Prepared by:
Emmons & Olivier Resources, Inc.
in cooperation with the Rice Creek Watershed District
for the Minnesota Pollution Control Agency

Hardwood Creek Impaired Biota (Fish) and Dissolved Oxygen TMDL

May 2009

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TMDL Summary Table

<table>
<tr><th>EPA/MPCA Required Elements</th><th colspan="3">Summary</th><th>Page #</th></tr>
<tr><td>Location</td><td colspan="3">Drainage Basin, Part of State, County, etc.</td><td>3</td></tr>
<tr><td>303(d) Listing Information</td><td colspan="3">Describe the waterbody as it is identified on the State/Tribe's 303(d) list:
• Waterbody name, description and ID# for each river segment, lake or wetland
• Impaired Beneficial Use(s) - List use(s) with source citation(s)
• Impairment/TMDL Pollutant(s) of Concern (e.g., nutrients: phosphorus; biota: sediment)
• Priority ranking of the waterbody (i.e. schedule)
• Original listing year</td><td>3</td></tr>
<tr><td>Applicable Water Quality Standards/ Numeric Targets</td><td colspan="3">List all applicable WQS/Targets with source citations. If the TMDL is based on a target other than a numeric water quality criterion, a description of the process used to derive the target must be included in the submittal.</td><td>20</td></tr>
<tr><td>Loading Capacity (expressed as daily load)</td><td colspan="3">Identify the waterbody's loading capacity for the applicable pollutant. Identify the critical condition.
For each pollutant: LC = X/day; and Critical Condition Summary</td><td>28</td></tr>
<tr><td rowspan="13">Wasteload Allocation</td><td colspan="3">Portion of the loading capacity allocated to existing and future point sources [40 CFR §130.2(h)].
Total WLA = X/day, for each pollutant</td><td></td></tr>
<tr><td>Source</td><td>Permit #</td><td>Categorical WLA</td><td></td></tr>
<tr><td colspan="3">Permitted stormwater:</td><td></td></tr>
<tr><td colspan="2"></td><td rowspan="10">TSS: 4% of TMDL
BOD: 6% of TMDL
(varies by flow)</td><td rowspan="10">35</td></tr>
<tr><td>City of Hugo</td><td>MS400094</td></tr>
<tr><td>City of Lino Lakes</td><td>MS400100</td></tr>
<tr><td>RCWD</td><td>MS400193</td></tr>
<tr><td>Anoka County</td><td>MS400001</td></tr>
<tr><td>Washington County</td><td>MS400160</td></tr>
<tr><td>Mn/DOT Metro District</td><td>MS400170</td></tr>
<tr><td>Construction stormwater</td><td>Various</td></tr>
<tr><td>Industrial stormwater</td><td>No current permitted sources</td></tr>
<tr></tr>
<tr><td rowspan="2">Load Allocation</td><td colspan="3">Identify the portion of the loading capacity allocated to existing and future nonpoint sources and to natural background if possible [40 CFR §130.2(g)].
Total LA = X/day, for each pollutant</td><td></td></tr>
<tr><td>Source</td><td colspan="2">LA</td><td></td></tr>
</table>

	LA	TSS: 86% of TMDL BOD: 84% of TMDL (varies by flow)	35
Margin of Safety	Include a MOS to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality [CWA §303(d)(1)(C), 40 CFR §130.7(c)(1)]. ***Identify <u>and explain</u> the implicit or explicit MOS for each pollutant***		31
Seasonal Variation	Statute and regulations require that a TMDL be established with consideration of seasonal variation. The method chosen for including seasonal variation in the TMDL should be described [CWA §303(d)(1)(C), 40 CFR §130.7(c)(1)] ***Seasonal Variation Summary for each pollutant***		30
Reasonable Assurance	***Summarize Reasonable Assurance*** *Note: In a water impaired by both point and nonpoint sources, where a point source is given a less stringent WLA based on an assumption that NPS load reductions will occur, reasonable assurance that the NPS reductions will happen must be explained.* *In a water impaired solely by NPS, reasonable assurances that load reductions will be achieved are not required (by EPA) in order for a TMDL to be approved.*		43
Monitoring	***Monitoring Plan included?*** *Note: EPA does not approve effectiveness monitoring plans but providing a general plan is helpful to meet reasonable assurance requirements for nonpoint source reductions. A monitoring plan should describe the additional data to be collected to determine if the load reductions provided for in the TMDL are occurring and leading to attainment of water quality standards.*		44
Implementation	***1. Implementation Strategy included?*** The MPCA requires a general implementation strategy/framework in the TMDL. *Note: Projects are required to submit a separate, more detailed implementation plan to MPCA within one year of the TMDL's approval by EPA.* ***2. Cost estimate included?*** The Clean Water Legacy Act requires that a TMDL include an overall approximation ("…a range of estimates") of the cost to implement a TMDL [MN Statutes 2007, section 114D.25]. *Note: EPA is not required to and does not approve TMDL implementation plans.*		38 42
Public Participation	• Public Comment period (dates) • Comments received? • Summary of other key elements of public participation process		36

	Note: EPA regulations require public review [40 CFR §130.7(c)(1)(ii), 40 CFR §25] consistent with State or Tribe's own continuing planning process and public participation requirements.	

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Abbreviations

BMP	Best management practice
BOD	Biochemical oxygen demand
CONCEPTS	Conservational Channel Evolution and Pollutant Transport System
CWA	Clean Water Act
DO	Dissolved oxygen
IBI	Index of biological integrity
JD	Judicial Ditch
LA	Load allocation
Mn/DOT	Minnesota Department of Transportation
MOS	Margin of safety
MPCA	Minnesota Pollution Control Agency
NPDES	National Pollutant Discharge Elimination System
PAC	Public Advisory Committee
QHEI	Qualified Habitat Evaluation Index
RCWD	Rice Creek Watershed District
SWPPP	Stormwater pollution prevention program
TAC	Technical advisory committee
TMDL	Total maximum daily load
TSS	Total suspended solids
US EPA	United States Environmental Protection Agency
WLA	Wasteload allocation

Executive Summary

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

In 2002, Hardwood Creek was listed on Minnesota's 303(d) List of Impaired Waters, for biological impairment resulting from a low fish index of biological integrity (IBI) score. In 2004, Hardwood Creek was again listed on Minnesota's 303(d) List of Impaired Waters for biological impairment, this time due to low DO. Due to the fact that both TMDLs are intrinsically linked, this TMDL study encompasses both impairments. The TMDL study entailed analysis of existing data, intensive synoptic water quality and biological surveys of the creek, completion of the stressor identification process, watershed modeling, and the development of implementation strategies to meet the goals of the TMDLs.

Hardwood Creek is located in the Rice Creek watershed in the Upper Mississippi River Basin in Central Minnesota. Its watershed is approximately 16,000 acres, consisting mainly of rural and agricultural areas. The watershed includes portions of May Township and the cities of Hugo, Forest Lake, and Lino Lakes. The upper two-thirds of Hardwood Creek is also known as Washington County Judicial Ditch (JD) #2 and it originates south of Rice Lake. Approximately 82% of the watershed is vacant/agricultural and approximately 18% is developed.

Through the stressor identification process, the primary causes of the low IBI in Hardwood Creek were identified as sedimentation and low DO. The TMDL for the biological impairment is based on total suspended solids (TSS) loads, which address sedimentation. Various candidate mechanisms affecting DO were identified and ultimately may all play a role in DO levels to varying degrees. However, the low DO TMDL focuses on biochemical oxygen demand (BOD) loading, which was identified as a significant stressor during 2004. Therefore the TMDL for the low DO is based on BOD loads.

This study used a variety of methods to evaluate the current loading, contributions by the various pollutant sources, as well as the allowable pollutant loading capacity of the creek. These methods included the load duration curve approach, which takes into account that loading capacity varies by stream flow. The average TSS concentration will need to be decreased 14% from approximately 22 mg/L to 19 mg/L. The average BOD concentration will need to be decreased 30% from approximately 4.6 mg/L to 3.2 mg/L.

Regulated stormwater source loading limits will be achieved through updating stormwater pollution prevention programs (SWPPPs) to comply with the WLAs. Implementation of nonpoint source reduction may be achieved through non-regulatory and voluntary incentive programs. A variety of mechanisms, such as stream bank stabilization, enhancement of riparian buffers, livestock management, stormwater management, and cost share best management programs will be evaluated and used to achieve needed loading reductions.

1. Background

A. 303(D) LISTING

The 303(d) impaired waters listings for Hardwood Creek are shown in Table 1. All three listings are for the protection of aquatic life: the upper reach due to low DO, and the lower reach due to DO and a fish bioassessment (see Figure 6 for reach locations).

Table 1. Listing Information

Name	Description	River ID	Pollutant or Stressor	Affected Use	Year First Listed	Target Start/ Completion (reflects priority ranking)	CALM Category*
Hardwood Creek	Headwaters to Hwy 61	07010206-595	Oxygen, dissolved	Aquatic life	2004	2004/2008	5C
Hardwood Creek	Hwy 61 to Peltier Lk	07010206-596	Fish bioassessments	Aquatic life	2002	2003/2008	5A
Hardwood Creek	Hwy 61 to Peltier Lk	07010206-596	Oxygen, dissolved	Aquatic life	2004	2004/2008	5A

*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

B. BACKGROUND

Hardwood Creek is located in the Rice Creek watershed in the Upper Mississippi Basin in Central Minnesota (Figure 1). In 2002, Hardwood Creek was listed on Minnesota's 303(d) list of impaired waters, for biological impairment resulting from a low fish index of biotic integrity (IBI) score. In 2004, Hardwood Creek was again listed on Minnesota's 303(d) list of impaired waters, this time due to low DO. Due to the fact that both TMDLs are intrinsically linked, this TMDL study encompasses both impairments.

Watershed Description

Hardwood Creek has an approximate 16,000-acre watershed that includes a significant portion of rural and agricultural areas. The watershed includes portions of May Township and the cities of Hugo, Forest Lake, and Lino Lakes (Table 2). The upper two-thirds of Hardwood Creek is also known as Washington County Judicial Ditch (JD) #2 and originates south of Rice Lake (see Figure 6). From Rice Lake, Hardwood Creek flows north to Corrie's Swamp, then turns and continues west until emptying into Peltier Lake, where it ends. The upper portion of the Hardwood Creek drainage-way, from Rice Lake to Highway 61, is a broad, low-lying swale containing wetland communities of significant natural resource values. Downstream from Highway 61, the soils become sandier and slope increases slightly (RCWD 2004).

Table 2. Municipality Areas within the Hardwood Creek Watershed

Municipality	Area (ac)	Percent Area (%)
City of Forest Lake	4,592	28%
City of Hugo	10,625	66%
City of Lino Lakes	627	4%
May Township	320	2%
Total	*16,164*	

Land Use

Based on year 2000 data (Generalized Land Use 2000 for the Twin Cities Metropolitan Area), approximately 82% of the watershed was vacant/agricultural and approximately 18% was developed (Figure 2). There are seven small registered feedlots located within the watershed. According to Minnesota Pollution Control Agency (MPCA) records, six are dairy and/or beef cattle operations and one is a horse operation. Projected land use (Regional Planned Land Use - Twin Cities Metropolitan Area) shows continuing urban growth in the watershed. In 2020, 65% of the watershed is predicted to be vacant/agricultural with 35% of the land becoming developed (Figure 3).

