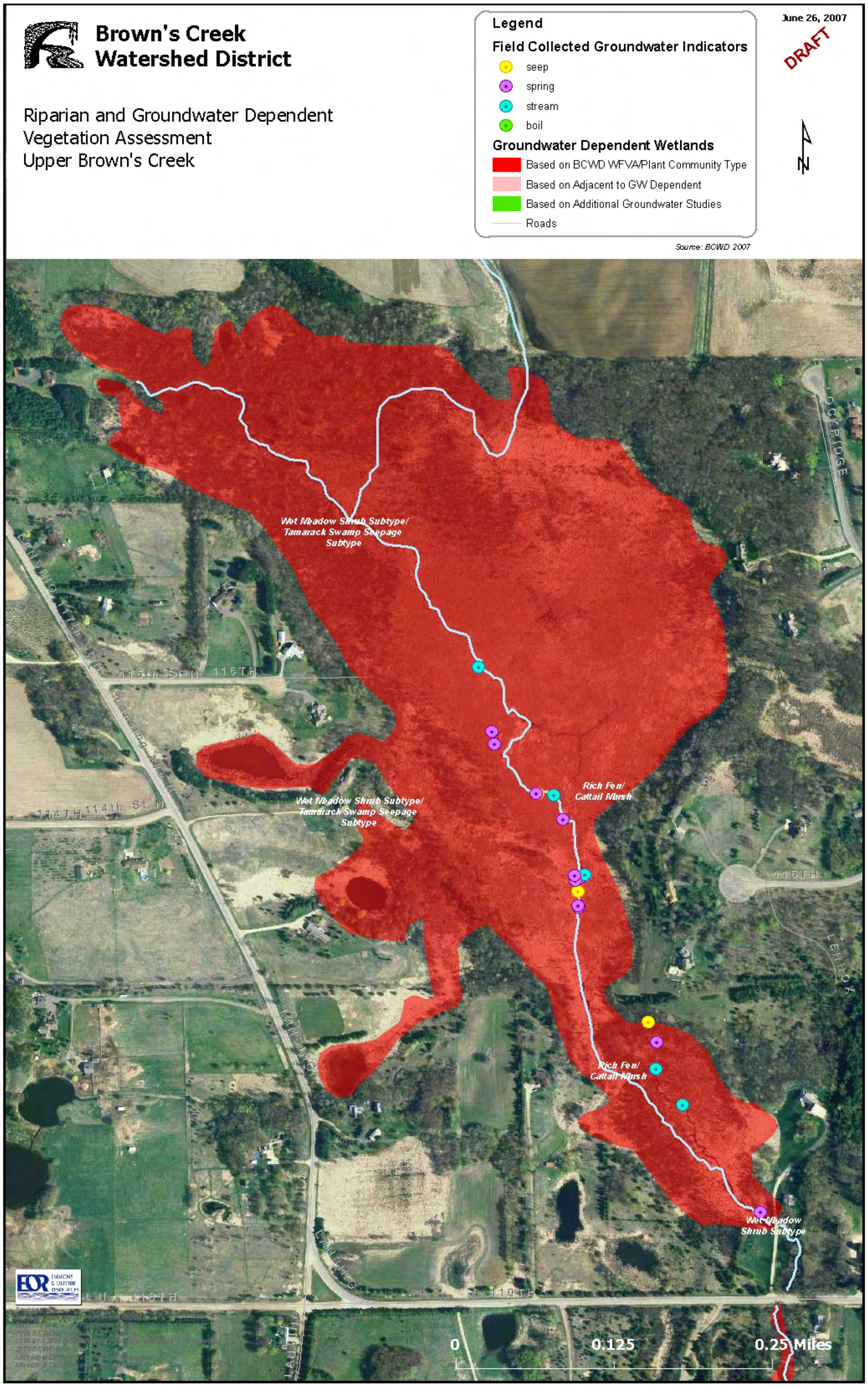
STREAM	*Brown's Creek (Washington County, MN)*
LOCATION	*Approximately 320 river feet upstream of Hwy 96*
DATE	*6/30/2008*
FIELD ID	*Site #8*

BANKFULL ELEVATION (ft)		686.75
CHANNEL DIMENSIONS	W_{bkf} (ft)	*13.50*
	D_{mean} (ft)	*1.23*
	W/D	*10.94*
	D_{max}(ft)	*1.60*
	2 x D_{max}(ft)	*3.19*
	CSA (ft^2)	*16.66*
	W_{flp} (ft)	*50.00*
	E	*3.70*
CHANNEL MATERIAL (D50)		*Very Fine Gravel*
SINUOSITY		*1.2*
SLOPE		*0.0034*
ROSGEN LEVEL II STREAM CLASSIFICATION		***E4***

GENERAL COMMENTS & CONCLUSIONS:

- Floodplain reach
- Riparian vegetation dominated by reed canary understory and limited alder overstory
- Slight thermal protection from shading
- Bank undercutting due to minimal root depths
- Channel reference pipes placed in this reach

Attachment D. Riparian and Groundwater Dependent Vegetation Assessment.


Brown's Creek
Watershed District
Riparian and Groundwater Dependent
Vegetation Assessment
Upper Brown's Creek
Legend
Field Collected Groundwater Indicators
seep
spring
stream
boil
Groundwater Dependent Wetlands
Based on BCWD WFVA/Plant Community Type
Based on Adjacent to GW Dependent
Based on Additional Groundwater Studies
Roads
Source: BCWD 2007
June 26, 2007
DRAFT
N
Wet Meadow Shrub Subtype/
Tamarack Swamp Seepage
Subtype
Rich Fen/
Cattail Marsh
Wet Meadow Shrub Subtype/
Tamarack Swamp Seepage
Subtype
Rich Fen/
Cattail Marsh
Wet Meadow
Shrub Subtype
0
0.125
0.25 Miles

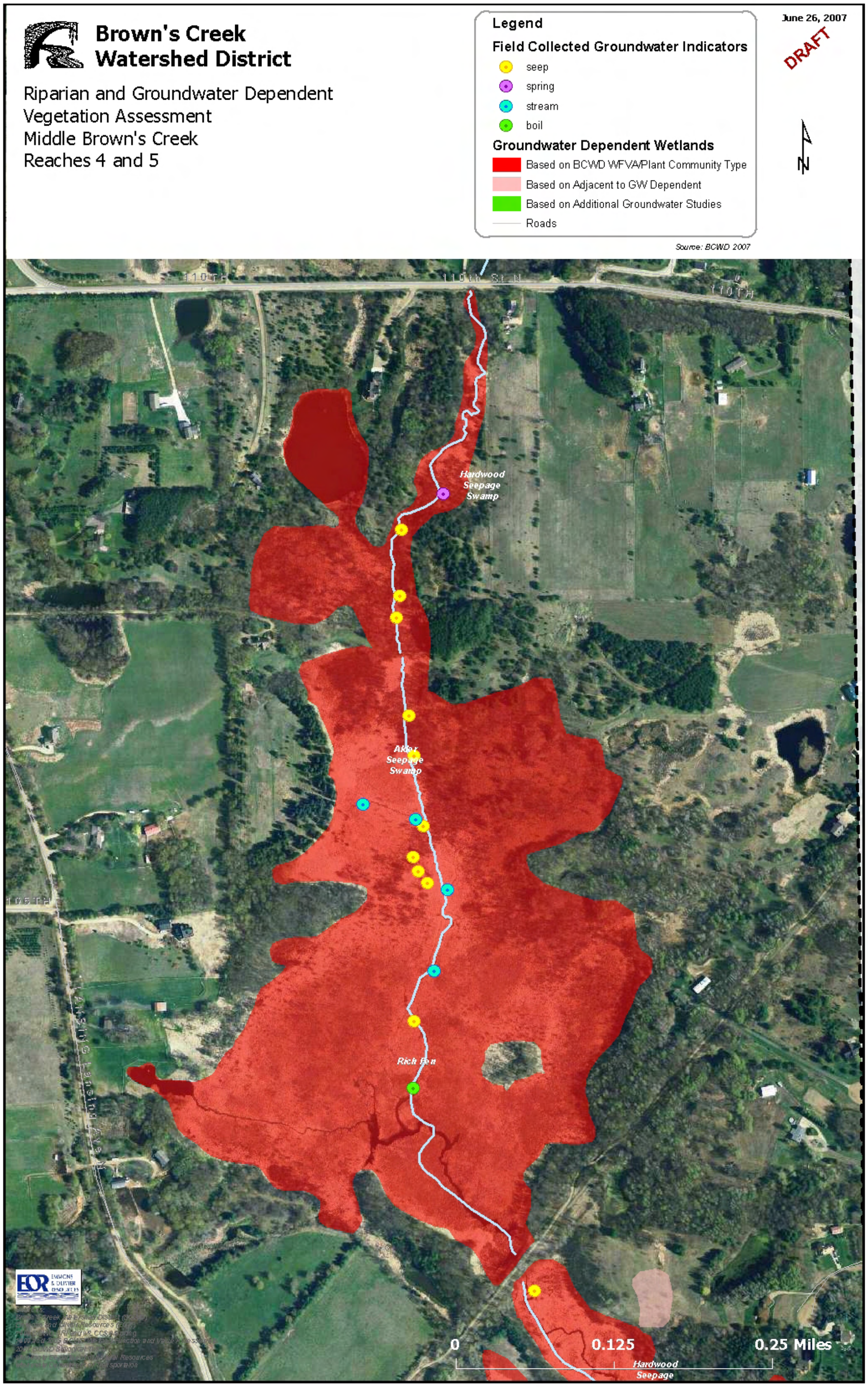
RIPARIAN AND GROUNDWATER DEPENDENT VEGETATION ASSESSMENT

A detailed assessment of the riparian corridor expanding 50 feet on both sides of the creek was conducted to evaluate the riparian and the groundwater dependent vegetation associated with Brown's Creek.