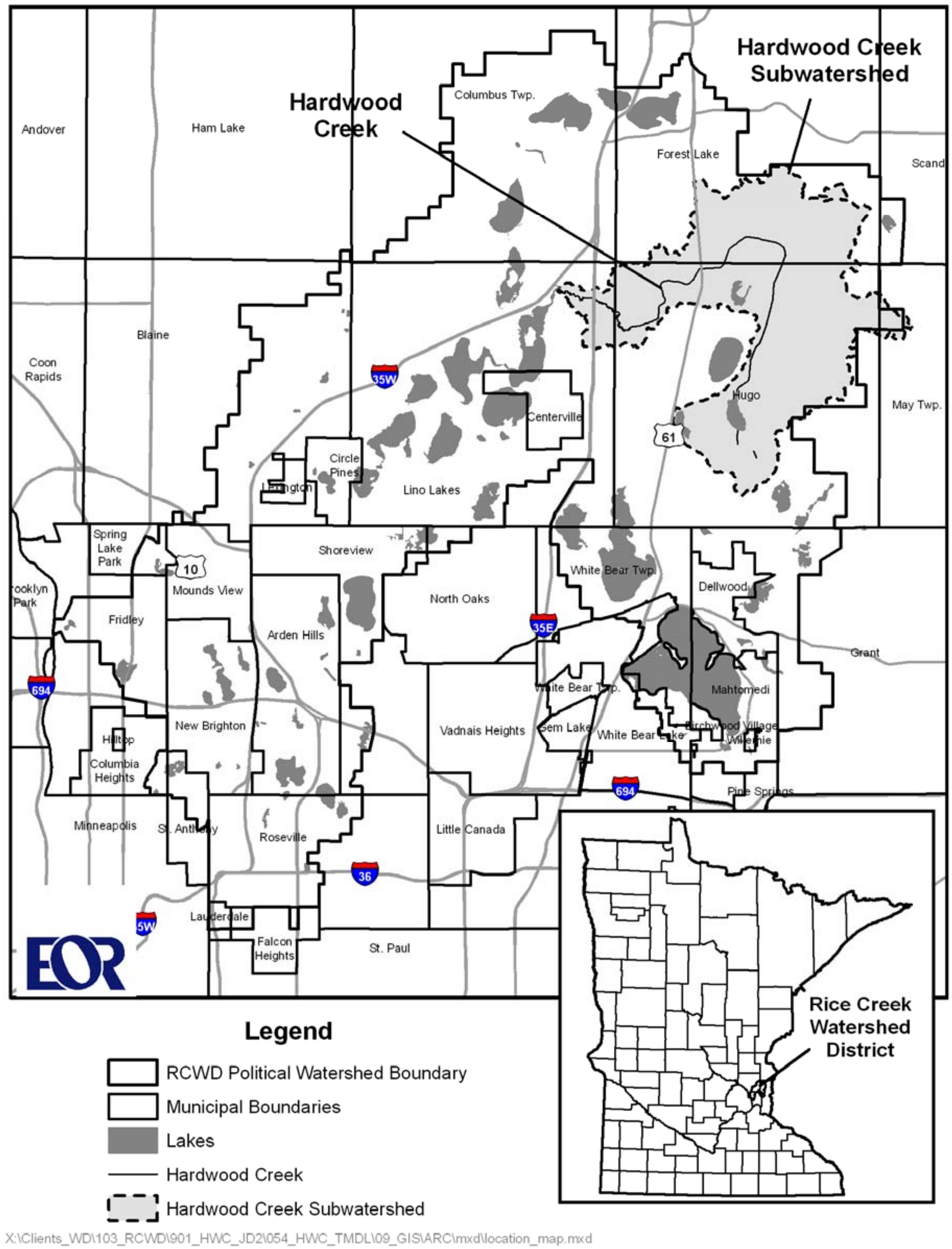

Figure 1. Location of the Hardwood Creek Watershed

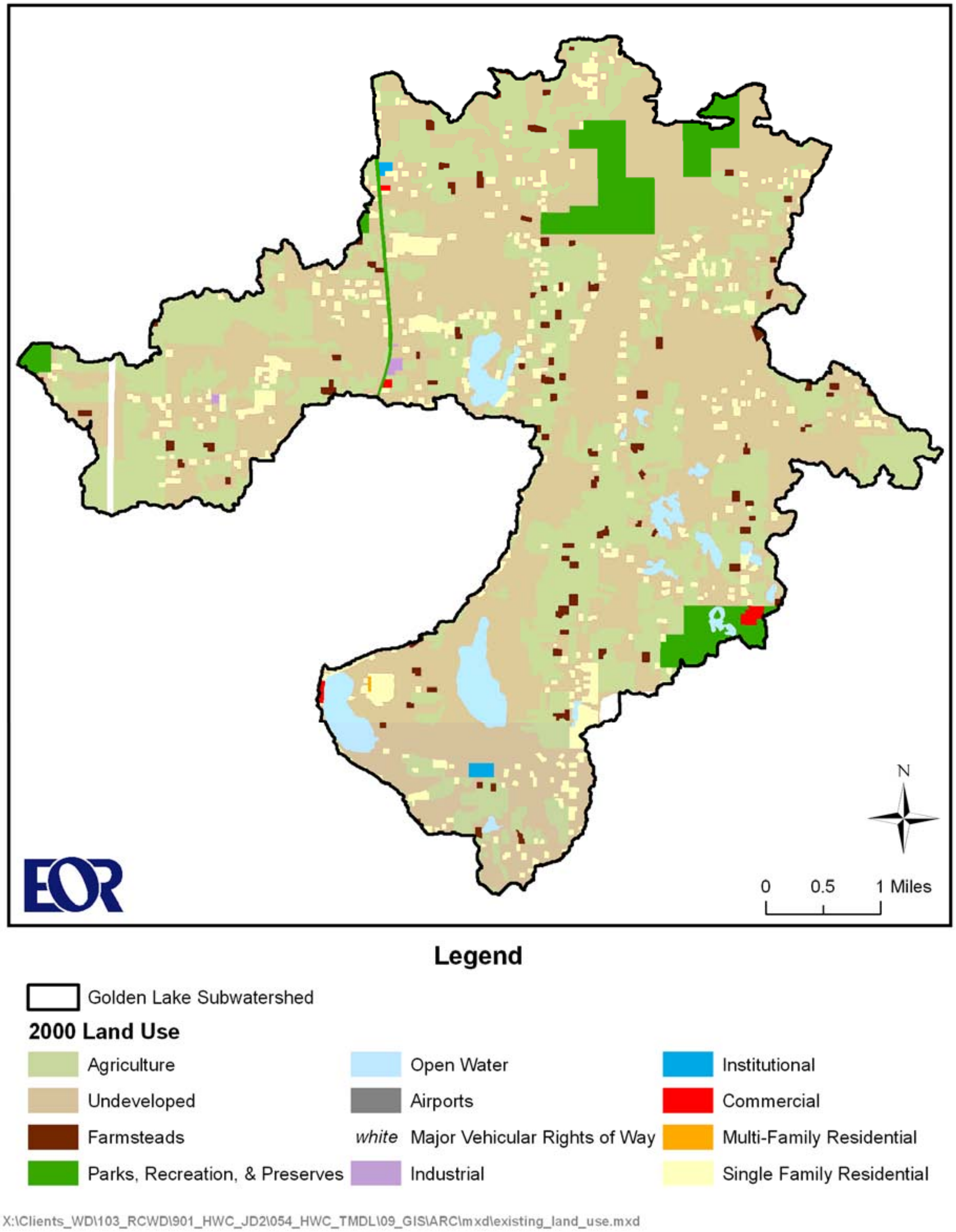

Figure 2. Existing Land Use in the Hardwood Creek Watershed
(Generalized Land Use 2000 for the Twin Cities Metropolitan Area)

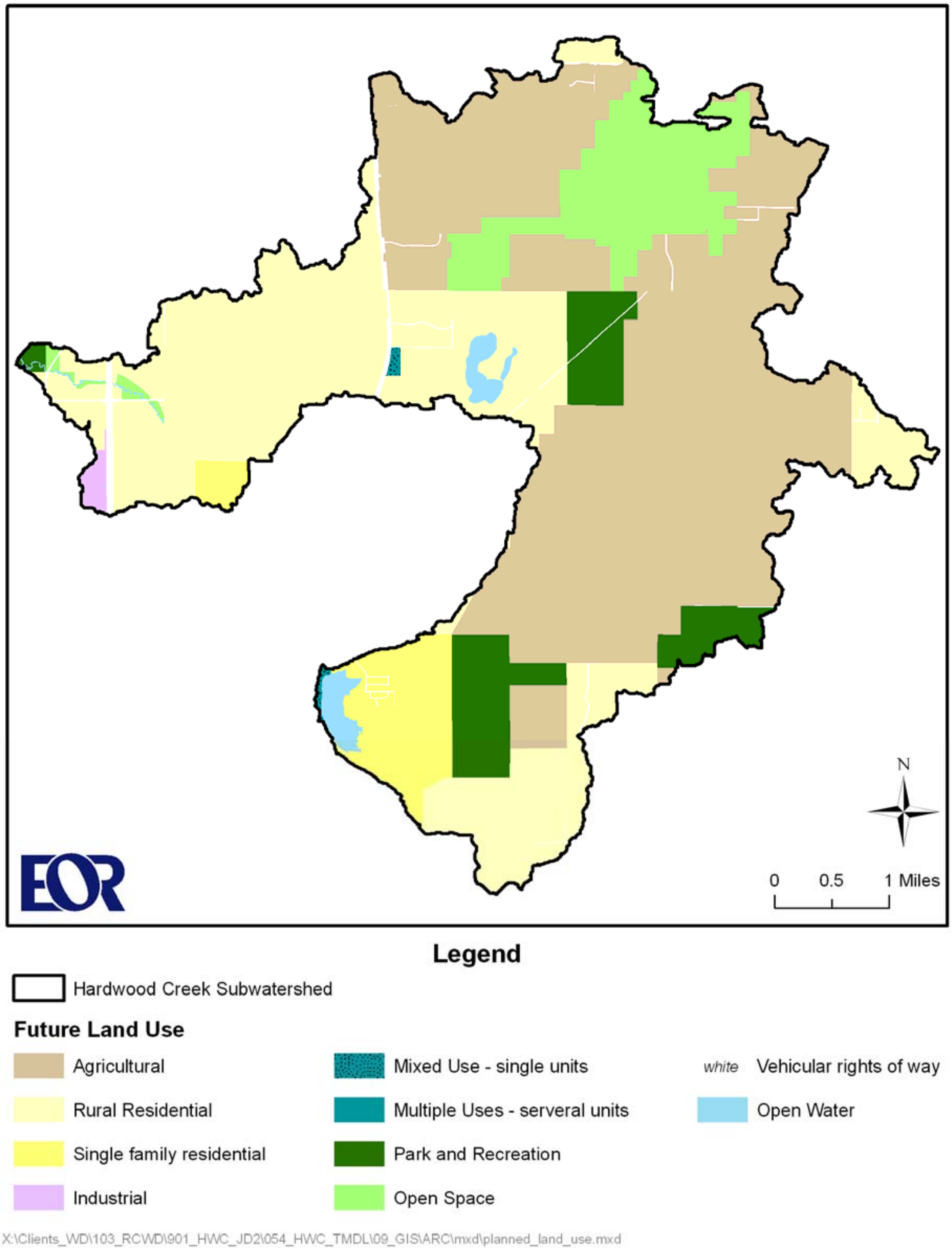

Figure 3. Planned Land Use in the Hardwood Creek Watershed
(Regional Planned Land Use - Twin Cities Metropolitan Area)

Land Cover

The Minnesota Land Cover Classification System classifications for the Hardwood Creek watershed were combined into five impervious surface area categories and six vegetative cover type categories for both existing (2000) and planned (2020) conditions (Figure 4). The 0% to 10% impervious cover and 51% to 75% impervious cover categories are predicted to increase the most in the future, with reductions coming from all terrestrial natural cover types – agricultural land, forests, woodlands, grasslands, and maintained natural areas (Table 3).

Table 3. Hardwood Creek Watershed Land Cover Summary

Land Cover Category	Percent Change (from existing to future conditions)
0% to 10% impervious cover	192%
11% to 25% impervious cover	31%
26% to 50% impervious cover	0%
51% to 75% impervious cover	75%
76% to 100% impervious cover	0%
Agricultural Land	-36%
Forests & Woodlands	-23%
Grasslands	-41%
Lakes & Open Water Wetlands	0%
Maintained Natural Areas	-24%
Wetlands	0%

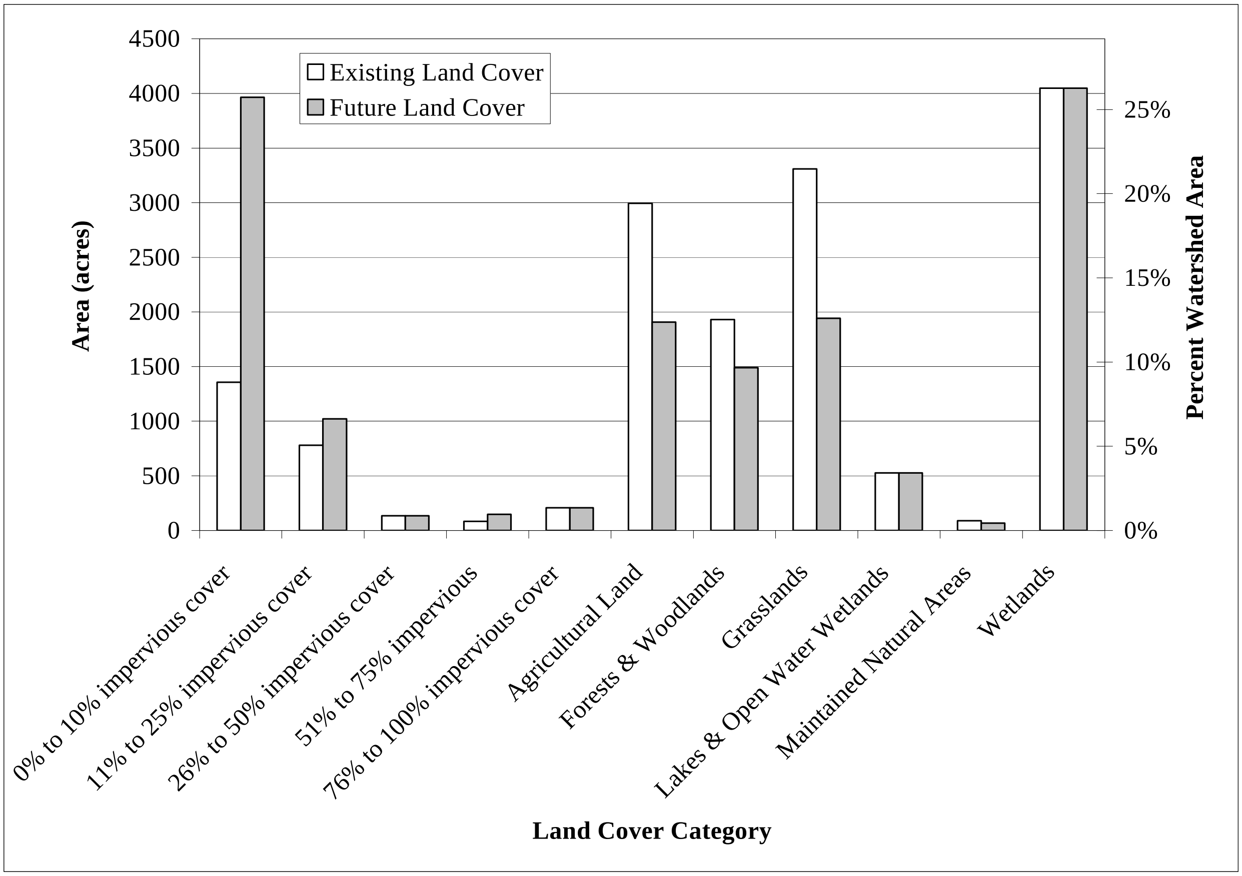

Figure 4. Land Cover Summary for the Hardwood Creek Watershed

C. WATER QUALITY AND BIOLOGICAL ASSESSMENT

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

Description of the impairment

The impairment on Hardwood Creek was characterized by a low IBI score. The IBI created by the MPCA uses fish sampling data to indicate the overall health and integrity of a stream (Niemela and Feist 2002). For small streams in the Upper Mississippi River basin the IBI assesses the health of fish communities using ten different metrics (Table 4). These ten metrics fall into three categories: species composition, trophic composition, and fish abundance and condition. Data are obtained for each of these metrics at a given site, and a number rating is assigned to each metric. The sum of the ten ratings yields an overall site score, with scores ranging from 0 for exceptionally poor quality to 100 for sites of exceptionally high quality. The

IBI integrates information from individual, population, community, and ecosystem levels into a single ecologically based index of water resource quality.

Table 4. Metrics used to calculate IBI scores for small streams in the Upper Mississippi River basin

	Scoring Criteria				
Metric	**10**	**7**	**5**	**2**	**0**
Species richness and composition metrics					
Total number of species	14 or more	11-13	8-10	5-7	0-4
Number of wetland species[1]	3 or more		1 or 2		0
Number of minnow species[1]	5 or more	4	2 or 3	1	0
Number of intolerant species	2 or more		1		0
Percent tolerant species[2]	0-40	41-55	56-70	71-85	86-100
Percent dominant two species[2]	0-52	53-64	65-76	77-88	89-100
Trophic and reproductive function metrics					
Number of invertivore species[1]	5 or more	4	2 or 3	1	0
Percent simple lithophils[2]	49-100	37-48	25-36	13-24	0-12
Fish abundance and condition metrics					
Number of fish per 100 meters[1]	5 or more				0–4
Percent DELT anomalies[2]	0-1		2 or 3		4 or more

[1]Number of wetland species, number of minnow species, number of invertivore species, and number of fish per 100 meters metrics do not include tolerant species.
[2]Round all percent metrics to the nearest 1 percent.

A total of three biological monitoring stations exist on Hardwood Creek between Highway 61 and Peltier Lake, of which only one (99UM103 near site H2) was used for assessment purposes (Figure 5 and Figure 6). The other two stations (06UM001 near site H1.1 and 06UM002 near site H1.2) were sampled as part of a problem investigation independent from the 303(d) assessment. IBI scores were not calculated for stations 06UM001 and 06UM002, but the fish assemblages were very similar to 99UM103. Station 99UM103 had an IBI of 38 in 1999, which was below the criteria of 46 for streams of this size for the purpose of impairment determination. This station was resampled in 2004 and 2006 and produced scores of 51 and 47, respectively (Table 5). The threshold for impairment is an IBI score of 46. Biological assessment procedures for listing impairments consider the previous ten years of IBI scores and a single score below the criteria can result in an impairment designation. To delist an impaired reach with a high degree of confidence generally requires a sustained period of meeting the criteria along with evidence of improved conditions that were believed responsible for the impairment (e.g., lower pollutant loading or improved habitat).

Table 5. IBI Scores at Station 99UM103

Year	IBI Score
1999	38
2004	51
2006	47

The fish community at 99UM103 is predominantly made up of tolerant minnow species and species more typically associated with lentic environments or larger rivers. The latter are likely migrating into Hardwood Creek from Peltier Lake, which is less than one mile downstream of 99UM103. Central mudminnow and northern pike were collected during all three sampling years. Bowfin, black bullhead, johnny darter, bluegill, and largemouth bass were collected two out of the three years of sampling. Other species collected include white sucker, common carp, yellow perch, green sunfish, pumpkinseed sunfish, and spottail shiner. Spottail shiner was the only intolerant species collected over the three sampling years.

The fish community at 99UM103, as evaluated in 1999, was considered impaired due to a low number of minnow species, especially those that are intolerant of disturbance. Also missing from the assemblage were simple lithophilic spawning fish (gravel spawners) and benthic insectivores, both of which require clean, coarse stream substrate. It is likely that the high sediment loads of Hardwood Creek are limiting the ability of these species to feed and reproduce.