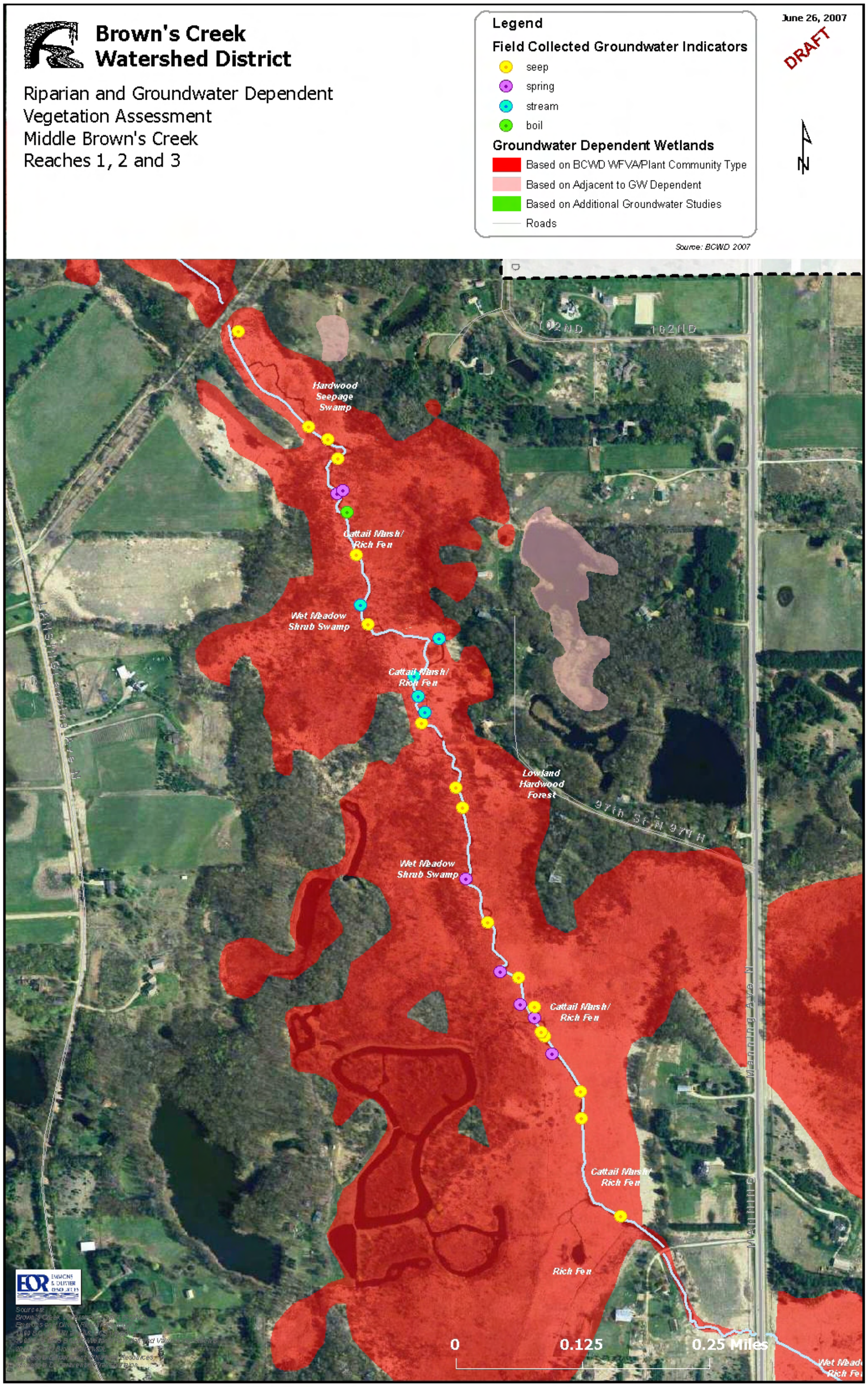
Riparian vegetation is very important in determining the structure and function of stream ecosystems. Most aquatic organisms, including invertebrates and fish, are directly or indirectly dependent on inputs of terrestrial detritus to the stream for their food. Natural changes in riparian vegetation and the biotic processing of detritus influence the kinds and abundance of aquatic biota living in streams.

Groundwater seepage to the surface environment provides highly specialized hydrologic conditions that support numerous plant species and natural communities. In the upper and lower watersheds of Brown's Creek, groundwater seepage areas in wetlands create favorable conditions for seepage swamps, fens, and wet meadows. Unique plant species that depend on the integrity of groundwater discharge systems include skunk cabbage and swamp willow. Along the entire stretch of Brown's Creek are specialized natural communities that have developed and are dependent on groundwater seepage. Therefore, maintaining base flow to the upper and lower portions of Brown's Creek also maintains the health of individual rare plants and natural communities that are dependent on groundwater seepage.

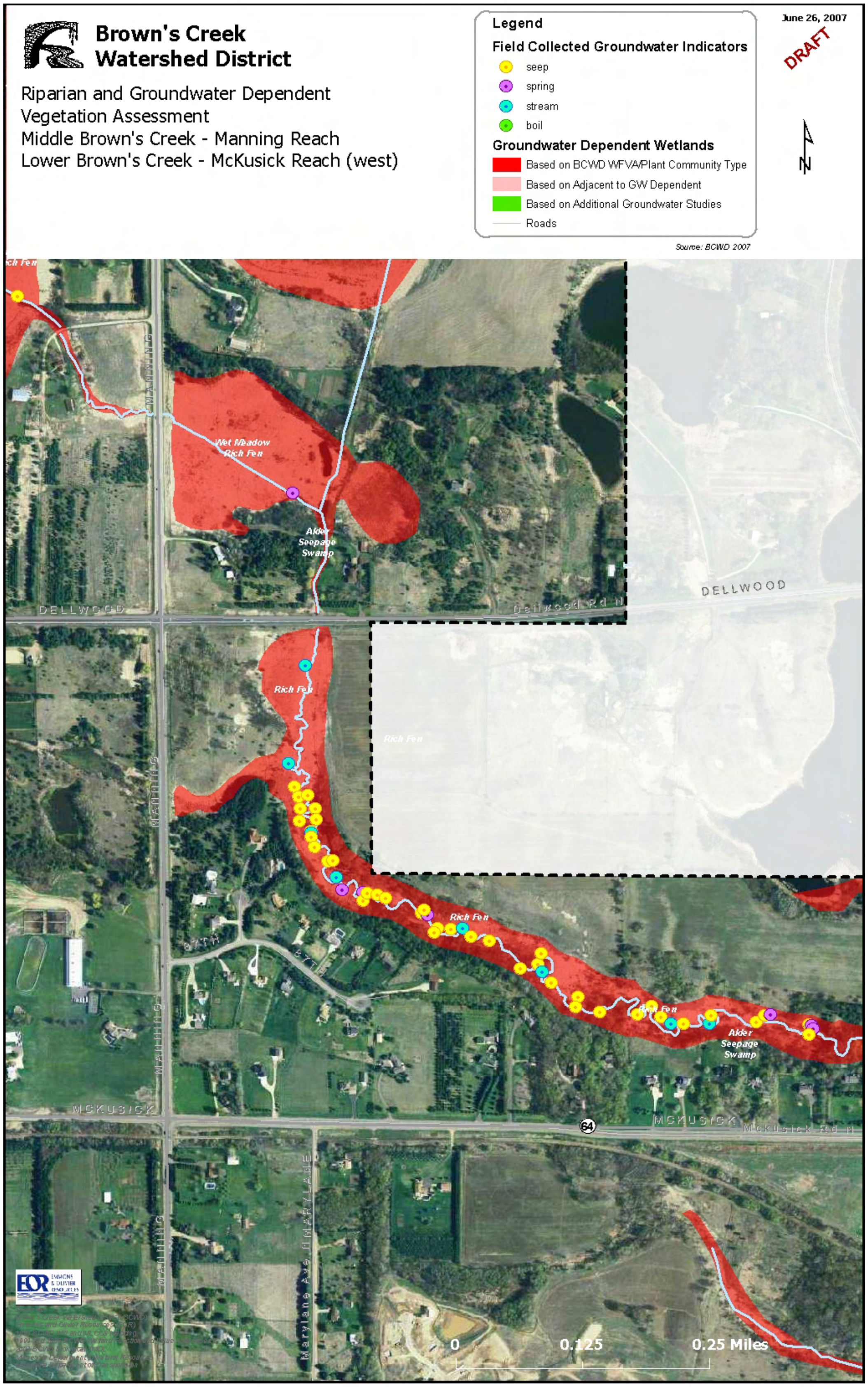
The BWCD identified a process to evaluate whether a wetland or lake was a groundwater dependent resource. Criteria to identify groundwater dependent wetlands and lakes are described in the BCWD Watershed Management Plan. These criteria were used in this assessment. Field investigations were conducted in May and June 2007 from the McKusick monitoring site north to the headwaters area. Field investigations were also conducted in August 2008 from the McKusick monitoring site south to the St. Croix River. Evidence of groundwater inputs were recorded using a Global Positioning System (GPS) with sub-meter accuracy, and divided into springs, seeps, and boils. The information collected on groundwater dependent vegetation in the following figures provides additional detail to the wetland inventory. The figures are ordered from upstream to downstream sites along Brown's Creek.