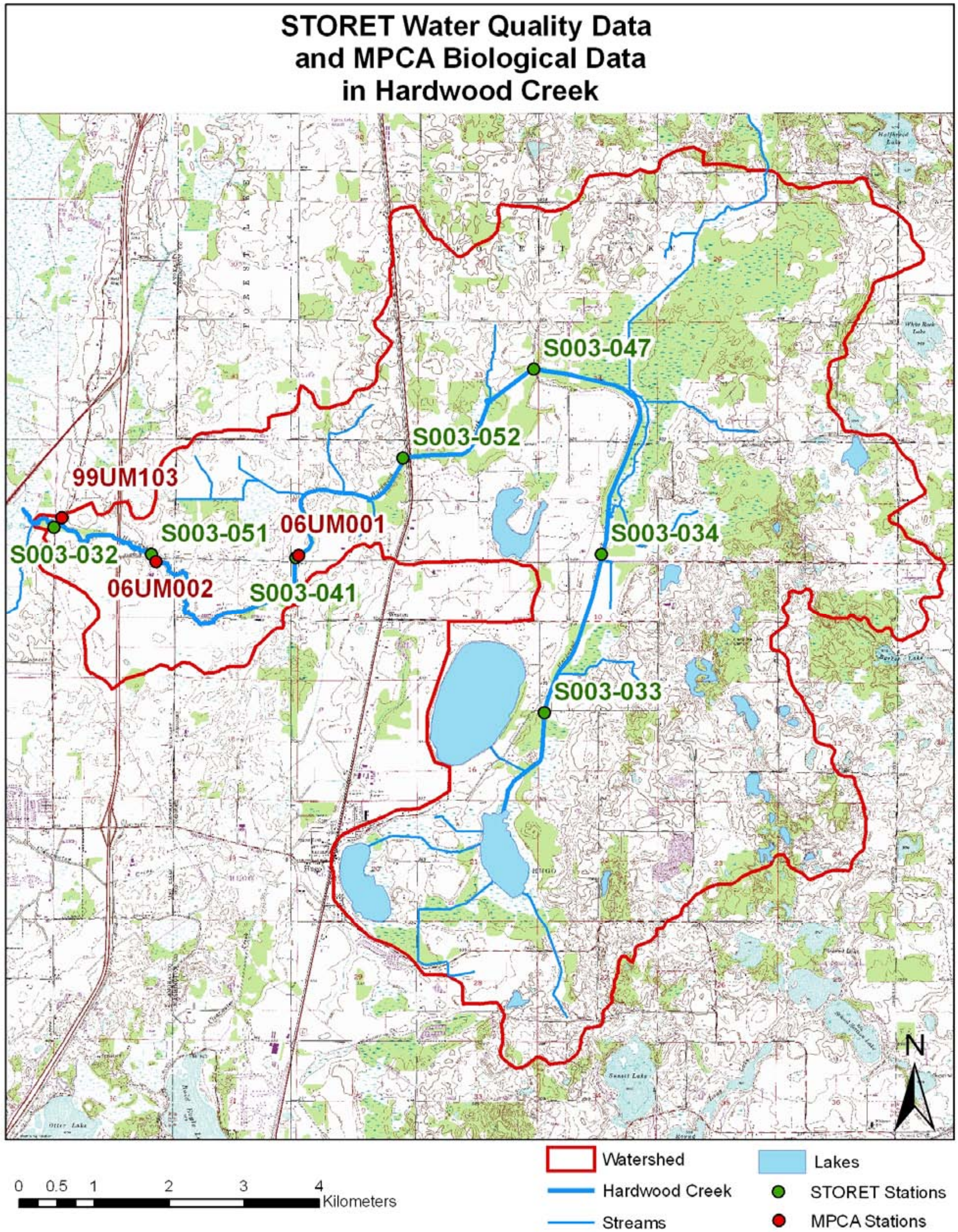

Figure 5. HWC Monitoring Site IDs - STORET and MPCA

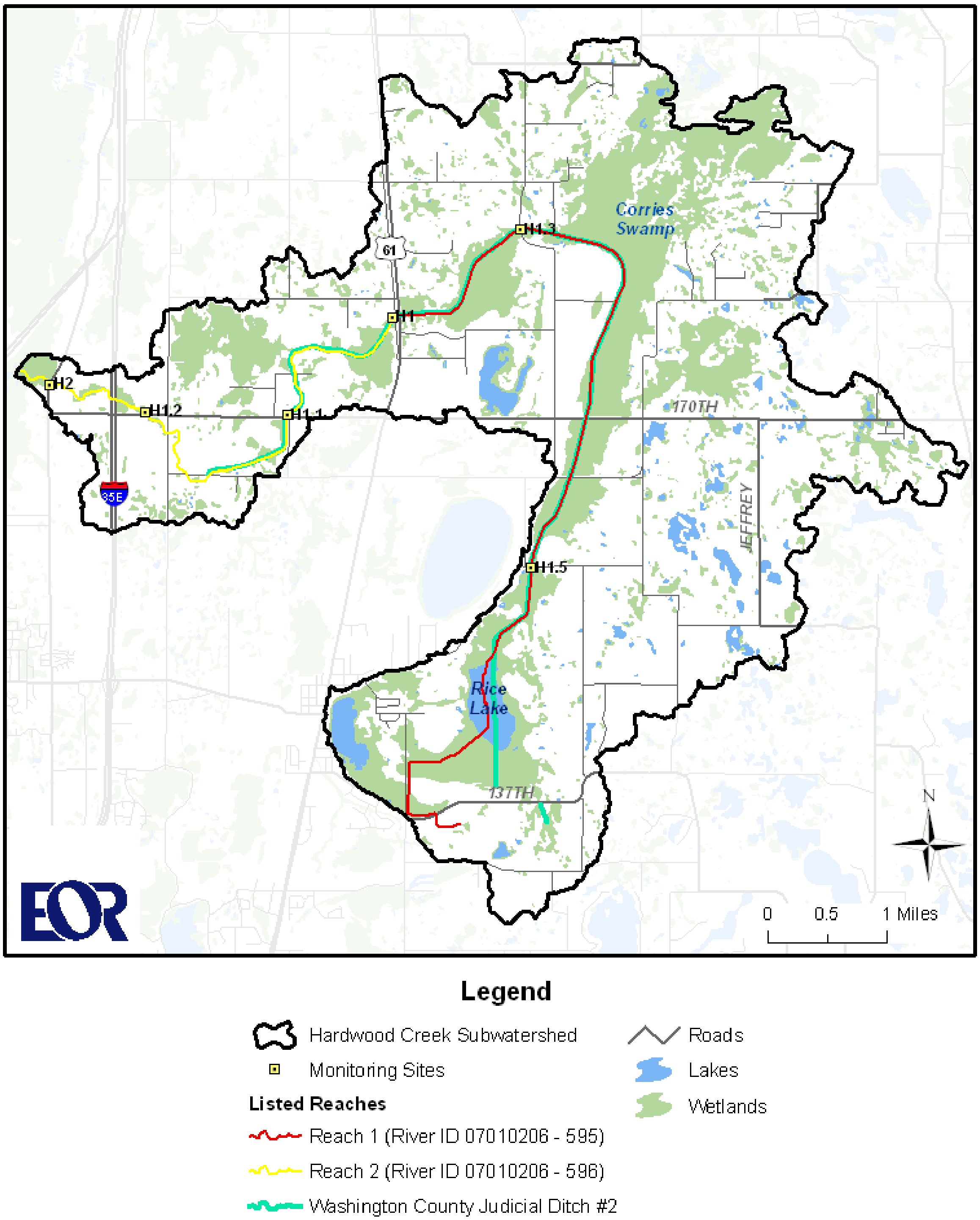

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Figure 6. HWC Monitoring Site IDs – RCWD

During the course of this study, Hardwood Creek was also listed for low DO. Even though both impairments were observed at only the most downstream monitoring site (H2, Figure 6), the entire stream length (13.38 miles) was originally listed on the 303(d) list of impaired waters, and therefore the scope of the study included the entire stream length from the headwaters to the mouth. However, on April 12, 2005, the MPCA split Hardwood Creek into two reaches: upstream from Highway 61 (8.33 miles) and downstream of Highway 61 (5.05 miles) based on technical information presented in the document entitled "Request to MPCA Professional Judgment Group to split Hardwood Creek into two reaches at Highway 61" (Appendix A).

The upper stretch of Hardwood Creek (from Rice Lake to Highway 61) has naturally occurring low DO due to the release of organics from underlying peat deposits and poorly oxygenated groundwater. Upon analyzing groundwater, surface water, and biological data, it was determined that changes in land use activities or changing the stream configuration could not achieve DO levels that would be above the Minnesota Class 2B standard of 5 milligrams per liter (mg/L) for this upper section of the creek. Because the case has been made that DO levels in the upper portion of the creek can only be expected to meet natural background conditions, the MPCA de-listed the upper portion of the creek for the fish IBI. The MPCA does not have tools to properly assess a biological community that resides in an environment where DO levels are below 5 mg/L. However, the upper reach does need to meet the site-specific DO requirement of maintaining the natural background conditions. An exact determination of the DO concentration that represents natural background has not been done, but based on the analysis presented in Appendix A, when flow is low and dominated by baseflow the groundwater moving through underlying peat may have DO concentrations less than 0.01 mg/L. Instream DO concentrations measured in 2004 at site H1.5 reached a daily average of less than 1 mg/L during August (Figure 11 in Appendix A). Moving downstream, daily average DO concentrations increase: at site H1.3 DO dropped to approximately 2 mg/L at times (Figure 12 in Appendix A), and at site H2 the daily average DO dropped to below 4 mg/L for several days in November (Figure 13 in Appendix A). It is unclear, however, whether or not DO levels were influenced by ditch maintenance activities earlier in the year. This pattern of increasing DO moving downstream is illustrated by box plots of summer DO data (Figure 7).

At site H2, the DO daily minimum drops below 5 mg/L during dry conditions and low flows (Figure 8). Low DO under low flows could be largely driven by the low DO in baseflow coming from the upstream reach, or by stagnant water conditions at the monitoring site itself. These data are from continuous monitoring that was completed in 2004. There are also instantaneous DO measurements at site H2 from previous years; these data show that there are times when DO drops below the standard during almost all flow regimes (Figure 9). Low DO during high flows could be driven by high BOD loading from the watershed or from instream erosion of organic matter.

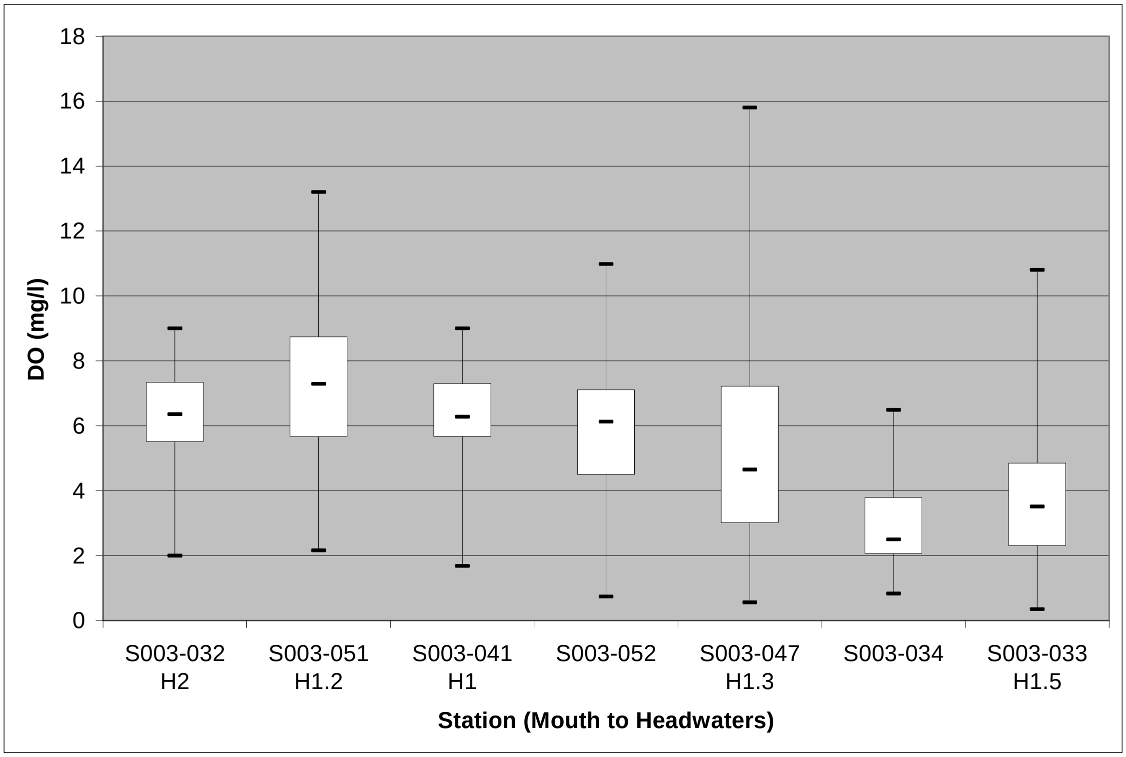


Figure 7. HWC DO data summary by site, June through August

Boxplots represent the interquartile range, and bars represent the data range. Site IDs starting with "S" are STORET site labels; site IDs starting with "H" are from RCWD and are used throughout this report.

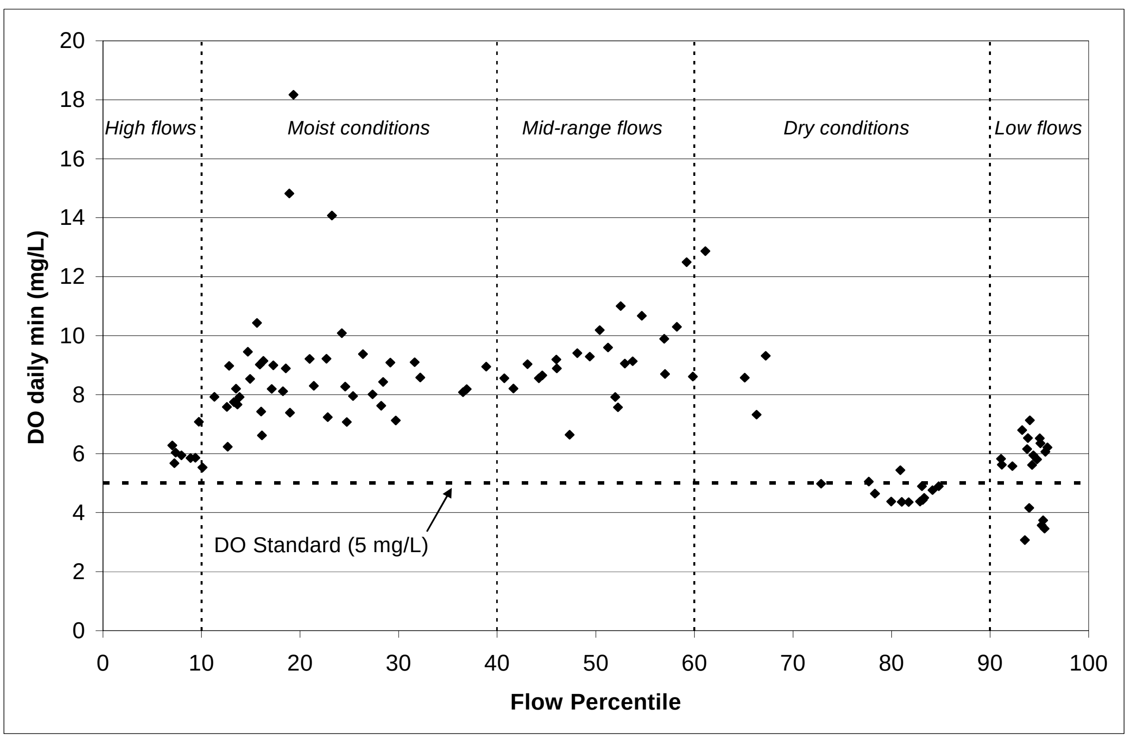


Figure 8. Site H2 DO water quality duration curve, 2004

DO data are daily minimums, determined from continuous DO measurements at 15-minute intervals. Flow data used to determine the flow percentiles are from 1999 to 2004.