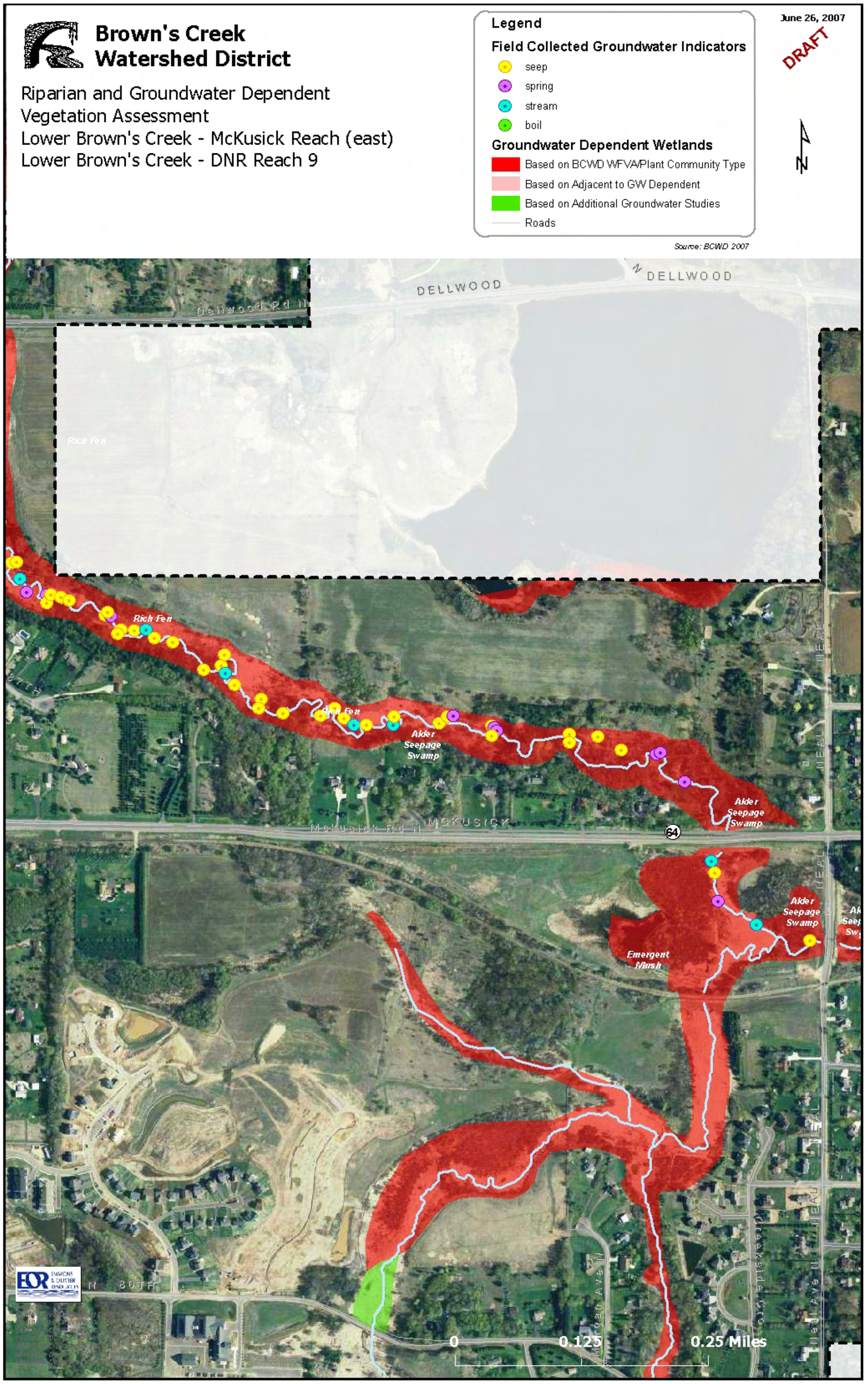


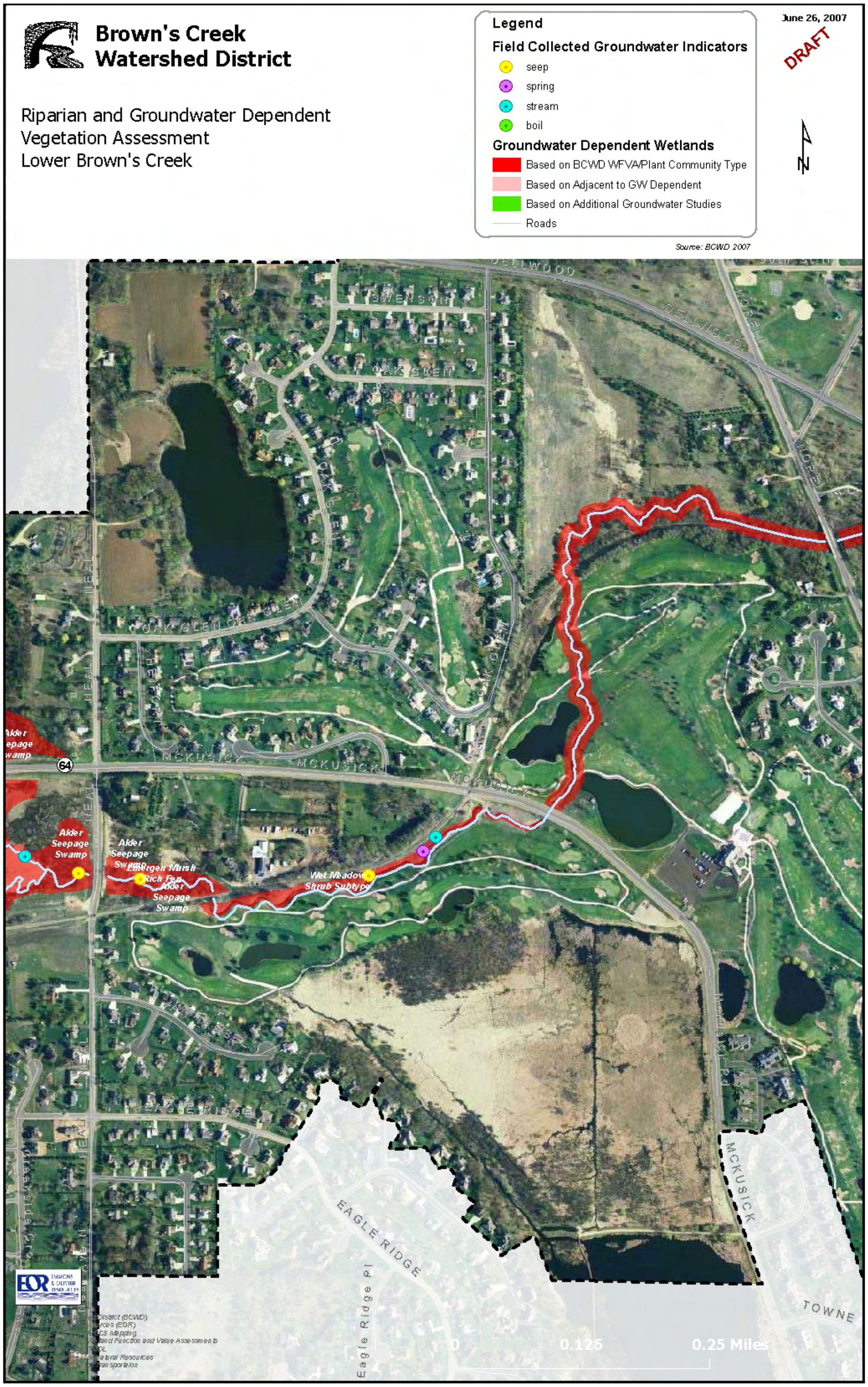
Brown's Creek
Watershed District
Riparian and Groundwater Dependent
Vegetation Assessment
Middle Brown's Creek
Reaches 4 and 5
Legend
Field Collected Groundwater Indicators
seep
spring
stream
boil
Groundwater Dependent Wetlands
Based on BCWD WFVA/Plant Community Type
Based on Adjacent to GW Dependent
Based on Additional Groundwater Studies
Roads
Source: BCWD 2007
June 26, 2007
DRAFT
N
Hardwood Seepage Swamp
Rich Fen
0
0.125
0.25 Miles
Hardwood Seepage