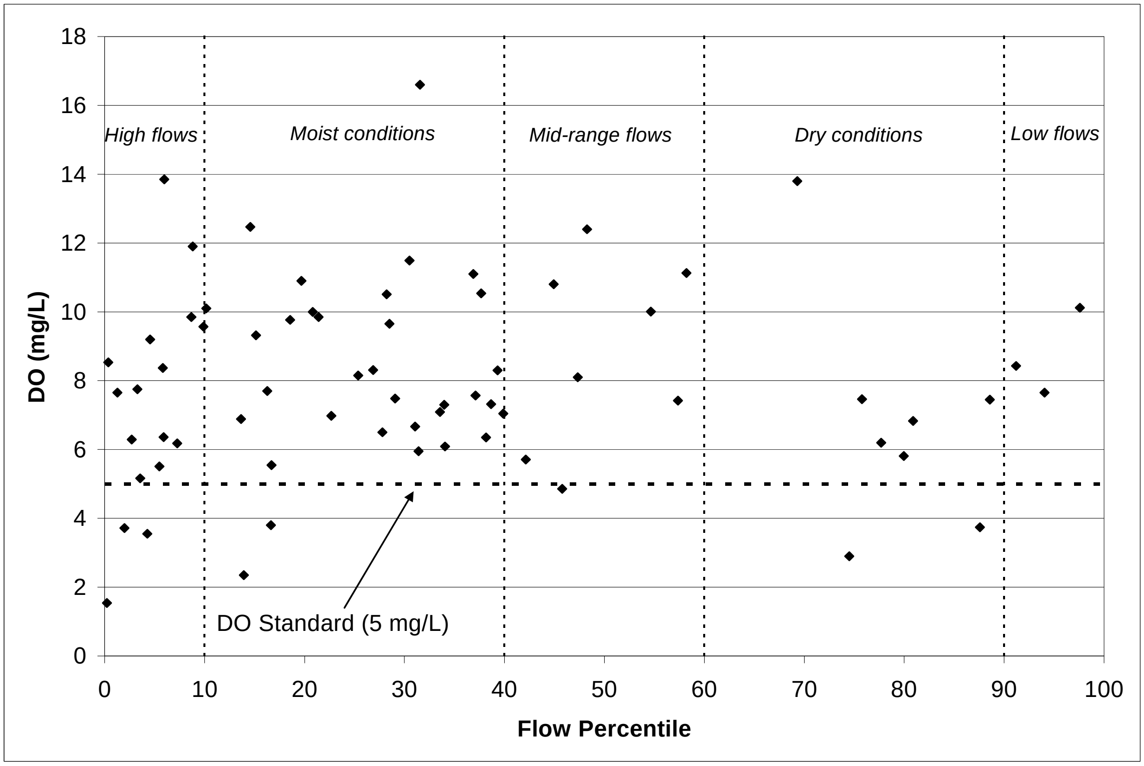


Figure 9. Site H2 DO water quality duration curve, 2000-2004 instantaneous data
Flow data used to determine the flow percentiles are from 1999 to 2004.

There are substantial diurnal DO fluctuations in the upper reach of Hardwood Creek. The monthly average of daily DO ranges is highest in July and August at site H1.3 (Table 6). The range is the lowest at site H2, where it ranges from 0.7 to 2.5 mg/L. These high swings in DO over the course of a day are commonly due to high instream primary production from either algae or macrophytes, which are both common in Hardwood Creek and the adjoining wetlands.

Table 6. Average daily DO ranges, 2004

Month	H1.5		H1.3		H2	
	DO Range (mg/L)	N	DO Range (mg/L)	N	DO Range (mg/L)	N
April	2.7	3	1.8	27	2.5	29
May	4.0	31	2.0	13	1.4	31
June	2.6	19	2.7	7	0.7	18
July	4.0	16	7.8	19	1.2	13
August	2.6	17	6.6	15	1.6	21
September	5.3	9	4.9	29	2.5	30
October	3.9	6	5.2	6	1.3	6

The primary stressors impacting the aquatic life in Hardwood Creek are sedimentation and low DO. Nutrient enrichment was identified as a secondary stressor. The following discussion provides information on each of these stressors. Appendix B provides the complete details on how these stressors were determined following the EPA Stressor Identification Process. The Stressor Identification was geared towards the biological impairment, but secondarily addressed the causes of low DO.

Sedimentation

Altered Habitat

Loss of reproductive habitat, feeding habitat, or refugia associated with unstable or unsuitable geological substrates is a common disturbance in stream systems and can occur due to excess silt and sediments entering the stream. Exterior sources of silt and sediment include bank erosion due to altered hydrology or overgrazing by livestock (leading to bank destabilization), farming activities, road ways and urban runoff, and dirt and gravel road systems in the drainage area. Naturally occurring stream features and landscape characteristics within the Hardwood Creek watershed may also affect stream sediment conditions, potentially altering the occurrence of suitable gravel substrates. Examples are beaver dams and low gradients, which decrease flow, causing particulates to settle and remain trapped. Another example in Hardwood Creek is that the lower portion of the system runs through the geologic area known as the Anoka Sand Plain, which is linked to the sandy soils found along the bank of the creek.

The result of this excess sediment is the covering and filling of cobbles and gravel substrate and interstitial spaces, decreasing pool depth, and the potential burial of larger coarse woody debris. In addition, excessive sediments can affect stream aquatic use conditions by eliminating stable, coarse substrates that provide shelter during high flow events, thereby potentially affecting fry, smaller fish, and the macroinvertebrate communities. Sediment sources within a stream include materials eroded from banks and scoured off the stream bed.

A habitat assessment following MPCA protocol was conducted along a 1,000-foot stretch at monitoring site H2 (Figure 6). In addition, two independent habitat assessments were conducted using the Qualified Habitat Evaluation Index (QHEI). The results of all three of these habitat assessments in this area indicate that sedimentation and channel instability were high. The low fish IBI scores in Hardwood Creek are likely a result of the stream's poor quality habitat. The relationship between high quality physical habitat and a healthy fish community in other systems is well documented (Gorman and Karr 1978, Allan and Flecker 1993, Allan *et al*. 1997, Saunders *et al.* 2002, Rhoads *et al*. 2003). Additional habitat assessments were conducted in the remaining reaches using the EPA rapid bioassessment habitat protocol. The EPA rapid bioassessment habitat protocol, although slightly different than the QHEI, also indicated that sedimentation and channel instability were high. In this case, different tools yielding the same result provide further evidence that altered habitat due to sedimentation is a likely stressor on the fish community.

Altered Hydrology

The upper two-thirds of Hardwood Creek (~10 miles) are channelized, or ditched. Ditching can produce more frequent and higher peak flows downstream leading to bank instability, which can increase suspended sediments (Prévost et al. 1998), and ultimately poor habitat quality. These phenomena have all been observed in Hardwood Creek. Higher peak flows result from less flow being attenuated in a channelized ditch and from watershed runoff being directed to the channel more quickly. Ditching can decrease local storage, and water that would have spread out onto the floodplain remains in the channel and is passed downstream more quickly (Brookes 1988, Saunders *et al.* 2002). Channelization can alter biological communities by changing both the physical structure of the stream and the flow characteristics of the water. Channelization ultimately lowers DO, increases siltation, and reduces substrate complexity. This complex suite of stressors also includes decreased woody debris, which reduces available substrate and changes the energy source for consumers; decreased sinuosity, which changes flow characteristics; erosional patterns and substrates; increased channel depth; loss of pools that act as refugia; and loss of riffles that oxygenate water and transport sediment.

Low Dissolved Oxygen

Four mechanisms have been identified in Hardwood Creek that could be contributing to the low DO in the lower reach.

1. *Organic enrichment* – Depletion of DO commonly occurs from organic enrichment. Organic enrichment is the most common cause of increased BOD and, in terms of anthropogenic sources, is commonly associated with wastewater treatment plants. There are no point sources of organic enrichment in the Hardwood Creek watershed. However, there are several nonpoint sources within the watershed including a large peatland that constitutes the majority of the headwaters area as well as agricultural sources. There is one registered dairy operation immediately adjacent to the creek and several smaller farms with horses or livestock within 1,000 feet of the creek. In some cases, livestock have direct access to the stream. The primary effect of this direct access comes in the form of manure inputs to the stream, both directly and through non-buffered runoff. The manure inputs contribute to nutrient and BOD enrichment of the stream. In addition, there are areas where row crop agriculture is farmed up to the banks of the creek with little or no riparian buffer.

Septic systems that are either failing or illegally connected to tile lines are believed to not represent a problem in this watershed and are therefore not believed to be a source of BOD to Hardwood Creek. This conclusion is based on surveys and information collected by the watershed district and the counties. Very few homes exist along the creek and any septic systems that are out of compliance are identified and addressed at the time of sale.

BOD data are only available from 2004. Although the BOD concentrations that year exceeded the concentration of minimally impacted streams in the ecoregion, it is uncertain if these are the common conditions in Hardwood Creek due to the ditch maintenance that occurred in 2004. Indirect evidence of potential BOD loading from livestock is suggested by relatively high fecal coliform bacteria levels observed in 2004 (the only year fecal coliform data were collected). Individual samples showed concentrations as high as 5000 fecal coliform bacteria/100 mL and concentrations in excess of 1000 fecal coliform bacteria/100 mL at most of the monitoring sites during some parts of the year were common. Such high numbers may be indicative of animal waste runoff or direct inputs by cattle in the creek.

2. *High nutrient concentrations* – High nutrient loadings entering a stream can accelerate primary production, allowing for increases in biological activities. When the plants and algae die, bacteria decomposing the plant tissue deplete DO while at the same time release nutrients into

the water column. Observational data suggest that there is a substantial amount of duckweed in Hardwood Creek; however, there do not seem to be excessive amounts of periphyton or macrophytes in the stream. Since chlorophyll-*a* and/or algae data were not collected in this study, and there are limited BOD data, it is not known if high primary production (and high bacterial decomposition) is causing low DO concentrations. There are high diurnal fluctuations in DO (Table 6), but the cause of these fluctuations is not known.

3. *Decreased canopy cover* – Often associated with agricultural and urban development, decreased canopy cover can lower DO by increasing water temperatures, which subsequently decreases the solubility of oxygen in water and increases primary production due to more light and warmer water temperatures (Allan 1995). Numerous parts of Hardwood Creek, especially in the upper reaches, have little or no riparian buffer to provide canopy cover. While some of the low canopy cover is due to anthropogenic changes, some parts of the upper reaches likely had little riparian cover naturally, especially in the wetland areas. Much of the lower reach of Hardwood Creek still has decent canopy cover.

4. *Changes in channel geomorphology* – As oxygen diffusion rates are generally highest in agitated waters, such as those flowing over riffles, changes to stream morphology that affect the number of riffles (e.g., channelization, increases in water depth, changes in surface area) also may affect DO concentrations. Due to past ditching activities and natural low stream gradients, much of Hardwood Creek has limited numbers of riffles.

Nutrient enrichment

Nutrient enrichment can cause changes in fish and benthic macroinvertebrate assemblages, including changes in dominant species, and can increase the abundance and biomass of some species because excessive nutrient loading can alter food resources. Generalists, with a broad diet, are typically more tolerant of perturbations (Barbour *et al*. 1996). Some macroinvertebrate trophic guilds fare poorly after excessive nutrient loading, even with adequate oxygen, as excessive algal growth can decrease visibility, habitat complexity, and respiratory effectiveness. This change in macroinvertebrate abundances can affect fish through prey availability.

Stressor Conclusions

Through the stressor identification process, the primary causes of the low IBI in Hardwood Creek were identified as sedimentation and low DO. Nutrient enrichment is likely to have some influence on the low IBI score but the strength of evidence analysis did not strongly support a causal relationship. Phosphorus enrichment is being addressed in the Peltier Lake eutrophication TMDL (lake ID 02-0004-00), the water body that Hardwood Creek outlets into. WLAs and LAs for phosphorus are being established as part of the Peltier Lake TMDL, which covers the Hardwood Creek watershed.

The TMDL for the biological impairment will be based on TSS loads, which address sedimentation. Various candidate mechanisms affecting DO were identified and ultimately may all play a role in DO levels to varying degrees. However, the low DO TMDL focuses on BOD loading, which was identified as a significant stressor during 2004. DO depression due to nutrient enrichment will be indirectly and separately addressed via the Peltier Lake eutrophication TMDL.

2. Applicable Water Quality Standards and Numeric Water Quality Targets

A. Minnesota Biologic Criteria – Fish

Under the CWA, every state must adopt water quality standards to protect, maintain, and improve the quality of the nation's surface waters. These standards represent a level of water quality that will support the goal of swimmable and fishable waters. The basis for assessing the biological community for impairment in the state of Minnesota is the narrative water quality standards and assessment factors in Minn. R. pt. 7050.0150. The attainment of water quality standards in Minnesota requires meeting criteria based on the health of the aquatic biological community (biocriteria). Chemical water quality criteria are established as a surrogate for direct measurement of the aquatic biological community to allow a determination if a particular pollutant is present in amounts that are projected to cause impairment in an aquatic community. A similar linkage between biocriteria and habitat condition can also be used to recommend habitat goals that are deemed favorable for full attainment of the stream's designated aquatic life uses.

Attainment of aquatic life uses is determined by directly measuring fish and aquatic macroinvertebrate populations to see how they compare to reference areas. The MPCA has been using fish community data to assess water resource quality for the last decade. Minnesota uses a regional reference site approach based on a major river basin framework. Attainment benchmarks are established for each subbasin in the form of biocriteria (Indexes of Biological Integrities, or IBIs). For the Upper Mississippi Watershed, a separate IBI has been developed for different stream size classes based on drainage area (Table 7). Hardwood Creek has a drainage area of approximately 27 square miles and the criterion is 46. Impairment thresholds are based on the range of IBI scores measured at the reference sites within each size class. In addition to the IBI score, the assessment decisions for impaired biota listings are also based on narrative criteria, which include such factors as habitat assessment and anthropogenic disturbance.

Table 7. Upper Mississippi Fish Index of Biological Integrity Criteria

Drainage Area	Full Support -- Not Listed	Non- Supporting -- Listed
$5 mi^2$ - $35 mi^2$	IBI > 46	IBI < 46
$35 mi^2$ - $200 mi^2$	IBI > 46	IBI < 46
$>200 mi^2$	IBI > 61	IBI < 61

B. Minnesota Dissolved Oxygen Criteria

All waters of Minnesota are assigned classes based on their suitability for the following beneficial uses:

1. Domestic consumption
2. Aquatic life and recreation

3. Industrial consumption
4. Agriculture and wildlife
5. Aesthetic enjoyment and navigation
6. Other uses
7. Limited resource value

All surface waters of the state are also protected for multiple uses. Hardwood Creek is not classified under Minnesota Rule 7050.0470. All waters that are not classified under this rule are designated for the following uses: 2B, 3B, 4A, 4B, 5 and 6 (Minnesota Rule 7050.0430) (Table 8).

The DO standard for Class 2B waters is 5 mg/L as a daily minimum. Compliance with the DO standard is required 50 percent of the days at which the flow of the receiving water is equal to or greater than the lowest weekly flow with a once in ten-year recurrence interval (7Q10). This standard was modified for the upper reach of Hardwood Creek. The site-specific standard is "to maintain natural background conditions."