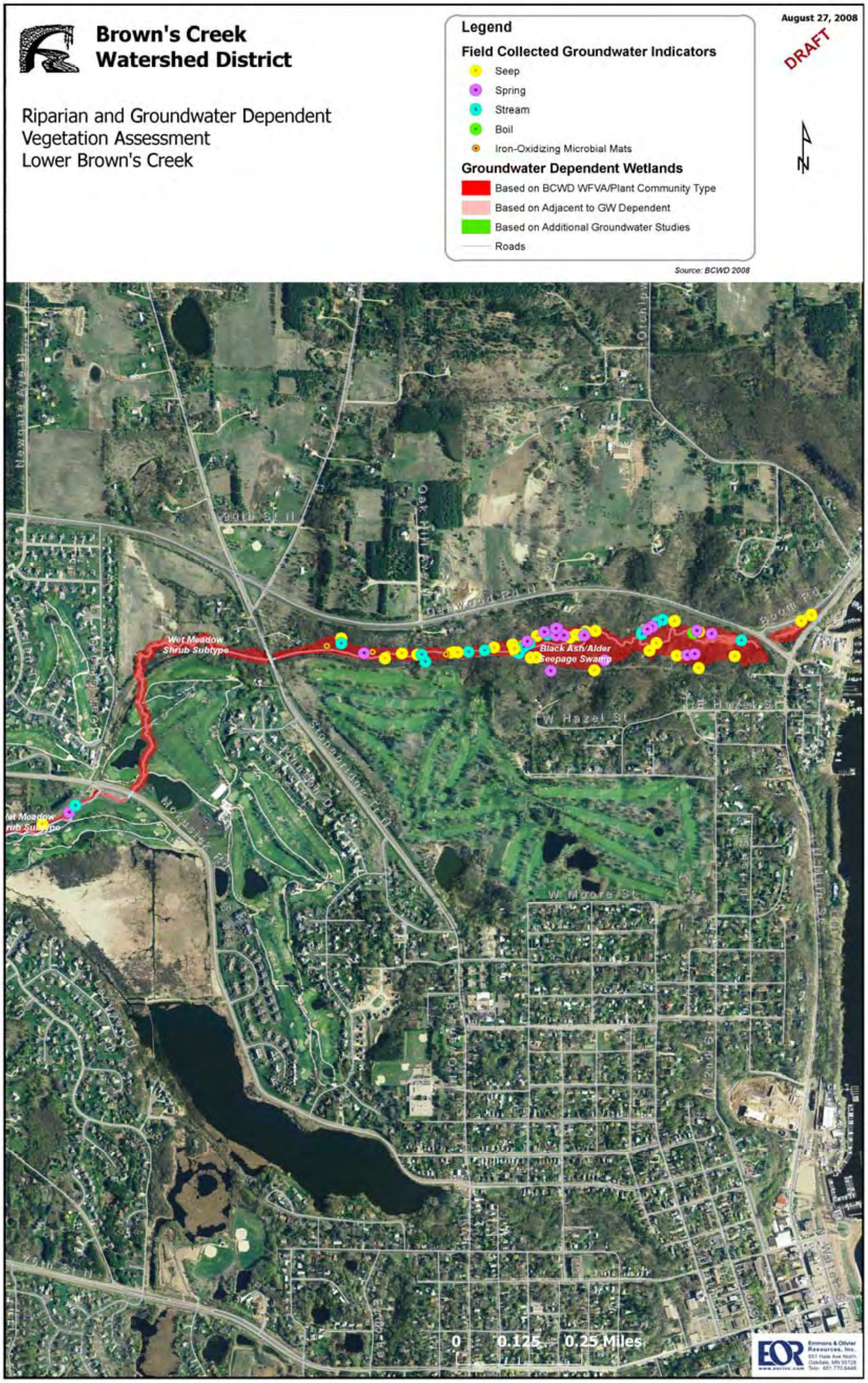
Brown's Creek
Watershed District
Riparian and Groundwater Dependent
Vegetation Assessment
Middle Brown's Creek
Reaches 1, 2 and 3
Legend
Field Collected Groundwater Indicators
seep
spring
stream
boil
Groundwater Dependent Wetlands
Based on BCWD WFVA/Plant Community Type
Based on Adjacent to GW Dependent
Based on Additional Groundwater Studies
Roads
Source: BCWD 2007
June 26, 2007
DRAFT
N
Hardwood Seepage Swamp
Cattail Marsh/ Rich Fen
Wet Meadow Shrub Swamp
Cattail Marsh/ Rich Fen
Lowland Hardwood Forest
Wet Meadow Shrub Swamp
Cattail Marsh/ Rich Fen
Cattail Marsh/ Rich Fen
Rich Fen
102ND
102ND
0
0.125
0.25 Miles


Brown's Creek
Watershed District
Riparian and Groundwater Dependent
Vegetation Assessment
Middle Brown's Creek - Manning Reach
Lower Brown's Creek - McKusick Reach (west)
Legend
Field Collected Groundwater Indicators
seep
spring
stream
boil
Groundwater Dependent Wetlands
Based on BCWD WFVA/Plant Community Type
Based on Adjacent to GW Dependent
Based on Additional Groundwater Studies
Roads
Source: BCWD 2007
June 26, 2007
DRAFT
N
Wet Meadow
Rich Fen
Alder
Seepage
Swamp
DELLWOOD
Dellwood Rd N
MANNING
Rich Fen
Rich Fen
Rich Fen
Rich Fen
Alder
Seepage
Swamp
MCKUSICK
McKusick Rd N
64
Maryland Ave
0
0.125
0.25 Miles


Brown's Creek
Watershed District
Riparian and Groundwater Dependent
Vegetation Assessment
Lower Brown's Creek - McKusick Reach (east)
Lower Brown's Creek - DNR Reach 9
Legend
Field Collected Groundwater Indicators
seep
spring
stream
boil
Groundwater Dependent Wetlands
Based on BCWD WFVA/Plant Community Type
Based on Adjacent to GW Dependent
Based on Additional Groundwater Studies
Roads
Source: BCWD 2007
June 26, 2007
DRAFT
N
DELLWOOD
DELLWOOD
Rich Fen
Rich Fen
Alder Seepage Swamp
Alder Seepage Swamp
Alder Seepage Swamp
Emergent Marsh
MCKUSICK
McKusick Rd N
64
0
0.125
0.25 Miles



Brown's Creek
Watershed District
Riparian and Groundwater Dependent
Vegetation Assessment
Lower Brown's Creek
Legend
Field Collected Groundwater Indicators
seep
spring
stream
boil
Groundwater Dependent Wetlands
Based on BCWD WFVA/Plant Community Type
Based on Adjacent to GW Dependent
Based on Additional Groundwater Studies
Roads
Source: BCWD 2007
June 26, 2007
DRAFT
N
Alder Seepage Swamp
Wet Meadow Shrub Subtype
MCKUSICK
EAGLE RIDGE
Eagle Ridge Pl
TOWNE
0
0.125
0.25 Miles



Brown's Creek
Watershed District
Riparian and Groundwater Dependent
Vegetation Assessment
Lower Brown's Creek
Legend
Field Collected Groundwater Indicators
Seep
Spring
Stream
Boil
Iron-Oxidizing Microbial Mats
Groundwater Dependent Wetlands
Based on BCWD WFVA/Plant Community Type
Based on Adjacent to GW Dependent
Based on Additional Groundwater Studies
Roads
Source: BCWD 2008
August 27, 2008
DRAFT
N
Wet Meadow
Shrub Subtype
Black Ash/Alder
Seepage Swamp
W Hazel St
W Moore St
Oak Hill
0 0.125 0.25 Miles
Emmons & Olivier Resources, Inc.

Attachment E. Bioassessment of Macroinvertebrates at Five Sites on Brown's Creek Near Stillwater, Minnesota.

FINAL REPORT

Bioassessment of Macroinvertebrates at Five Sites on Brown's Creek Near Stillwater, Minnesota

by

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8 June 2009

Introduction

In this document the community structure of macroinvertebrates is summarized for five sample sites in Brown's Creek, Washington County, Minnesota. Data for this study were generated using a standard field sampling approach according to a protocol for collecting dip-net samples by the Minnesota Pollution Control Agency (Anonymous, available on-line). This report summarizes results for dip-net samples collected on four dates: 20 April 2008, 22 June 2008, 7 September 2008 and 22 November 2008. Raw data by sample site and date are included in Appendix Table 1.

This comprehensive study of macroinvertebrates in Brown's Creek consisted of four sampling events in 2008 that were timed to capture seasonal variability inherent in community structure of stream macroinvertebrates. Past studies focused on Chironomidae have shown considerable seasonal variability in growth and development in streams (Chou *et al*. 1999; Coffman 1973, 1974, 1980, Ferrington 1993b, 1994, 1998; Ferrington *et al*. 1994, 1995), consequently the four sample events are considered to be the minimum number needed to generate data for TMDL analysis. It has been a working hypothesis that samples from very late autumn, winter or early spring will provide better discrimination of macroinvertebrate communities that can serve as indicators of water quality in groundwater dominated stretches of stream that support trout populations than samples collected during late spring, summer or early autumn periods when water temperatures are warm or at their annual highest values.