Table 8. Designated beneficial uses for water classes found in Hardwood Creek

Class	Beneficial use
2B	Propagation and maintenance of cool or warm water sport or commercial fish and associated aquatic life, and their habitats [7050.0222, subp.4]
3B	General industrial purposes, except for food processing, with only a moderate degree of treatment [7050.0223, subp.3]
4A	Irrigation without significant damage or adverse effects upon any crops or vegetation usually grown in the waters or area, including truck garden crops [7050.0224, subp.2]
4B	Livestock and wildlife without injurious effects [7050.0224, subp.3]
5	Aesthetic enjoyment of scenery and should not interfere with navigation or cause damage to property [7050.0225]
6	Other possible beneficial uses not specifically listed [7050.0226]

C. Total Suspended Solids and Oxygen Targets

Total Suspended Solids Goal

TSS was selected as a surrogate to represent sedimentation and habitat quality in streams, and an instream TSS concentration goal was used to calculate the TMDL. Minnesota does not have numeric sediment criteria developed for rivers and streams in the state. Therefore, a numeric TSS goal was developed with the aim of improving and protecting instream habitat. The effects of recent stream restoration projects in Hardwood Creek were used to determine the instream TSS concentration as a result of these activities, and this concentration was used as the TSS goal. The restored habitat results in less erosion and a lower contribution of sediment.

The goal was developed by using an instream sediment transport model, CONCEPTS, to predict the instream TSS concentration under different scenarios. CONCEPTS (CONservational Channel Evolution and Pollutant Transport System) is a computer model that simulates open channel hydraulics, sediment transport, channel morphology, and geotechnical processes of bank failure by tracking bed changes and channel widening. The restored channel modeled scenario represents the effects of the instream stabilization practices implemented in lower Hardwood Creek, involving primarily live stakes and rock vanes. Appendix C provides the CONCEPTS model background information and results.

The existing conditions modeled scenario (i.e., pre-restoration condition in 2002) predicts an average annual instream TSS concentration of 22 mg/L, and the restored channel scenario predicts an average annual instream TSS concentration of 19 mg/L. 19 mg/L TSS was used as the instream TSS goal for the Hardwood Creek TMDL.

Biochemical Oxygen Demand Goal

BOD was used as the target parameter to address the DO TMDL. Minnesota does not have numeric BOD criteria developed for rivers and streams in the state. However, the state has ecoregion guidance in a technical report entitled “Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota’s Seven Ecoregions” (McCollor and Heiskary 1993). The technical team for this TMDL considered this guidance and decided to set the BOD goal for the Hardwood Creek TMDL at the 75th percentile of the minimally impacted streams in the North Central Hardwood Forests ecoregion, which is 3.2 mg/L BOD. In the absence of more watershed-specific data, using historical ecoregion data with emphasis on the 75th percentile levels is an appropriate approach and is among the options recommended by EPA for water quality criteria (e.g., see USEPA, 2000 for nutrient criteria in rivers and streams) and was used recently by the MPCA for development of the state’s lake eutrophication standards.

3. Loading Capacity

This section describes the derivation of the TMDL for Hardwood Creek. The TMDL is the sum of the wasteload allocations (WLAs) for the point or National Pollutant Discharge Elimination System (NPDES)-permitted sources and the load allocation (LA) for natural background and nonpoint sources in a watershed. After the TMDL was calculated, a margin of safety (MOS) to account for any uncertainty regarding the relationship between pollutant load and water quality was calculated (Section 5: Margin of Safety). The difference between the TMDL and the MOS was then apportioned between the WLAs and the LAs.

The major causes of non-attainment of the aquatic life standard are sedimentation and low DO (Section 1: Background). The loading capacity of Hardwood Creek was determined using several analytical techniques and is described in this section. Load-based TMDLs were developed for TSS for the biological impairment, and for BOD for both the biological impairment and the low DO impairment.

A. Methods

Different analytical techniques were used to quantify and determine TMDLs for Hardwood Creek. These approaches are summarized in Table 9.

Table 9. Modeling Approach Summary

Models or Analytical Technique	Parameters Analyzed	How the method or model was used
Load Duration Analysis	Flow, TSS, BOD	Examined streamflow variation and load distributions for stressor identification. Calculated TMDLs for TSS and BOD for each of five flow intervals.
Load Estimator (LOADEST)	TSS loads	Used program to estimate annual TSS loads based on 2002-2004 monitoring data.
XP-SWMM	Hydrology and hydraulics	Analyzed current and future conditions flows within the watershed. Used as flow input to CONCEPTS model.
CONCEPTS	Sediment export, bed and bank erosion	Estimated instream sediment load from bed and bank erosion.

Flow Duration Analysis

The cumulative frequency of the flow data from each of the six monitoring sites was used to develop flow duration curves for each monitoring site. The analysis resulted in a curve, for each monitoring site, that relates flow values to the percent of time those values have been met or exceeded. Thus for each monitoring site, the full range of stream flows is considered. Low flows are exceeded a majority of the time, whereas floods are exceeded infrequently. Duration curve analysis identifies intervals that can be used as a general indicator of hydrologic conditions (i.e. wet versus dry and to what degree). This indicator, when combined with other basic elements of watershed planning, can help guide solutions towards relevant watershed processes, important contributing areas, and key delivery mechanisms.

The flow duration curves were used to develop the load duration curves, which were used to establish the TMDL loading goals.

Five years of flow data were used to determine the flow duration curve, and while this amount of time does not necessarily constitute a long-term record these five years do cover both high and low flow regimes (Table 10). Furthermore, as Figure 10 shows, the span of flow conditions ranges from flood conditions to no flow. A more extensive flow record would therefore not be expected to expand this range.

Table 10. Precipitation Data

Year	Precipitation (in)*
1999	33.1
2000	32.4
2001	33.6
2002	41.8
2003	26.4
2004	32.3
Long term average**	31.8

*Data for Washington County from MN Climatology Working Group
**In City of Hugo, summary from The Weather Channel

Load Duration Analysis

A load duration curve is created by multiplying the values in the flow duration curve by the applicable water quality criterion or target. The x-axis remains as the flow duration interval and the y-axis depicts the load at that flow duration interval. The curve represents the allowable load at each flow condition. By comparing the load duration curve to the loads from samples collected over a wide range of flow conditions, it is possible to determine if pollutant exceedences are more likely the result of point or continuous sources (exceedences typically associated with low-flow conditions) versus nonpoint sources (exceedences typically associated with high-flow conditions). This helps estimate the magnitude of load reductions needed to meet the TMDL target under each flow interval and evaluate which conditions are more critical. The points above the curve represent monitoring data that exceed the target load and points on or below the curve indicate when the target is being met (with the exception of DO, which is the reverse).

The load duration curves were used to calculate the loading capacity of Hardwood Creek across the range of flow conditions as well as for five different flow intervals. The TMDL for each flow interval can be represented by the midpoint of the flow interval and is calculated by multiplying the flow at that point by the instream concentration goal (19 mg/L TSS or 3.2 mg/L BOD).

Load Estimator (LOADEST)

LOADEST is a program developed by the United States Geological Survey that estimates constituent loads in streams based on a time series of streamflow and constituent concentration. LOADEST develops a regression model for estimating constituent loads over a user-specified time interval. Mean load estimates, standard errors, and 95 percent confidence intervals are then developed on a monthly and seasonal basis. LOADEST was used to summarize the TSS monitoring data in Hardwood Creek and estimate TSS loads to calibrate the CONCEPTS model (Appendix C, section 5: Model calibration), which was used to develop the instream TSS goal.

XP-SWMM (Hydrology and Hydraulics)

As part of the JD2 repair report completed by Rice Creek Watershed District (RCWD 2004), an XP-SWMM model was created for the Hardwood Creek watershed to evaluate various hydrologic modification scenarios. Flow predictions from the model were used as input to the CONCEPTS model (Appendix C).

Conservational Channel Evolution and Pollutant Transport System - CONCEPTS

CONCEPTS was used to develop the instream TSS goal for Hardwood Creek, by predicting the instream TSS concentration under different scenarios (see above Section 2C: Total Suspended Solids Goal, and Appendix C).

B. Results

At monitoring site H2, flows are less than two cfs during 10% of the time (Figure 10). Low streamflow constitutes a constraint to attainment of water quality and biological targets in the Hardwood Creek watershed, particularly during the warmer summer months.

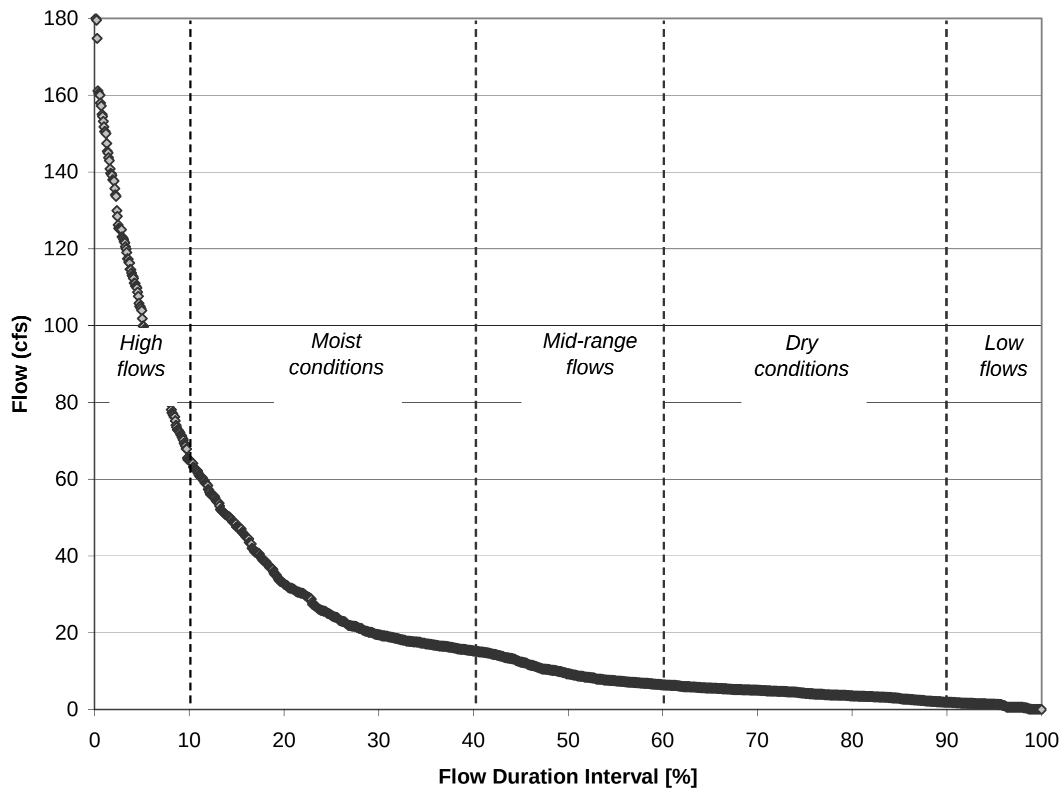


Figure 10. 1999-2004 Flow Duration Curve for Hardwood Creek, MN at Site H2

Although flow is not listed as a direct stressor, increases in flow within Hardwood Creek will only exacerbate sedimentation within the lower portion of the creek.

Loading Capacity

The loading capacity for Hardwood Creek is based on flow data at Site H2 since it is the most downstream monitoring site; all other segments contribute loads to this point and this downstream location reflects the assimilation of stressors into the creek system. Additionally, this is the station where the IBI was calculated.

Exceedences of the TSS goal are most common during moist conditions and high flows (Figure 11), indicating that most sediment entering Hardwood Creek is from either the watershed or from instream erosion during high flows. See the Stressor Identification (Appendix B) for load duration curves for the other five monitoring sites.

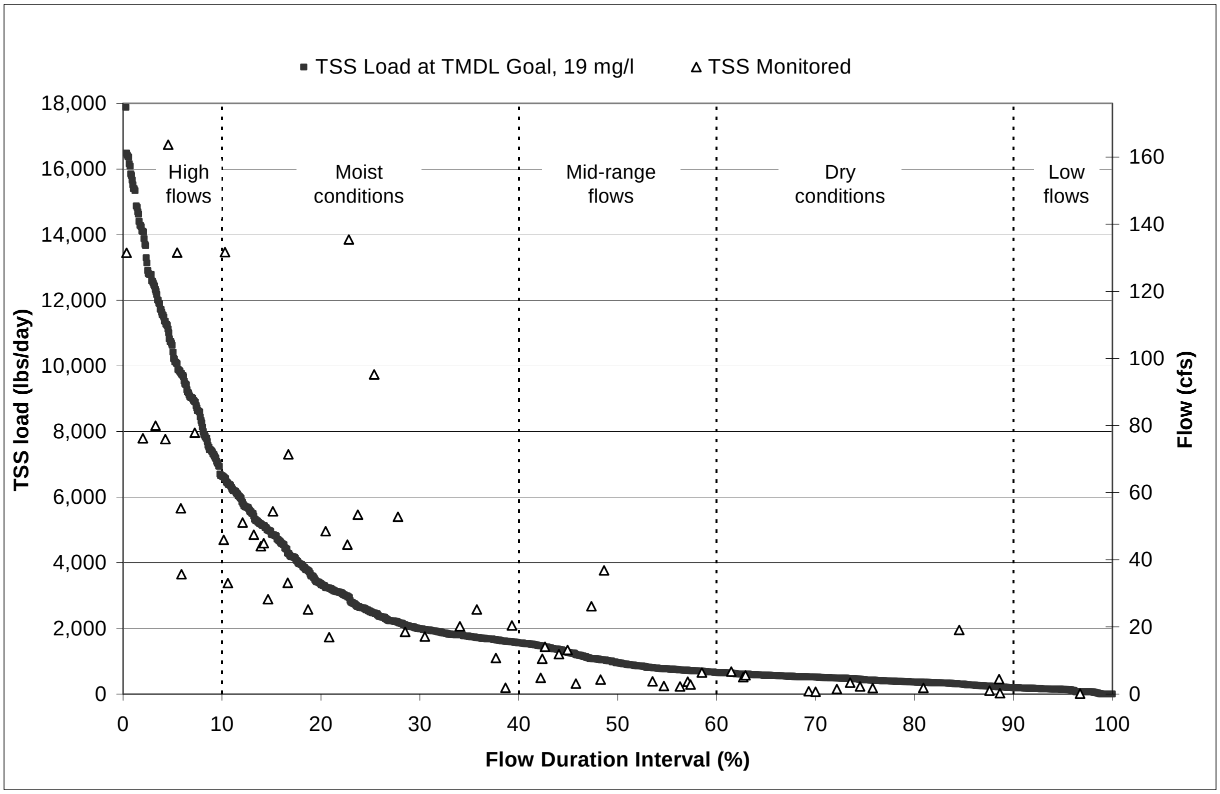


Figure 11. TSS Load Duration Curve for Hardwood Creek, MN at Site H2.
(Flow and TSS data from 1999-2004.)

The overall needed TSS reduction basin-wide is estimated to be 14% based on the difference between the existing TSS concentration (22 mg/L) and the TSS goal (19 mg/L). The existing conditions model was based on 2002 data; 2002 was considered to represent baseline conditions since it was before minor maintenance of the creek occurred in 2004. The minor maintenance in 2004 led to elevated TSS loads in Hardwood Creek.

There are limited BOD monitoring data at H2 (Figure 12). The overall needed BOD reduction basin-wide is estimated to be 30% based on the difference between the target concentration (3.2 mg/L) and the estimated current concentration at H2 (4.6 mg/L). Critical conditions for DO in the lower portion of Hardwood Creek occur during summer low flows.