Locations of Sample Sites

The locations of the sites sampled with dip-nets during this project were selected to coincide with (1) the locations of sites for which historical data exist for fish community structure and (2) places that are being monitored for physical and chemical parameters. According to our new numbering system, the uppermost is referred to as Site 1 and is located just downstream of Hwy 110. Consequently, the area sampled for this project was slightly downstream of the area sampled in 2007 (Ferrington, 2007). Sample sites 3 and 4 are the same as the middle and lower sites sampled in 2007. Sample site 10 is located just upstream of the stone bridge and previously was not sampled by Ferrington (2007). Site 12 corresponds to the downstream-most sample site that was previously sampled for surface-floating pupal exuviae by Ferrington (2007).

Methods

Collection of Samples

Dip-net samples were collected according to the SOP provided on-line by the Minnesota Pollution Control Agency. Samples were also preserved, sorted and processed according to guidelines developed by MPCA, except that all macroinvertebrates visible without magnification were removed, identified and counted according to the protocol described in the next section.

Sorting of Samples

All samples were sorted in-lab for four hours or until at least 50% of the sample was inspected. Care was taken to remove small invertebrates, including Chironomidae, and standard operating procedures for preserving and storing material were followed. Voucher specimens of all taxa have been assembled and will be archived.

Metrics Calculated

The following standard metrics were calculated for dip-net samples from each of the sites investigated in this project: (1) cumulative species richness by sample site; (2) Brillouin's Diversity Index (based on cumulative totals of all samples per site); (3) number of EPT taxa; (4) percent of EPT; (5) number of Diptera taxa; and (6) percent Diptera.

Species diversity indices were calculated from the cumulative data available for each sample site. The indices were calculated using ECOMEAS© software developed by the Water Quality & Freshwater Ecology Program at the Kansas Biological Survey of the University of Kansas. This software calculates ten of the more commonly used diversity indices and, when appropriate, their associated Evenness and Equitability values. Copies of the print outs for each composited sample are available on request.

Brillouin's Index of Diversity will be used in this report to document patterns of diversity among sites. This index is considered most appropriate to quantify the diversity content of samples when not all taxa in the sample area can be expected to be represented in random samples taken from the site (Magurran 1998). Results of the other commonly reported indices such as the Shannon Index or Margelef's Index are not discussed but can be provided for persons that are more familiar with, or prefer to use, these two other indices.

For purposes of interpretation, empirical results from numerous studies using collections of SFPE (mostly in Kansas, and dealing primarily with organic loading in urban streams) have shown that index values of 2.000 nats or greater are typical for collections of SFPE from streams with excellent to very good water quality. Values of less than 1.000 nats generally occur only when very significant alterations of Chironomidae communities have occurred as a consequence of pollutant-related stresses. Values between 1.500 nats and 2.000 nats are cautiously interpreted as a sign of either response to pollutant stress or reduced habitat heterogeneity. Values between 1.000 nats and 1.500 nats are confidently interpreted as a response to pollutant stress, since reduced habitat heterogeneity alone generally does not result in index values this low.

Analysis of Faunal Similarities Among Sample Sites

A numerical analysis of the similarities of all macroinvertebrates collected in dip-nets samples was calculated using the Community Similarity option in the ECOMEAS© software developed by the Water Quality & Freshwater Ecology Program at the Kansas Biological Survey of the University of Kansas. The Community Similarity option in the software calculates 16 of the more commonly used coefficients of community similarity. Copies of the print outs for each pair of sample sites can be made available on request. Jaccard's Coefficient of community similarity is used in this report to document patterns of similarity among pairs of sample sites. Jaccard's

Coefficient is considered appropriate to quantify the similarity of two communities based on presence/absence data (Magurran 1998), and it is commonly reported in other studies (e. g., Blackwood *et al.* 1995). Results of other commonly reported coefficients such as the Sorensen's or Ochiai's Coefficient will not be discussed but the index values can be obtained by persons that are more familiar with, or prefer to use, these other coefficients.

Jaccard's Coefficient is calculated as the formula a/(a + b + c) where a is the number of species in common among two sample sites, b is the number of species present only in the first of the two sample sites being compared and c is the number of species present only in the second of the two sample sites being compared. With five different sample sites the number of two-site comparisons is calculated as N*(N-1)/2 where N is the number of sample sites. Thus, in this study there are 10 unique comparisons of sample sites taken two at a time.

Cluster Analysis

Cluster analysis (CA) was performed using NCSS Software. Software settings used for the analysis are the recommended default settings consisting of Euclidean Distance as the measure of similarity, Unweighted Pair-Group Average (UPGA) approach to linking clusters and raw data coded by adding 0.5 to all counts.

Non-metric Multidimensional Scaling Analysis

Non-metric multidimensional scaling analysis (MDS) was performed using NCSS Software. Software settings used for the analysis are the recommended default settings consisting of random initial configuration, maximum of 10 dimensions, maximum of 50 iterations per dimension and stopping values of minimum stress set at 0.00001. The original data set was pruned of rare taxa, defined as those taxa with cumulative project abundances less than 1% of total specimens.

Results and Discusion

A total of 12,754 invertebrates representing 95 taxa were sorted and identified in this project. Species richness estimates by sample date and cumulatively by sample site are provided in Table 1. Chironomidae were the most species rich family (40 Taxa) and Diptera were the most species rich order (53 taxa). By contrast, EPT comprised 18 species distributed among 13 families in the three orders.

At all sample sites the highest detected richness values occurred in April (sites 3, 4 and 10) or November (sites 1 and 12), just after ice-melt or just before fall freeze. This pattern was especially pronounced at Site 12, where 53 of the total 59 taxa detected at the site were collected. Lowest species richness values occurred during late summer (September), followed by early summer (June). These results confirm that biomonitoring of trout streams that are strongly dominated by ground waters and remain relatively warm and ice-free, or nearly so in winter, should be timed to colder months of the year if species richness is to be efficiently documented with minimal sampling effort. However, even when averaged across all sample sites the seasonal pattern of more efficient detection of species richness is shown by the average richness values in the bottom line of the table. Across all sites the averages for April and November (38.6 taxa per site and 36.4 taxa per site) are substantially higher than the values obtained for sampling efforts in June (27.4 taxa per site) and September (25.6 taxa per site).

Table 1. Species richness by sample site and sample date.

Sample Site	April	June	September	November	Total
Site 1 (Downstream of Hwy 110)	28	25	25	32	46
Site 3 (Upstream of Hwy 15)	33	25	22	23	48
Site 4 (Upstream of Hwy 96)	44	28	22	33	55
Site 10 (Stone Bridge)	44	30	24	41	62
Site 12 (WOMP Site)	44	29	35	53	59
Average Richness by Sample Date	38.6	27.4	25.6	36.4	---

Results of metrics calculated from the cumulative results of dip-net samples are shown in Table 2. Calculated in this manner the diversity Index values do not differ substantively among sites and all are higher than the value of 2.000 nats that historically has been used as an empirical cut-off for un-stressed sits. The value for Site 1, although lowest, is markedly higher than 2.000 nats. Metrics based on EPT are lowest at the upstream site and are consistent with responses of EPT to slightly lowered levels of DO, but still signify a somewhat intolerant assemblage of EPT. Percent EPT increases steadily from upstream to downstream, paralleling changes in water quality and DO that result in stream conditions at site 12 that are supporting trout populations. None of the metric values suggest extreme depletion of DO.

Table 2: Summary of metrics for collections of dip-nets.

Sample Site	Brillouin's Diversity Index (nats)	Evenness	# EPT	% EPT	# Diptera	% Diptera
Site 1 (Downstream of Hwy 110)	2.301	0.592	8	10.5 %	28	34.8 %
Site 3 (Upstream of Hwy 15)	2.592	0.666	10	20.8 %	26	27.2 %
Site 4 (Upstream of Hwy 96)	2.449	0.604	12	26.6 %	28	20.6 %
Site 10 (Stone Bridge)	2.829	0.681	15	39.4 %	31	27.7 %
Site 12 (WOMP Site)	2.661	0.648	11	52.0 %	34	34.2 %

Results of the numerical analysis of the similarities of macroinvertebrate composition across all five sample sites based on Jaccard's Coefficient are presented in Table 3. Values below the diagonal represent the raw coefficient scores. Numbers above the diagonal indicate the rank similarities among pairs of sample sites.

Table 3: Similarity of taxonomic composition among pairs of sample sites based on Jaccard's Coefficient of Similarity

Sample Sites	**Site 1**	**Site 3**	**Site 4**	**Site 10**	**Site 12**
Site 1	**-----**	**4**	**5**	**8**	**9**
Site 3	**0.541**	**-----**	**2**	**3**	**10**
Site 4	**0.530**	**0.585**	**-----**	**1**	**8**
Site 10	**0.500**	**0.549**	**0.625**	**-----**	**6**
Site 12	**0.479**	**0.466**	**0.500**	**0.512**	**----**

Jaccard's Coefficient values can range from 1.0 representing complete overlap in community composition to 0.0 indicating no overlap in community composition. When multiplied by 100 the resulting value represents the percent of species shared among the two sample sites being compared. Three patterns are apparent from the coefficients. The first pattern is that the upper three sites, site 1, 3 and 4, are the least similar to sites 12 and 10.