It is recommended that the load reductions necessary for BOD be further refined after additional data have been collected. The current estimated BOD load is based on five months of data collected after minor maintenance of Hardwood Creek that occurred in 2004. It is likely that the maintenance had an effect on the BOD in Hardwood Creek, but it is unclear exactly what those effects were since previous data are not available.

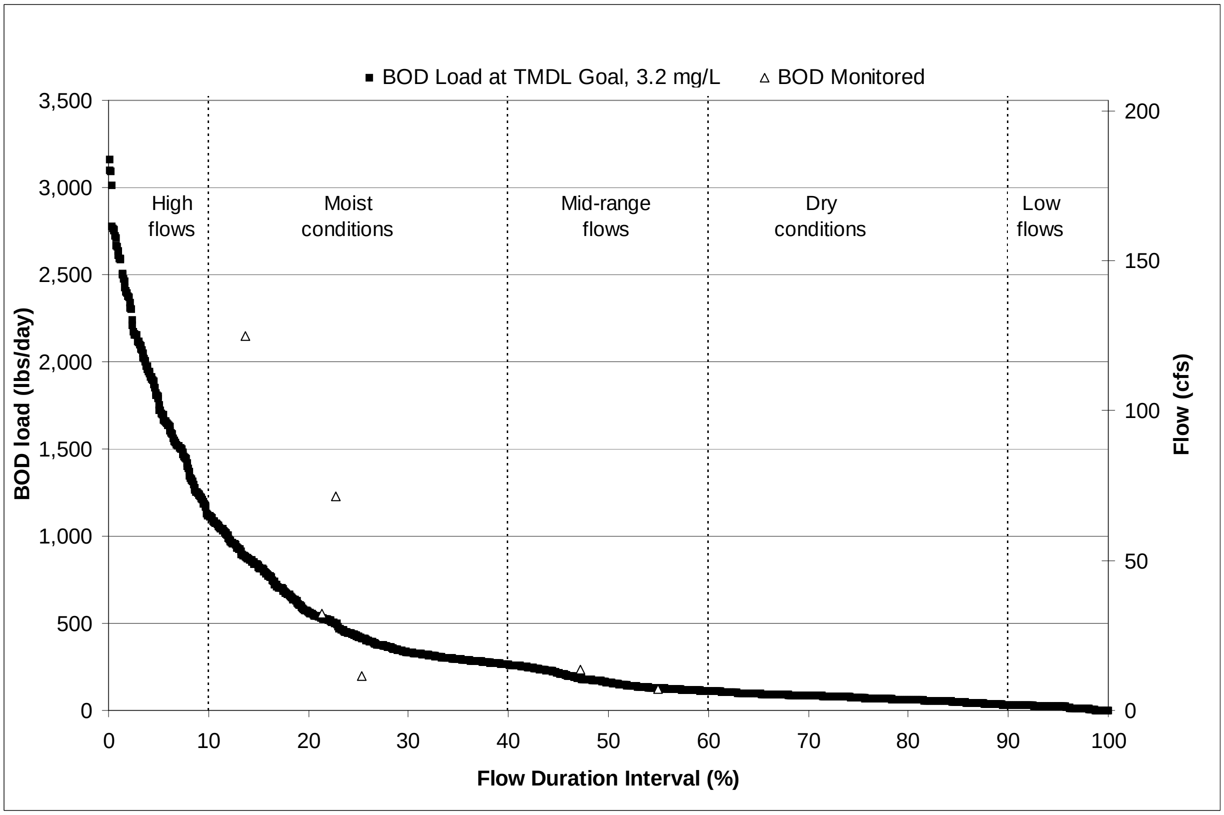


Figure 12. BOD Load Duration Curve for Hardwood Creek, MN at Site H2.
(Flow data from 1999-2004, BOD data from 2004.)

The TMDLs for both TSS and BOD were based on flow; since the goals are based on instream concentrations, the allowable load varies according to flow. The TMDL is represented by the curves presented in Figure 11 and Figure 12. The TMDLs for five different flow regimes were calculated to illustrate representative points from the overall curves (Table 11). The assimilative capacity of the stream varies according to its flow rates, and therefore a TMDL that also varies by flow protects the stream under all flow regimes.

Table 11. Hardwood Creek Assimilative Capacity of TSS and BOD

Parameter	TMDL (lbs/day) during Flow Duration Interval				
	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
	183.7 - 65.0 cfs	65.0 - 15.3 cfs	15.3 - 6.4 cfs	6.4 - 1.9 cfs	1.9 - 0.0 cfs
TSS	10,319	2,503	954	432	142
BOD	1,738	421	161	73	24

Target Loads for Upstream Sites

TSS and BOD concentrations vary throughout the watershed (Table 12). Target loads for sites upstream of monitoring Site H2 were estimated and are provided primarily to inform implementation planning throughout the watershed. Annual average water volumes were calculated for all monitoring stations from the available flow data. Target loads were calculated by multiplying the recommended target concentration by the average annual water volume at each site (Table 13).

TSS and BOD reductions throughout the watershed, in combination with improved habitat and DO conditions, should attain standards in all segments of the stream if improvements are targeted to the critical areas and matched with appropriate implementation actions.

Table 12. TSS and BOD Average Annual Concentrations at Hardwood Creek Monitoring Sites

Site	Concentration (mg/L)	
	TSS[1]	BOD[2]
H2	26.6	4.6
H1.2	40.4	4.4
H1.1	21.9	4.6
H1	31.5	4.1
H1.3	12.4	4.4
H1.5	8.4	4.6

[1]Years of data – H2:1999-2004; H1.2, H1.1, H1, H1.3: 2002-2004; H1.5: 2002, 2004
[2]Years of data – 2004

Table 13. Water Quality Loading Goals for Hardwood Creek

Monitoring Station	Average Annual Volume (acre-feet/yr)	Annual TSS Loading Goal[1] (lbs/yr)	Annual BOD Loading Goal[2] (lbs/yr)
H2	11,262	579,024	97,520
H1.2	11,597	596,248	100,421
H1.1	9,957	511,929	86,220
H1	7,897	406,016	68,382
H1.3	5,917	304,217	51,236
H1.5	4,038	207,610	34,966

[1]Based on 19 mg/L TSS
[2]Based on 3.2 mg/L BOD

4. Critical Conditions and Seasonal Variation

The critical condition for aquatic organisms is the summer when the aquatic life activity and biomass production are at their highest levels. Summer is also when excessive algal growth, high instream temperatures, and reduced stream flows typically occur, leading to lower DO concentrations that can have a negative impact on organisms. MPCA's biological, habitat, and nutrient targets are set to be protective during critical periods, e.g., summer low flow conditions. Further, assessing the biology during the summer months evaluates the biological performance during the most critical time of the year. Both the TSS and the BOD TMDLs are protective of the stream during all flow conditions (including the low flow critical periods) since the allowable loadings are based on load duration curves and therefore vary according to flow.

A. Sedimentation

Seasonality is accounted for in the IBI and the QHEI. Both the IBI and the QHEI are measures of aggregate annual conditions reflecting compounding factors over time. The use of these indices reflects the collective seasonal effects on the biota. The measurement of these indices during the summer period reflects the biotic performance during critical conditions.

B. Dissolved Oxygen

The conditions that are the most critical to the instream DO of the Hardwood Creek watershed occur when water temperatures are high and stream flow is low, such as occurs during the summer months. Since the TMDL was set based on various flow regimes, it is protective of the low flow events in the summer.

5. Margin of Safety

The statute and regulations require that a TMDL include an MOS to account for both the inability to precisely describe current water quality conditions and the unknowns in the relationship between the LAs and the stream water quality (CWA § 303(d) (1) (C), 40 C.F.R. § 130.7(c) (1)). U.S. EPA guidance explains that the MOS may be implicit, that is, incorporated into the TMDL through conservative assumptions in the analysis, or explicit, that is, expressed in the TMDL as a set aside load. An explicit MOS was used in this TMDL.

An explicit MOS of 10% was used for both the TSS and BOD TMDL equations. This MOS accounts for the uncertainty in predicting the loads to Hardwood Creek, the uncertainty in determining the fate and transport of the loads, and the uncertainty in how the stream responds to changes in loading. The 10% MOS is appropriate due to the following:

- The use of flow duration curves to set the TMDL already accounts for variability of flow, in that the TMDL is proportionally higher during high flow conditions and proportionally lower during low flow conditions. There is only a very small (but difficult to quantify) margin of error in the daily flow calculations that were used to develop the flow data set.
- A wide range of agricultural and urban stormwater BMPs have been identified and shown to be effective in reducing TSS and BOD loading. Follow-up monitoring will provide a means to evaluate installed BMPs in terms of compliance with allocations.

6. Load (LA) and Wasteload Allocations (WLA)

The difference between the TMDL and the MOS represents the total load that can be allocated between the WLAs and the LAs. The two main sources of TSS load are stormwater runoff and instream load from bed and bank erosion (Table 14). The primary BOD source was considered to be from the watershed (stormwater runoff) rather than from instream bed and bank erosion.

Table 14. Source Categories for WLAs and LAs

Source	TSS	BOD
MS4 stormwater	WLA	WLA
Non-MS4 stormwater	LA	LA
Instream bed and bank erosion	LA	--

The percent distribution of each TSS source was estimated using annual average data (Table 15). The baseline load from bed and bank erosion is based on the 2002 CONCEPTS model scenario; the TMDL bed and bank load is based on the restored channel scenario (see Appendix C). This baseline load from the bed and bank accounts for much of what would be considered the natural background load in the TMDL.

Since the total instream load in Hardwood Creek was based on monitoring data, the watershed load was calculated by subtracting the bed and bank erosion load from the total load in the stream.

Three cities and one township are located within the Hardwood Creek watershed: the City of Hugo, the City of Forest Lake, the City of Lino Lakes, and May Township. The three cities are required to meet NPDES Phase II requirements for MS4s (municipal separate storm sewer systems). The nonagricultural land area of those MS4s that is projected to be served by storm water conveyances by 2020 (a year for which land use projections exist; see Figure 3) will be included in the WLA. The remaining land area as well as the loading for May Township will fall under the LA. (At this time the City of Forest Lake is not projected to have any nonagricultural land area served by storm water conveyances by 2020 in the Hardwood Creek watershed.)

The other MS4 communities within the watershed, Washington County, Anoka County, Minnesota Department of Transportation (Mn/DOT) and RCWD, are also included in the WLA. The remaining permitted stormwater sources, construction stormwater and industrial stormwater, are included as well.

The WLA is categorical in that it includes all of the NPDES-permitted stormwater runoff: MS4, construction, and industrial stormwater. The sources will collectively need to meet the WLA.

Table 15. TMDL Distribution of TSS Loads

Source		Percent of TMDL	Baseline (2002) (lbs/year)	TMDL (lbs/yr)
LA - Total		**86%**	**1.12E+06**	**9.20E+05**
LA - Instream		29%	4.40E+05	3.10E+05
LA - Non-permitted stormwater * (93% of watershed total)		57%	6.75E+05	6.10E+05
WLA – Permitted stormwater (7% of watershed total)**		**4%**	**5.08E+04**	**4.28E+04**
MS4 or other source	Permit #			
City of Hugo	MS400094			
City of Lino Lakes	MS400100			
RCWD	MS400193			
Anoka County	MS400001			
Washington County	MS400160			
Mn/DOT Metro District	MS400170			
Construction stormwater	Various			
Industrial stormwater	No current permitted sources			
MOS		**10%**		**1.07E+05**
Total		**100%**	**1.17E+06**	**1.07E+06**

* Includes May Township, agricultural areas and other areas not projected to be served by stormwater conveyances (open space, open water, park and recreation, rural residential)
** Includes MS4 stormwater (nonagricultural areas served by stormwater conveyances), construction stormwater, and industrial stormwater

A similar approach was used to distribute the BOD loads, except that there is no instream load considered (Table 16). The watershed stormwater load was divided into the WLA and LA on an areal basis with the WLA being estimated as the nonagricultural land area of the MS4s that is projected to be served by storm water conveyances by 2020 and the LA being all remaining land (including the non-MS4 community May Township).

Because future land use is already factored into the WLA estimate no portion of the allowable loading is being explicitly set aside as reserve capacity.

Table 16. TMDL Distribution of BOD Loads

Source		Percent of TMDL
LA – Non-permitted stormwater * (93% of watershed total)		84%
WLA - Permitted stormwater** (7% of watershed total)		6%
MS4 or other source	Permit #	
City of Hugo	MS400094	
City of Lino Lakes	MS400100	
RCWD	MS400193	
Anoka County	MS400001	
Washington County	MS400160	
Mn/DOT Metro District	MS400170	
Construction stormwater	Various	
Industrial stormwater	No current permitted sources	
MOS		10%
Total		**100%**

* Includes May Township, agricultural areas and other areas not projected to be served by stormwater conveyances (open space, open water, park and recreation, rural residential)
** Includes MS4 stormwater (nonagricultural areas served by stormwater conveyances), construction stormwater, and industrial stormwater

The percent distribution of the WLAs, LA, and MOS represent the breakdown of the TMDL under any specific flow regime. These percentages were applied to the TMDL from each of the five representative flow regimes (Table 17 and Table 18). The TSS loading capacity represents the average daily load, averaged over the course of a year under the identified flow condition, that the stream can assimilate. Since it is the cumulative impact of TSS on habitat that is relevant to the biota, the long term loading is relevant. The BOD loading capacity represents the maximum daily load, under the identified flow condition, that the stream can assimilate. Since BOD affects DO concentrations in the short term, it is the daily maximum that is relevant.

Table 17. TSS TMDL: LA, WLA, MOS

Source		% Allocation	TMDL (average lbs/day)				
			High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
			183.7 - 65.0 cfs	65.0 - 15.3 cfs	15.3 - 6.4 cfs	6.4 - 1.9 cfs	1.9 - 0.0 cfs
LA		86%	8,874	2,153	821	372	122
WLA – Permitted stormwater		4%	413	100	38	17	6
MS4 or other source	Permit #						
City of Hugo	MS400094						
City of Lino Lakes	MS400100						
RCWD	MS400193						
Anoka County	MS400001						
Washington County	MS400160						
Mn/DOT Metro District	MS400170						
Construction stormwater	Various						
Industrial stormwater	No current permitted sources						
MOS		10%	1,032	250	95	43	14
Total		**100%**	**10,319**	**2,503**	**954**	**432**	**142**

Table 18. BOD TMDL: LA, WLA, MOS

Source		% Allocation	TMDL (lbs/day)				
			High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
			183.7 - 65.0 cfs	65.0 - 15.3 cfs	15.3 - 6.4 cfs	6.4 - 1.9 cfs	1.9 - 0.0 cfs
LA		84%	1,460	354	135	61	20
WLA – Permitted stormwater		6%	104	25	10	5	2
MS4 or other source	Permit #						
City of Hugo	MS400094						
City of Lino Lakes	MS400100						
RCWD	MS400193						
Anoka County	MS400001						
Washington County	MS400160						
Mn/DOT Metro District	MS400170						
Construction stormwater	Various						
Industrial stormwater	No current permitted sources						
MOS		10%	174	42	16	7	2
Total		**100%**	**1,738**	**421**	**161**	**73**	**24**

7. Public Participation

Public participation associated with this TMDL began in 2003 with the public meetings held by RCWD regarding the restoration of the upper reach of Hardwood Creek. In addition, both a technical advisory committee (TAC) and a public advisory committee (PAC) were formed that consisted of local stakeholders in the watershed from local city officials to local farmers. Members are included in Table 19. These two committees were formed based upon the premise that local involvement is crucial in applying science to community water quality and water quantity problems successfully.

Five TAC meetings were held to go over the approach of the project, to provide technical updates, and to review the LAs. Members of the TAC were notified via email about meeting times and dates (Table 20). Four PAC meetings were held to build trust, develop a common understanding of water resource issues and their relationship to identified problems, provide an opportunity for local prioritization of issues, and enhance participant dedication to eventual implementation (Table 21). Members of the PAC were notified via email about meeting times and dates. One public meeting was held on November 20, 2008, prior to the release of the draft TMDL report. An opportunity for further public comment of the TMDL draft was done through a public notice in the State Register of a 30-day comment period that occurred from March 9 to April 8, 2009.

Table 19. TAC and PAC members for the Hardwood Creek TMDL

Attendees	Committee	Area of Representation
Marcey Westrick	PAC/TAC	Emmons and Oliver Resources, Inc. – Aquatic Ecologist
Steve Hobbs	PAC/TAC	Rice Creek Watershed District - Administrator
Chuck Johnson	PAC/TAC	Rice Creek Watershed District - Biologist
Tim Larson	PAC/TAC	Minnesota Pollution Control Agency - Project Manager
Dave Shuman	PAC	Resident of the City of Hugo
Vince Niemczyk	PAC	Resident of the City of Hugo
John Waller	PAC	Resident of the City of Hugo
Travis Germunson	PAC	Minnesota Department of Natural Resources
Nick Proulx	TAC	Minnesota Department of Natural Resources
Daniel Huff	PAC	Friends of the Mississippi
Jay Riggs	PAC/TAC	Washington Conservation District
Mike Grochela	PAC	City of Lino Lakes – Community Development Director
Marty Asleson	PAC	City of Lino Lakes – Environmental Director
Phil Belfiori	TAC	City of Hugo – Engineer
Paul Hornby	PAC	City of Forest Lake - Engineer
Wayne LaBlanc	PAC	Peltier Lake Association
Bruce Vondracek	TAC	University of Minnesota - Fisheries
Mike Feist	TAC	MPCA – Fisheries Biologist
Len Farrington	TAC	University of Minnesota – Entomology
Scott Alexander	TAC	University of Minnesota - Hydrogeology
Joe Magner	TAC	MPCA - Hydrologist

Table 20. TAC meetings held for the Hardwood Creek TMDL

Meeting Number	Meeting Topic	Meeting Date
Meeting #1	Review work plan and finalize 2004 monitoring plan	October 22, 2003
Meeting #2	Review Stressor ID process and historical water quality data analyses	February 4, 2004
Meeting #3	Review 2004 monitoring data	November 22, 2004
Meeting #4	Review data to support splitting Hardwood Creek into two reaches at Highway 61	January 4, 2005
Meeting #5	Review final stressor identification documents and review LAs	September 2, 2005

Table 21. PAC meetings held for the Hardwood Creek TMDL

Meeting Number	Meeting Topic	Meeting Date
Meeting #1	General Introduction of the TMDL Process/ Why is Hardwood Creek considered	May 10, 2005
Meeting #2	Stressor Identification Process	June 9, 2005
Meeting #3	Habitat Alteration	July 28, 2005
Meeting #4	DO/Total Phosphorus	September 6, 2005

8. Implementation Strategy

This section of the TMDL report outlines the ways to achieve the LAs and WLAs. A separate more detailed implementation plan will be developed following approval of the TMDL.

The challenge of implementing the TMDL will be to find acceptable methods that simultaneously manage and meet the human needs for agricultural drainage, erosion protection, and flood reduction, along with the ecological needs of the Hardwood Creek system.

Regulated stormwater source loading limits will be achieved through updating stormwater pollution prevention programs (SWPPPs) to comply with the WLAs. Implementation of nonpoint source reductions may be achieved through non-regulatory and voluntary incentive programs. Achievement of all of these loading goals and the improvements to instream habitat are necessary to restore the biological community in Hardwood Creek. A variety of mechanisms, discussed below, will be evaluated and used to achieve these loading reductions for either or both TSS and BOD.

A. Stream Bank Stabilization

There are several areas along Hardwood Creek that are severely eroded. Two of these areas have been identified by the RCWD as a high priority for restoration activities. These areas are affected by either variable flows or cattle grazing and could be stabilized by promoting streamside reforestation, livestock exclusion, and streambank stabilization using bioengineering techniques.

B. Forested Riparian Buffers

Riparian buffer zones play an important role in stream ecosystems and provide numerous benefits. Recent literature reviews on riparian buffers suggest applying different riparian buffer widths to meet different riparian goals. In the case of Hardwood Creek, the primary goals for reestablishing buffers would be to filter sediment and pollutants, reduce the impacts of floods, stabilize stream banks, decrease water temperatures, and improve instream habitat.

A 300-foot buffer is preferable but perhaps unfeasible to establish. A 100-foot buffer would be adequate for water quality and native aquatic organisms. However, a 50-foot buffer is more feasible and should, under most conditions, provide good protection to the stream morphology and habitat preservation. The risk is that heavy rain, floods, or poor management of contaminant sources could more easily overwhelm the buffer.

C. Meander Restoration

Meandered channels that are designed based on the bankfull conditions of current hydrology are stable and result in less instream erosion than in non-meandered channels (RCWD 2004).

Due to the hydrologic alterations of the system, reestablishing meanders within sections of Hardwood Creek would allow the channel to have the capacity to carry the current hydrology of the system. Meanders would also reconnect the channel to its floodplain, allowing for sediment deposition and nutrient storage. Currently, the RCWD has identified two segments of Hardwood

Creek in the lower reach as prime candidates for re-meandering. However, the RCWD should not limit itself to these areas and should pursue restoration opportunities as they arise.

D. Livestock Management

Management of livestock in riparian areas of Hardwood Creek would greatly help in the removal of nonpoint source discharge of sediment, BOD, and nutrient inputs. A combination of BMPs (best management practices) is recommended to address these issues.

Livestock exclusion fencing

Livestock can impact stream systems by removing vegetation and compacting soils, resulting in soil erosion and excessive runoff. In addition, the removal of streambank vegetation increases water temperature and changes stream channel morphology. Installation of livestock exclusion fencing will restrict livestock from the stream riparian area and allow for subsequent vegetation and soil restoration.

Livestock crossings and pathways

For areas where livestock have direct access to the stream, livestock fencing would limit access to available pasture land; therefore, an alternate location must be found. Installation of a livestock crossing across Hardwood Creek would be needed, and pathways would need to be installed to access these new areas. The creek crossing could be accomplished by installation of a rock or concrete ford, earthen fill with designed culvert, or bridge. Additional study would be needed to determine which alternative is best, considering stream hydrology, cattle safety, and resource protection.

Pasture Management

Rotational grazing is recommended for areas where livestock currently graze the riparian area of Hardwood Creek. This approach would provide adequate forage in other locations while limiting livestock influences on the creek.

Stockwater ponds

In areas where fencing or rotational grazing would move livestock away from Hardwood Creek, an alternate watering source may be needed. Additional investigation would be needed to determine whether areas exist where soils are capable of retaining water and whether a well and/or pump would be needed. Since such sites could concentrate cattle use, they would need to be carefully placed as to not result in runoff into Hardwood Creek.

Diversions

Areas with steep slopes and concentrated flows that are within a practical fence line may have inadequate runoff treatment. In these cases, an earthen diversion is recommended. This diversion would direct runoff away from these sensitive areas and release it in a location where adequate treatment could be provided.

Feedlot runoff control

To address water runoff from the feedlot area, clean water diversions and guttering is recommended. These BMPs are an attempt to prevent water from flushing the feedlot runoff into Hardwood Creek.

Manure Management

It is not uncommon for cattle and horse operations to have excess manure production with inadequate area for disposal. A manure management plan could be developed with landowners to address manure application and storage and prevent manure runoff into Hardwood Creek.

E. STORMWATER MANAGEMENT

Due to historic channelization and changes in land use over time, the hydrology of Hardwood Creek has been altered. This change in hydrology has had a profound effect on sediment, nutrients, oxygen, and instream habitat. Additional changes in hydrology will only exacerbate the current problems. Therefore, in order to protect the geomorphological and ecological integrity of Hardwood Creek and limit impacts to Peltier Lake, stormwater discharge or hydrologic modifications that increase runoff rates or volumes into the creek should be minimized or avoided entirely. New district-wide rules were approved by RCWD in 2008 that focus on infiltration and volume control.

Local Authorities

The local authorities that exist within the Hardwood Creek watershed will play important roles in the implementation of loading reductions recommended in this TMDL. The Cities of Hugo, Forest Lake, Lino Lakes, and the RCWD, through zoning, planning or permitting have the ability to reduce pollutant loading, reduce stormwater runoff rates and volumes, preserve wetlands, and make riparian corridors a preferential land use in those areas.

General Permits for Construction Site Stormwater and Industrial Stormwater

One way to control storm water is through the issuance of general permits under the NPDES program. These permits are issued for construction activities and industrial activities, and are issued to control stormwater that is discharged from a discrete conveyance, such as pipes or confined conduits. NPDES individual and general permits are issued to individuals, private entities, and local government entities. These permits function together to form a web of state and local authority under which stormwater is controlled.

Loads from construction stormwater are considered to be a small percent of the total WLA and are difficult to quantify. Construction stormwater activities are therefore considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install, and maintain all BMPs required under the permit, including any applicable additional BMPs required in Appendix A of the Construction General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

For construction permits that apply to ditch maintenance activities, in addition to the BMPs described in the General Permit, the permit holder will follow a list of BMPs developed specifically for ditch maintenance (Appendix D). By using these BMPs, the stream will be protected from excessive sedimentation during and after the maintenance activities.

As with construction stormwater, loads from industrial stormwater are considered to be a small percent of the total WLA and are difficult to quantify. Industrial stormwater activities are considered in compliance with provisions of the TMDL if they obtain an Industrial Stormwater General Permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit, or meet local industrial stormwater requirements if they are more restrictive than requirements of the permit.

Phase II MS4 Permits For Local Jurisdictions

Federal storm water regulations call for the issuance of Phase II NPDES (MS4) stormwater permits to smaller municipalities. Within 18 months of EPA approval of the TMDL, the MS4 communities must review their SWPPP for compliance with the WLA and update their SWPPP if necessary.

F. BMP Programs

Conservation Reserve Enhancement Program (CREP)

The Conservation Reserve Enhancement Program (CREP) is a federally and locally funded initiative that is aimed at buffers and wetlands on cropland and marginal pastureland. This program can serve as an important means to addressing nonpoint source pollutants related to agricultural runoff.

The CREP is a voluntary, incentive-based conservation program that emerged out of the 1996 Farm Bill as a part of the older Conservation Reserve Program (CRP). Practices that are eligible through this program include both native and non-native grass filter strips, hardwood and coniferous tree plantings, wildlife habitat buffers, wetland restoration, and the installation and use of water table management infrastructure. CREP contracts are for 14 to 15 years in duration and enrollees are under no obligation to maintain those conservation practices after that time.

The buffer widths (i.e., linear distance perpendicular to the direction of channel flow) are likely to vary, which is related to the situational differences in the area of eligible land on a particular farm as well as the preferences of the prospective enrollees. Cropland that is eligible for enrollment includes a riparian area that extends 200 feet from the top of the streambank or ditch, while the minimum width for enrollment is 20 feet from the top of the bank.

Environmental Quality Incentives Program (EQIP)

The Environmental Quality Incentives Program (EQIP) is a United States Department of Agriculture (USDA) program that began following the 1996 Farm Bill and is administered by the Natural Resource Conservation Service (NRCS). The objective of this incentive based, voluntary program is to increase the use of agriculturally related best management and conservation practices. There are numerous conservation practices that are eligible for payments. These practices cover broad categories such as nutrient and pesticide management, conservation tillage, conservation crop rotation, cover cropping, manure management and storage, pesticide and fertilizer handling facilities, livestock fencing, pastureland management, and drainage water management, among others. More information is available on the NRCS website at www.nrcs.usda.gov.

Section 319 Nonpoint Source Grants

Section 319 of the 1987 CWA created a national program to control and prevent nonpoint source pollution of the nation's surface and ground water resources. The MPCA, Minnesota's designated water quality agency, is responsible for administering the program in Minnesota. The Section 319 Implementation Grant program is designed to provide financial assistance to projects that eliminate or reduce water quality impairments caused by nonpoint source pollution and prevent future nonpoint source pollution related impairments.

A clear, strong rationale for project work is required for each award along with a match of local resources. This rationale directs Minnesota 319 awards to watersheds with state endorsed watershed plans and late stage TMDLs.

G. Cost Estimate

The Clean Water Legacy Act requires that a TMDL include an overall approximation of the cost to implement a TMDL [MN Statutes 2007, section 114D.25]. Based on the needs identified in the implementation strategy section of this report, along with cost estimates made in 2004 by a state-level interagency working group that assessed restoration costs for several TMDLs including this one, the initial estimate for implementing the Hardwood Creek impaired biota and DO TMDL is approximately $5,000,000. This estimate will be refined when the detailed implementation plan is developed, following approval of the TMDL study.

9. Reasonable Assurances

As part of an implementation strategy, reasonable assurances provide a level of confidence that the allocations in this TMDL will be implemented by federal, state, or local authorities. Implementation of the Hardwood Creek TMDL will be accomplished by both state and local action on many fronts. State implementation of the TMDL will be through action on NPDES permits for both point sources and stormwater and through the 401 water quality certification program. At the federal level, funding will be provided through CREP, EQIP, and Section 319 grants to provide cost share dollars to implement voluntary activities in the watershed.

Locally, the RCWD is updating its watershed management plan. This plan will be well poised to evaluate and implement TMDL recommendations through a locally driven process. Extensive public involvement for several years has occurred through this process. The Cities of Lino Lakes has embarked upon land use planning efforts to plan for development. In addition, the City of Hugo and the City of Lino Lakes must review the adequacy of their SWPPP to ensure that it meets the TMDL's WLA set for stormwater sources. If the SWPPP from any of the cities does not meet the applicable requirements, schedules, and objectives of the TMDL, the city will be required to modify their SWPPP, as appropriate, within 18 months after the TMDL is approved by the U.S. EPA.

10. Monitoring Plan

An important component of the TMDL process is follow-up monitoring. This monitoring will help determine whether implementation activities have improved water quality. In addition, monitoring will help determine the effectiveness of various BMPs on habitat conditions and indicate when adaptive management should be initiated.

Sampling locations will remain the same as the historic stations established along Hardwood Creek. In addition, biological monitoring will occur at sites where restoration projects have been implemented. Monitoring will consist of three aspects:

1. BMP treatment effectiveness
2. Water quality attainment
3. Instream biological community attainment

RCWD will be the lead for water quality monitoring associated with assessing BMP treatment effectiveness and water quality attainment, and MPCA will be the lead on biological monitoring. The timing and frequency of monitoring activities has yet to be determined and will be dependent on funding availability and the timing of implementation activities.

11. References

Allan, J. D. 1995. Stream Ecology - Structure and function of running waters. Chapman and Hall, U.K.

Allan, J. D., and A. S. Flecker. 1993. Biodiversity conservation in running waters: identifying the major factors that threaten destruction of riverine species and ecosystems. *BioScience* 43:33–43.

Allan, J. D., D. L. Erickson, and J. Fay. 1997. The influence of catchment land use on stream integrity across multiple spatial scales. *Freshwater Biology* 37: 149–161.

Barbour, M., J. Stribling, J. Gerritsen, J.R. Karr. 1996. Biological Criteria: Technical Guidance for Streams and Small Rivers, revised ed. EPA 822-B-96-001. US EPA, Office of Water, Washington, DC.

Brookes, A. 1988. Channelized Rivers: Perspectives for Environmental Management. John Wiley & Sons, Chichester.