The second conspicuous pattern is that the two most similar sites, site 4 and site 10, are physically adjacent to each other and flank the areas of stream where it begins to experience the transition from surface water dominated to more strongly groundwater influenced.

The third pattern in terms of macroinvertebrate taxonomic composition is that sites 3 and 4 and sites 3 and 10 are also very similar. Two of these three sites are in areas where the stream is dominated by surface water discharge, but are not as influenced by lower DO as is site 1.

Taxa that occurred only at site 12, and serve to differentiate the macroinvertebrate community of the area more strongly influenced by groundwaters, are shown in Table 4. It should be noted that eight of the ten taxa are Diptera, of which seven are Chironomidae. All of the Chironomidae are common in trout streams in the metro area that have been studied previously, and several are commonly detected during winter as both mature larvae and adults. Three of the genera, *Pagastia, Odontomesa* and *Orthocladius (Euorthocladius),* are cold adapted and are rare or absent from streams with warmer thermal regimes (Ferrington 1998, 2000).

Three additional genera of Chironomidae are very uncommonly collected in warmer streams, but also are usually not collected in high abundance in trout streams. Although they are likely to be reliable indicators of groundwater-dominated trout streams, their low abundances may make them less useful as indicator taxa. The taxa are: *Orthocladius (Symposiocladius), Stilocladius* and *Krenosmittia*.

Table 4: Taxa only occurring at Site 12

Order	**Family**	**Genus**	**Common Name**	**Count**
Coleoptera	Dytiscidae	*Laccophilus*	Water Scavenger Beetles	7
Trichoptera	Lepidostomatidae	*Lepidostoma*	Lepidostomatid Case-Makers	29
Diptera	Dixidae	*Dixella*	Meniscus Midges	29
Diptera	Chironomidae	*Pagastia*	Non-biting Midges	17
Diptera	Chironomidae	*Odontomesa*	Non-biting Midges	32
Diptera	Chironomidae	*Krenosmittia*	Non-biting Midges	3
Diptera	Chironomidae	*Orthocladius (Euorthocladius)*	Non-biting Midges	6
Diptera	Chironomidae	*Orthocladius (Orthocladius)*	Non-biting Midges	5
Diptera	Chironomidae	*Orthocladius (Symposiocladius)*	Non-biting Midges	1
Diptera	Chironomidae	*Stilocladius*	Non-biting Midges	1

Eight additional taxa were most common at Site 12 and, although they occur in lower numbers at one or more other sites, may also serve as reliable indicators of areas of stream strongly dominated by groundwaters (Table 5).

Table 5: Taxa occurring at more two or more sites
but are most abundant at Site 12

Order	**Family**	**Genus**	**Common Name**	**Count (% at Site 12)**
Coleoptera	Elmidae	*Macronychus*	Riffle Beetles	19 (51%)
Trichoptera	Brachycentridae	*Brachycentris*	Humpless Case-Maker Caddis	636 (88%)
Ephemeroptera	Baetidae	*Baetis*	Small Minnow Mayflies	926 (65%)
Diptera	Chironomidae	*Diamesa*	Non-biting Midges	263 (89%)
Diptera	Chironomidae	*Prodiamesa*	Non-biting Midges	46 (87%)
Diptera	Chironomidae	*Eukiefferiella*	Non-biting Midges	79 (80%)
Diptera	Chironomidae	*Thienemanniella*	Non-biting Midges	121 (59%)
Diptera	Chironomidae	*Zavrelimyia*	Non-biting Midges	2 (67%)

All of the taxa listed in Table 5 can only be reliably identified to genus based on specimens collected during this study. Several of the genera, however, may actually consist of two or more species. This is very likely the case for the chironomid genera *Diamesa*, *Thienemanniella* and

Eukiefferiella. Adults of *Diamesa* collected at Site 12 all consisted of *Diamesa mendotae*, a species that is very much restricted in its known distribution to trout streams. By contrast, adults of *Diamesa* collected from Site 1 were all *Diamesa nivoriunda*, a species that is more commonly collected from sections of stream that are less thermally buffered than stretches that support trout due to large amounts of groundwater input. Unfortunately, at this time it is not possible to differentiate larvae of these two species and for this project the actual numbers of *Diamesa* larvae that are *D. mendotae* versus *D. nivoriunda* cannot be determined by sample site. It seems likely, however, that all larvae collected from Site 12 are *D. mendotae*, and larvae of *Diamesa* from other sites are *D. nivoriunda* or a mixture of both species. Consequently, it is possible that *D mendotae* is a very reliable indicator of groundwater-dominated sections of Brown's Creek and *D. nivoriunda* or *D. nivoriunda* combined with *D. mendotae* characterize the more thermally variable sections of the stream. It will be necessary to isolate egg masses from adults of the two species and grow larvae to maturity in order to discover how to differentialte these two species as larvae and pupae. Similar situations could occur with species of *Thienemanniella* and *Eukiefferiella* since collections of pupal exuviae indicate multiple species of these genera occur in Brown's Creek.

CA (Figure 1) and MDS (Figure 2) show similar, but not identical patterns. Both of these analyses clearly indicate that the macroinvertebrate community structure at site 12 is most different from all remaining sites. CA, using data for all species shows sites 3 & 4 as most similar, with site 10 falling within the same cluster. By contrast, MDS based on numerically abundant taxa results in sites 1, 3 and 4 as most similar in two-dimensional space, with site 10 and 12 less similar to these three sites and also to each other.

Figure 1: Results of cluster analysis, showing dendrogram plot

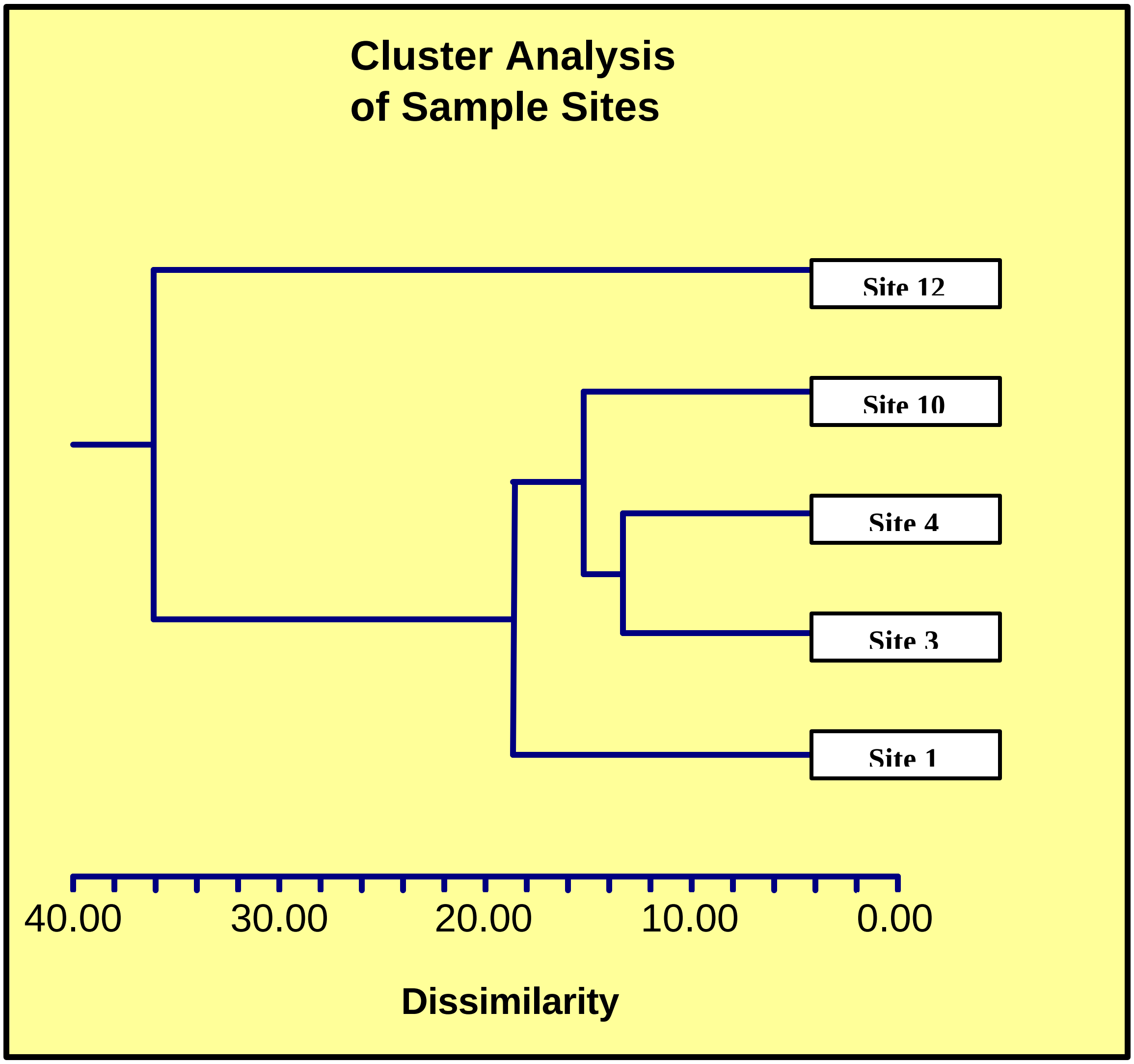
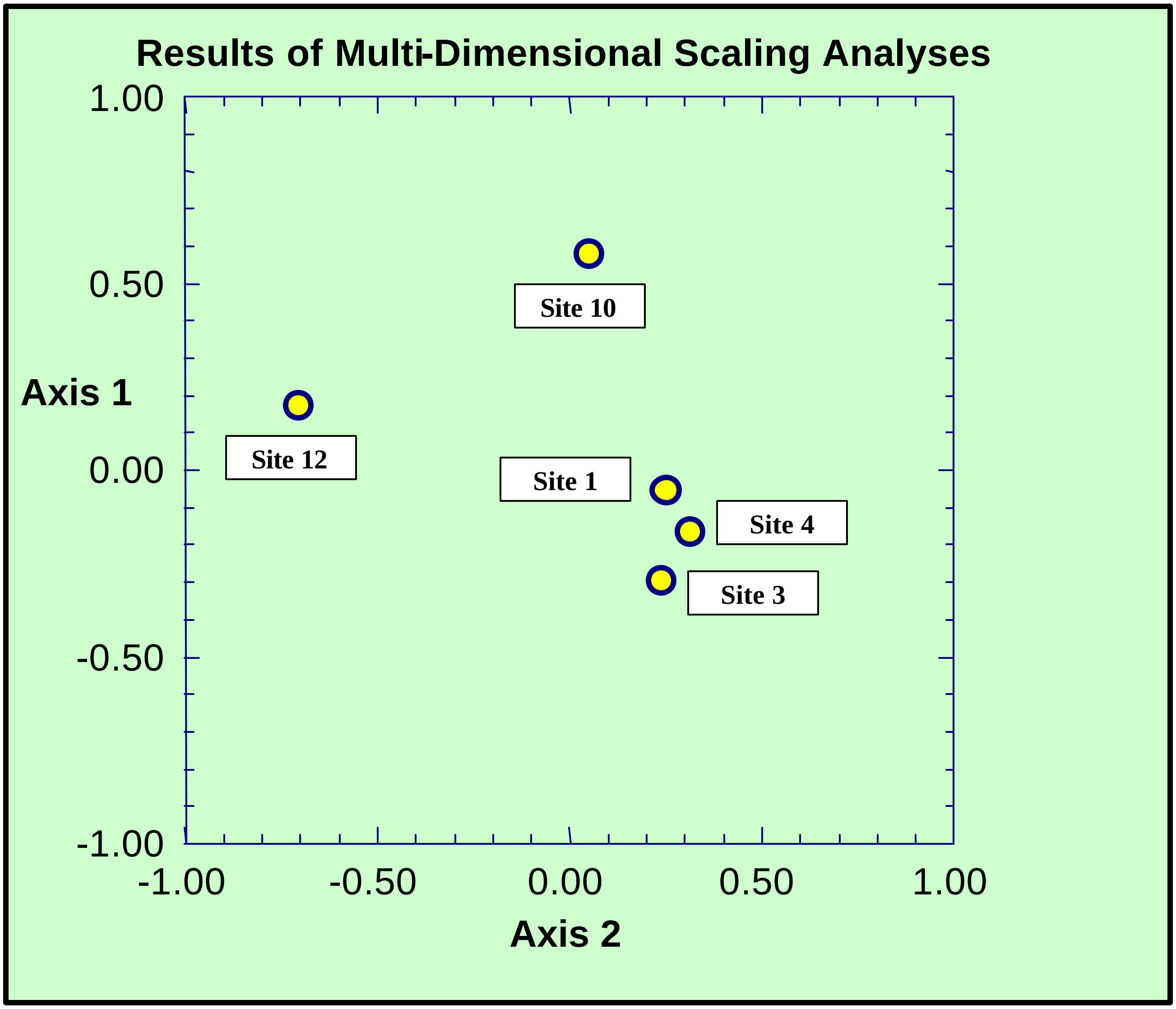


Figure 2: MDS Plot



Discussion and Conclusions

The macroinvertebrate communities at sites 3, 4, 10 and 12 show no strong indications of responses to stress. Site 1 consistently shows lower metric scores than the remaining sites, but also does not show a strong indication of response to lowered DO, and the lower metric scores most likely represent poorer habitat heterogeneity and less discharge than the other sites further downstream. However, Site 1 is most dissimilar to Site 12, reflecting the effect that strongly divergent temperature, discharge and habitat conditions have on community structure of macroinvertebrates at the two sites.

Sampling in April and November produced the highest species richness estimates and most dissimilar values for macroinvertebrates when Site 12 is compared to sites upstream with warmer summer temperatures. Consequently, sampling in late spring, late fall or winter is recommended when assessing groundwater-dominated streams for potential responses to stress, especially when shifts in temperature regimes or possible responses to transient reductions in DO are suspected as potential stressors. Of these three preferred potential times for sampling, collections in mid-winter should be most appropriate for detecting responses to stress if any biotic impairments have occurred.

In this project a total of eighteen species of macroinvertebrates have been identified as potential indicators of groundwater-dominated stretches of stream that have conditions capable of supporting trout. Ten of the taxa only were collected from Site 12 and can be considered as the best subset of species that can potentially be developed as indicator species. The remaining 8 species show strong trends in abundance at the groundwater-dominated site, but occur in lower abundances at one or more additional sites. Although they, too, may be acceptable indicators of groundwater-dominated stretches, it may be necessary to develop abundance measures rather than presence-absence criteria for the eight taxa to be effective indicators of groundwater dominated stretches. In addition, several of these taxa are or may be represented by two or more species in Brown's Creek. Consequently it will be necessary to do additional research on life histories, autecology and taxonomy of the species in order to better discern their potential for development as indicator taxa for sections dominated by groundwater inputs. It is recommended that all 18 taxa should be tested by performing similar field collections timed seasonally in other streams with strong gradients of groundwater versus surface water-dominated stretches.

Thirteen of the 18 potential indicator species are aquatic Diptera, and all but one of these taxa are Chironomidae. These Chironomidae taxa are moderate to strongly coldwater tolerant and grow and often emerge as adults during winter or early spring conditions. Most are not detected or common as larvae during summer months. Consequently, timing sampling efforts to early spring soon after ice-melt or late fall just before ice-over is critical to doing bioassessments. Stretches of stream that are more strongly groundwater-dominated and do not ice-over during winter should be sampled also during winter when possible.

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APPENDIX TABLE 1: Macroinvertebrate Monitoring Results					Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative
Stream:	Browns Creek				Totals	Totals	Totals	Totals	Totals	Totals
Year:	2008				For	For	For	For	For	For
					Sample	Sample	Sample	Sample	Sample	All Sample
Class	Order	Family	Genus	Life Stage	Site 1	Site 3	Site 4	Site 10	Site 12	Sites
Crustacea	Amphipoda	Gammaridae	*Gammarus*	Adult	166	398	218	5	12	799
Crustacea	Amphipoda	Hyallelidae	*Hyalella*	Adult	9	1	4	1	1	16
Crustacea	Isopoda	Asellidae	*Caecidotea*	Adult	41	119	92	27	42	321
Insecta	Coleoptera	Curculionidae	*Rhinoncus*	Adult	0	9	1	0	0	10
Insecta	Coleoptera	Elmidae	*Dubiraphia*	Larvae	0	0	0	13	0	13
Insecta	Coleoptera	Elmidae	*Optioservus*	Larvae	860	705	934	508	268	3275
Insecta	Coleoptera	Elmidae	*Optioservus*	Adult	29	63	144	12	12	260
Insecta	Coleoptera	Elmidae	*Stenelmis*	Larvae	1	0	1	76	3	81
Insecta	Coleoptera	Elmidae	*Stenelmis*	Adult	0	0	1	11	9	21
Insecta	Coleoptera	Elmidae	*Macronychus*	Larvae	0	0	0	11	2	13
Insecta	Coleoptera	Elmidae	*Macronychus*	Adult	0	0	0	7	17	24
Insecta	Coleoptera	Dytiscidae	*Laccophilus*	Larvae	9	0	0	0	3	12
Insecta	Coleoptera	Dytiscidae	*Laccophilus*	Adult	0	0	0	0	4	4
Insecta	Coleoptera	Dytiscidae	*Liodessus*	Adult	0	1	0	0	3	4
Insecta	Collembola	Isotomidae	Not identified to genus.	Adult	0	2	0	1	4	7
Insecta	Odonata	Aeshnidae	*Boyeria*	Larvae	0	0	0	1	3	4
Insecta	Odonata	Calopterygidae	*Calopteryx*	Larvae	0	0	0	2	0	2
Insecta	Hemiptera	Gerridae	*Aquarius*	Adult	0	0	0	1	0	1
Insecta	Hemiptera	Gerridae	*Trepobates*	Adult	10	4	0	0	1	15
Insecta	Plecoptera	Perlidae	*Perlesta*	Larvae	0	11	27	19	3	60
Insecta	Plecoptera	Perlodidae	*Isoperla*	Larvae	0	2	16	92	25	135
Insecta	Plecoptera	Perlodidae	Too young to tell!	Larvae	0	1	0	0	0	1
Insecta	Ephemeroptera	Baetidae	*Baetis*	Larvae	61	101	128	208	926	1424
Insecta	Ephemeroptera	Heptageniidae	*Heptagenia*	Larvae	0	0	0	1	0	1
Insecta	Ephemeroptera	Heptageniidae	*Stenacron*	Larvae	0	0	1	2	0	3
Insecta	Ephemeroptera	Heptageniidae	*Stenonema*	Larvae	0	0	4	21	4	29
Insecta	Ephemeroptera	Isonychiidae	*Isonychia*	Larvae	3	0	0	0	0	3
Insecta	Ephemeroptera	Leptophlebiidae	*Paraleptophlebia*	Larvae	0	0	0	1	0	1

Insecta	Trichoptera	Brachycentridae	*Brachycentris*	Larvae	11	44	24	6	636	721
Insecta	Trichoptera	Glossosomatidae	*Glossosoma*	Larvae	0	15	81	10	24	130
Insecta	Trichoptera	Glossosomatidae	*Glossosoma*	Pupae	1	1	0	0	0	2
Insecta	Trichoptera	Hydropsychidae	*Hydropsyche*	Larvae	29	57	229	220	11	546
Insecta	Trichoptera	Hydropsychidae	*Ceratopsyche*	Larvae	1	177	52	18	16	264
Insecta	Trichoptera	Hydropsychidae	*Cheumatopsyche*	Larvae	24	10	28	26	37	125
Insecta	Trichoptera	Hydropsychidae		Pupae	0	0	7	1	0	8
Insecta	Trichoptera	Hydropsychidae	Too young to tell!	Larvae	87	85	62	60	16	310
Insecta	Trichoptera	Hydroptilidae	Too young to tell!	Larvae	0	0	2	0	0	2
Insecta	Trichoptera	Lepidostomatidae	*Lepidostoma*	Larvae	0	0	0	0	29	29
Insecta	Trichoptera	Limnephilidae	*Limnephilus*	Larvae	0	0	1	0	0	1
Insecta	Trichoptera	Limnephilidae	*Pycnopsyche*	Larvae	0	2	2	7	0	11
Insecta	Trichoptera	Philopotamidae	*Chimarra*	Larvae	0	0	1	40	4	45
Insecta	Trichoptera	Uenoidae	*Neophylax*	Larvae	4	24	48	94	0	170
Insecta	Diptera	Ceratopogonidae	*Bezzia/Palpomyia*	Larvae	6	1	0	1	0	8
Insecta	Diptera	Ceratopogonidae	*Ceratopogon*	Larvae	0	0	0	2	1	3
Insecta	Diptera	Ceratopogonidae	*Sphaeromias*	Larvae	0	1	0	0	0	1
Insecta	Diptera	Culicidae	*Anopheles*	Pupae	0	1	0	0	0	1
Insecta	Diptera	Dixidae	*Dixella*	Larvae	0	0	0	0	29	29
Insecta	Diptera	Empididae	*Hemerodromia*	Larvae	5	10	22	4	0	41
Insecta	Diptera	Empididae	*Hemerodromia*	Pupae	0	0	1	0	0	1
Insecta	Diptera	Empididae	*Neoplasta*	Larvae	0	0	1	5	9	15
Insecta	Diptera	Simuliidae		Pupae	27	31	3	19	1	81
Insecta	Diptera	Simuliidae	*Simulium*	Larvae	85	10	32	27	14	168
Insecta	Diptera	Tipulidae	*Dicranota*	Larvae	43	38	32	3	14	130
Insecta	Diptera	Tipulidae	*Gonomyia*	Larvae	2	0	1	0	3	6
Insecta	Diptera	Tipulidae	*Limnophila*	Larvae	0	0	3	4	0	7
Insecta	Diptera	Tipulidae	*Phantolabis* (?)	Larvae	0	0	0	2	0	2
Insecta	Diptera	Tipulidae	*Tipula*	Larvae	0	0	4	14	5	23
Insecta	Diptera	Chironomidae	*Diamesa*	Immatures	28	0	5	0	263	296
Insecta	Diptera	Chironomidae	*Pagastia*	Immatures	0	0	0	0	17	17
Insecta	Diptera	Chironomidae	*Odontomesa*	Immatures	0	0	0	0	32	32
Insecta	Diptera	Chironomidae	*Prodiamesa*	Immatures	7	0	0	0	46	53

Insecta	Diptera	Chironomidae	*Brillia*	Immatures	8	8	7	4	23	50
Insecta	Diptera	Chironomidae	*Cardiocladius*	Immatures	0	0	0	0	1	1
Insecta	Diptera	Chironomidae	*Corynoneura*	Immatures	53	71	55	52	67	298
Insecta	Diptera	Chironomidae	*Cricotopus*	Immatures	102	27	43	33	54	259
Insecta	Diptera	Chironomidae	*Diplocladius*	Immatures	10	0	0	0	2	12
Insecta	Diptera	Chironomidae	*Eukiefferiella*	Immatures	0	6	4	10	79	99
Insecta	Diptera	Chironomidae	*Heterotrissocladius*	Immatures	0	1	0	0	0	1
Insecta	Diptera	Chironomidae	*Krenosmittia*	Immatures	0	0	0	0	3	3
Insecta	Diptera	Chironomidae	*Limnophyes*	Immatures	0	0	0	1	0	1
Insecta	Diptera	Chironomidae	*Nanocladius*	Immatures	3	4	2	4	1	14
Insecta	Diptera	Chironomidae	*Orthocladius/Cricotopus*	Immatures	14	38	28	68	46	194
Insecta	Diptera	Chironomidae	*Orthocladius (Euorthocladius)*	Immatures	0	0	0	0	6	6
Insecta	Diptera	Chironomidae	*Orthocladius (Orthocladius)*	Immatures	0	0	0	0	5	5
Insecta	Diptera	Chironomidae	*Orthocladius (Symposiocladius)*	Immatures	0	0	0	0	1	1
Insecta	Diptera	Chironomidae	*Parachaetocladius*	Immatures	1	0	0	1	0	2
Insecta	Diptera	Chironomidae	*Parakiefferiella*	Immatures	1	0	0	0	5	6
Insecta	Diptera	Chironomidae	*Parametriocnemus*	Immatures	101	44	11	51	49	256
Insecta	Diptera	Chironomidae	*Pseudosmittia*	Immatures	0	1	0	0	0	1
Insecta	Diptera	Chironomidae	*Psilometriocnemus*	Immatures	0	0	1	0	0	1
Insecta	Diptera	Chironomidae	*Rheocricotopus*	Immatures	29	43	17	4	15	108
Insecta	Diptera	Chironomidae	*Stilocladius*	Immatures	0	0	0	0	1	1
Insecta	Diptera	Chironomidae	*Thienemanniella*	Immatures	2	45	24	12	121	204
Insecta	Diptera	Chironomidae	*Tvetenia*	Immatures	3	28	78	132	58	299
Insecta	Diptera	Chironomidae	*Cryptochironomus*	Immatures	4	0	0	0	0	4
Insecta	Diptera	Chironomidae	*Dicrotendipes*	Immatures	14	34	0	1	0	49
Insecta	Diptera	Chironomidae	*Microtendipes*	Immatures	1	14	6	2	0	23
Insecta	Diptera	Chironomidae	*Phaenopsectra*	Immatures	0	1	0	0	0	1
Insecta	Diptera	Chironomidae	*Paratendipes*	Immatures	3	0	1	1	0	5
Insecta	Diptera	Chironomidae	*Polypedilum*	Immatures	64	103	73	27	19	286
Insecta	Diptera	Chironomidae	*Micropsectra*	Immatures	0	0	1	3	0	4
Insecta	Diptera	Chironomidae	*Paratanytarsus*	Immatures	1	14	20	1	0	36
Insecta	Diptera	Chironomidae	*Rheotanytarsus*	Immatures	16	11	35	61	80	203
Insecta	Diptera	Chironomidae	*Tanytarsus*	Immatures	7	12	8	12	17	56

Insecta	Diptera	Chironomidae	*Conchapelopia/Thienemannimyia*	Immatures	52	69	28	16	42	207
Insecta	Diptera	Chironomidae	*Larsia*	Immatures	0	0	1	0	0	1
Insecta	Diptera	Chironomidae	*Zavrelimyia*	Immatures	0	0	0	1	2	3
Insecta	Diptera	Chironomidae	Too young to tell!	Immatures	38	28	6	3	8	83
Turbellaria			Not identified to genus.	Adults	0	0	0	2	0	2
Oligochaeta			Not identified to genus.	Adults	0	20	9	6	66	101
Gastropoda		Physidae	*Aplexa*		0	0	1	0	0	1
Gastropoda		Physidae	*Physella*		13	0	3	0	0	16
Gastropoda		Ancylidae	*Ferrissia*		0	1	5	0	0	6
Hirudinea		Erpobdellidae	*Mooreobdella microstoma*		2	0	0	1	0	3
Hydracarina			Not identified to genus.		0	2	1	3	6	12
Bivalvia	Veneroida	Sphaeriidae	*Musculium*		0	0	1	0	0	1
Bivalvia	Veneroida	Sphaeriidae	*Pisidium*		5	1	2	1	3	12
					2096	2550	2683	2096	3329	12754
					50	54	63	69	66	107