Gorman, O.T., J.R. Karr. 1978. Habitat Structure and Stream Fish Communities. *Ecology*. 59(3):507-515.

McCollor, S and S. Heiskary. 1993. Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions, Addendum to: Descriptive Characteristics of the Seven Ecoregions of Minnesota. Minnesota Pollution Control Agency, Water Quality Division.

Niemela, S.L., and M.D. Feist. 2002. Index of Biotic Integrity Guidance for Coolwater Rivers and Streams of the Upper Mississippi River Basin. St. Paul, MN: Minnesota Pollution Control Agency. 56 p.

Prévost, M., A.P. Plamondon, and P. Belleau. 1998. Effects of drainage of a forested peatland on water quality and quantity. *Journal of Hydrology* 214:130-143.

Rhoads, BL, JS Schwartz, S Porter. 2003. Stream geomorphology, bank vegetation, and three-dimensional habitat hydraulics for fish in Midwestern agricultural streams. *Water Resources Research* 39(8): 1218.

RCWD (Rice Creek Watershed District). 2004. Washington County Judicial Ditch #2 Repair Report. Prepared by Emmons & Olivier Resources, Inc.

Saunders, D.L., J.J. Meeuwig, and A.C.J. Vincent. 2002. Freshwater Protected Areas: Strategies for conservation. *Conservation Biology* 16(1): 30-41.

USEPA. 2000. Nutrient Criteria Technical Guidance Manual: Rivers and Streams. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-B-00-002.

Appendix A. Request to Professional Judgment Group to split Hardwood Creek into two reaches at Highway 61

Hardwood Creek Dissolved Oxygen TMDL

Request to Minnesota Pollution Control Agency Professional Judgment Group to split Hardwood Creek into two reaches at Highway 61.

Prepared by:

Emmons and Olivier Resources, Inc.

Scott Alexander – University of Minnesota

Dr. Leonard Ferrington Jr. – University of Minnesota

The purpose of this interim report is to provide the Professional Judgment Group with evidence that we feel supports our request to split Hardwood Creek into two reaches: upstream from Highway 61 and downstream of Highway 61. It is our best professional judgment that the upper stretch of Hardwood Creek (from Rice Lake to Highway 61) has naturally occurring low dissolved oxygen due to the release of organics from underlying peat deposits and poorly oxygenated groundwater supporting the baseflow of the creek. Upon analyzing groundwater data, surface water data and biological data, it is our interpretation that changes in land use activities or stream configuration through restoration could not achieve dissolved oxygen levels that would be above the Minnesota Class 2B standard of 5 milligrams per liter (mg/L) for this upper section of the creek.

Background Information

In 2002, Hardwood Creek was listed on Minnesota's 303(d) List of Impaired Waters (Minnesota Pollution Control Agency - MPCA), for biological impairment resulting from a low Fish Index of Biotic Integrity (IBI). As part of the stressor identification process required for the Fish IBI TMDL, dissolved oxygen (DO) was listed as a potential stressor. In 2004, Hardwood Creek was again listed on Minnesota's 303(d) List of Impaired Waters, for biological impairment, this time due to low dissolved oxygen. Due to the fact that both TMDLs are intrinsically linked, the Rice Creek Watershed District (RCWD) is currently in the process of conducting a TMDL study that encompasses both impairments.

Dissolved oxygen greatly affects aquatic life as nearly all stream organisms are sensitive to oxygen concentrations. The DO standard applicable for Hardwood Creek is the Minnesota Class 2B standard of 5 milligrams per liter (mg/L). Commonly, 5 mg/L is identified as the threshold level for healthy biological communities, while 2 mg/L is required for maintaining any aerobic life in streams. During the summer months, average DO concentrations in the upper stretch of Hardwood Creek are well below the state standard.

Depletion of DO commonly occurs from increases in biological oxygen demand (BOD) from organic pollution in wastewater discharge or organically-enriched sediments (Allen, 1995). Other factors that cause oxygen depletion are high nutrient loadings that can increase biological growth and decomposition; decreased canopy cover, often associated with agricultural and urban development; and changes in stream morphology that affect the number of riffles (e.g., channelization, increases in water depth, changes in surface area). While all of these circumstance occur to some degree throughout Hardwood Creek, it is hypothesized that in the upper portion of the system natural factors such as topography, hydric soils, and high groundwater discharge account for low dissolved oxygen levels much more than anthropogenic sources.

Landscape Context

The upper portion of Hardwood Creek is also known as Washington County Judicial Ditch 2 (JD2). JD2 does not end at Highway 61 but continues west to 170th Street. The upper portion of the creek is a broad, low-lying swale that contains wetland communities of significant natural resource value, including tamarack swamp, sedge meadow, hardwood seepage swamp, and rich fen. The soils in this portion of the watershed are mapped as Seelyeville, Rifle, Markey, and Cathro mucks (EOR, 2004). The descriptions of these soils include muck or mucky peat overlying water-saturated sands and loams. Soil borings collected by RCWD from Rice Lake to Highway 61 show that peat depths reach a maximum depth of 30 feet (EOR, 2004).

Hydrologic measurements, water budget analysis, and floodplain modeling were used to characterize the hydrology of Hardwood Creek from Rice Lake to Highway 61. The water budget indicates that approximately 50%-70% of the annual water source is from groundwater (RCWD, 2004). The soil data, coupled with the hydrology, can be used to describe the physical condition of the upper portion of Hardwood Creek as a groundwater-supported peatland system. A detailed description of the soils can be found in the Washington County Judicial 2 Engineers Report (RCWD,2004). www.ricecreek.org/projects/hwc

Another key aspect of the hydrology of this upper portion of Hardwood Creek concerns the relationship of topography, slope, and velocity to water movement. The average slope from Rice Lake to the Highway 61 crossing is 0.03%. Measured stream flows in this section of the creek range from less than 1 cubic foot per second (cfs) during the summer months to over 100 cfs during snowmelt, indicating that this is a relatively low-velocity channel (EOR, 2004).

In addition, in the upper reaches of Hardwood Creek data from the Integrating Groundwater and Surface Water Management Study for Northern Washington County (EOR, 2003) suggest that the low DO levels in Hardwood Creek are influenced by the high discharge of groundwater flowing through thick peats before reaching the creek. In contrast, the low dissolved oxygen in the lower reach is thought to be more due to anthropogenic sources. To verify this hypothesis and establish a reasonable and achievable DO goal for Hardwood Creek, groundwater data, surface water data and biological data were collected and analyzed.

Groundwater Data – Scott Alexander

Ground waters and surface waters were analyzed for major and minor chemical elements to differentiate water sources and pathways. Determination of the source and pathway of waters allows identification of causes leading to low oxygen levels in Hardwood Creek. Supervision of sampling procedures and analytical services were provided by Scott C. Alexander at the University of Minnesota Department of Geology & Geophysics.

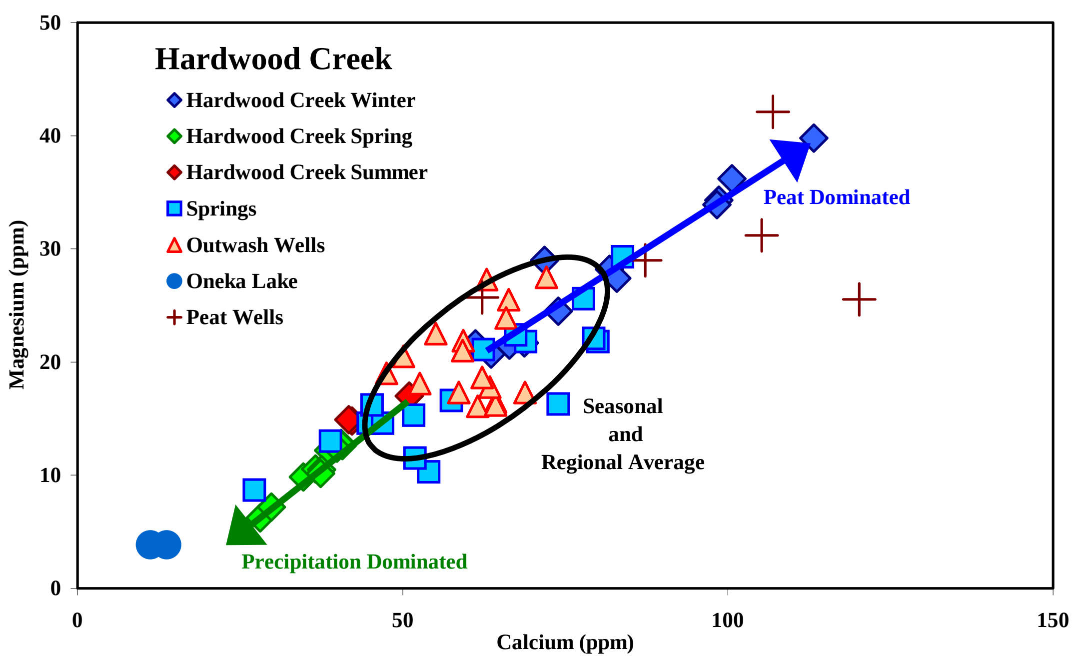
Cations were analyzed by ICP-MS utilizing EPA 200.8 methods. Anions were analyzed by Ion Chromatography following EPA 300.0 methods.

Inorganic Chemistry:

Calcium and magnesium are the two dominant cations in the water samples collected from the Hardwood Creek study area. Both calcium and magnesium are primarily derived from carbonate rocks in the underlying glacial drift. The dominance of the glacial drift results in the linear relationship between calcium and magnesium with most of the Hardwood Creek samples falling along one line (Figure 1).

In the wettest part of the year, following snowmelt and augmented by spring rains, calcium and magnesium reach the lowest levels of the year. This influx of precipitation water brings well-oxygenated surface waters into Hardwood Creek. These well-oxygenated waters also have relatively low carbon dioxide levels typical of atmospheric levels ($10^{-3.5}$ atmospheres CO_2). The Oneka Lake points in Figure 1 are an extreme example of a precipitation-dominated system with very low carbon dioxide levels. Low carbon dioxide levels lead to lower solubility of calcium and magnesium in solution creating the spring trend line towards lower calcium and magnesium (Figure 1). During the late summer, as precipitation generally declines, calcium and magnesium levels rise back to seasonal averages. At these lower water levels, the base flow is dominated by natural ground water recharge through the peat sediments.

Figure 1. Calcium and Magnesium Relationship in Hardwood Creek, MN



During the winter, the primary source of water to Hardwood Creek is recharging groundwater. This water interacts extensively with the underlying peat deposits. These peat deposits are up to 30 feet thick through the upper reaches of Hardwood Creek (the area above Highway 61). Peat deposits occur where the accumulation rate of biologic materials is greater than the decomposition rate. Low wet areas can have very high biologic productivity rates and saturated materials restrict oxygen movement, preventing decomposition. The peat deposits, particularly near the surface, are slowly decaying and in the process release large amounts of carbon dioxide. This decomposition process is slowed down in the winter by low temperatures and in the spring and fall by high water levels that restrict oxygen movement within the peats. Carbon dioxide levels within the peat may exceed levels of $10^{-1.0}$ atmospheres or about 300 times greater than atmospheric levels. The increase in carbon dioxide levels increases the solubility of calcium and magnesium. This increased solubility creates elevated levels of calcium and magnesium in Hardwood Creek during the winter.

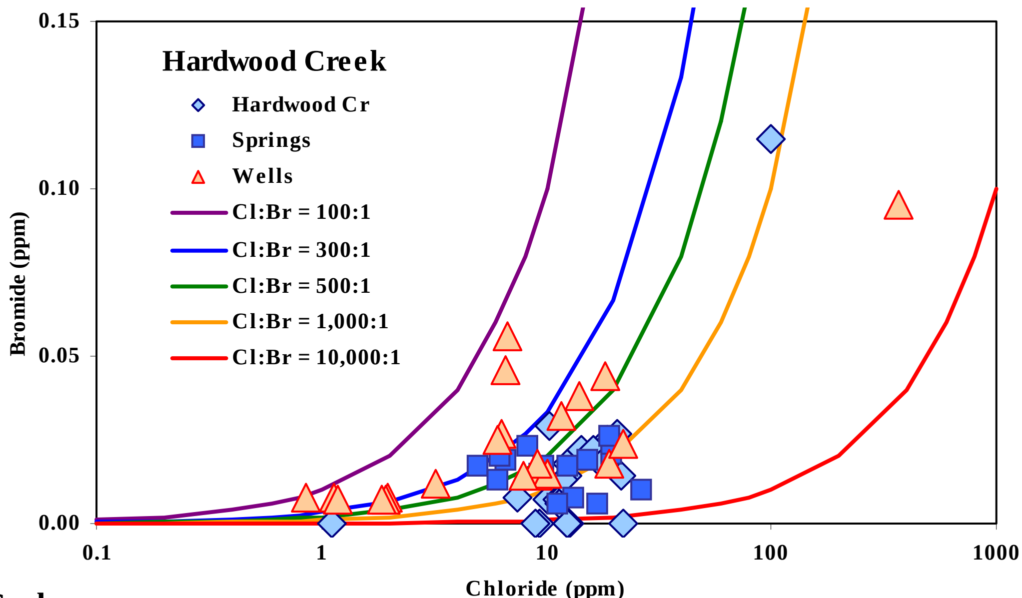
During the late summer period, some of the lowest oxygen levels are recorded in the upper reaches of Hardwood Creek. Decomposition rates are the highest when water levels are the lowest, allowing more oxygen to penetrate into the peat deposits and warm temperatures to accelerate biologic activity. Both of these processes release more organic carbon into Hardwood Creek consuming large amounts of the available in-stream oxygen. The low stream gradients above Highway 61 limit advective mixing of atmospheric oxygen and higher water temperatures restrict the solubility of oxygen.

Chloride and bromide are commonly used as conservative indicators of source waters. Both of these anions tend to accumulate in solution and are not easily removed. Natural sources of chloride in Minnesota are dominated by precipitation. Both rain and snow originate primarily as seawater and carry a chloride to bromide ratio reflective of the sea (Cl:Br = 300:1). Concentrations of chloride in rainwater are generally less than 0.5 ppm. These rainwater concentrations of chloride are elevated by evaporation and transpiration to levels ranging from 1 to 20 ppm. Lower chloride levels (1 to 5 ppm) are typically found in wetland environments while higher levels (5 to 20 ppm) are more indicative of upland recharge environments. Wetland and upland evapo-transpiration concentrated waters typically have Cl:Br ratios between 100:1 and 500:1.

Average chloride levels in Hardwood Creek are around 10 ppm indicating recharge from nearby upland areas dominated by the Superior Lobe glacial moraine (Figure 3). A few samples associated with highways in close proximity to the creek have elevated chloride levels. The reach of Hardwood Creek below Highway 61 receives runoff from both Highway 61 and Highway 35E; both roads are kept ice-free during the winter months by the application of road salt. Road salt is mined from halite deposits with very pure chloride (Cl:Br > 10,000:1). Intermediate Cl:Br ratios of 1,000 to 2,000:1 are commonly associated with human and agricultural sources.

Results plotted on the chloride versus bromide graph show two main trends along the Cl:Br ratio line (Figure 2). Data plotted along the 300:1 line consists of mainly wells and springs. A second trend follows the 1,000:1 line and is composed of samples from wells, springs, and Hardwood Creek. A few samples are found along the chloride axis and are related to road salt; they are samples collected near County Road 4 or downstream of Highways 61 and 35E. The trend of data points parallel to the 1,000:1 line indicates anthropogenic impacts are present in the spring waters originating from the adjacent Superior Lobe Moraine that discharge into Hardwood Creek.

Figure 2. Chloride and Bromide relationship in Hardwood Creek, MN

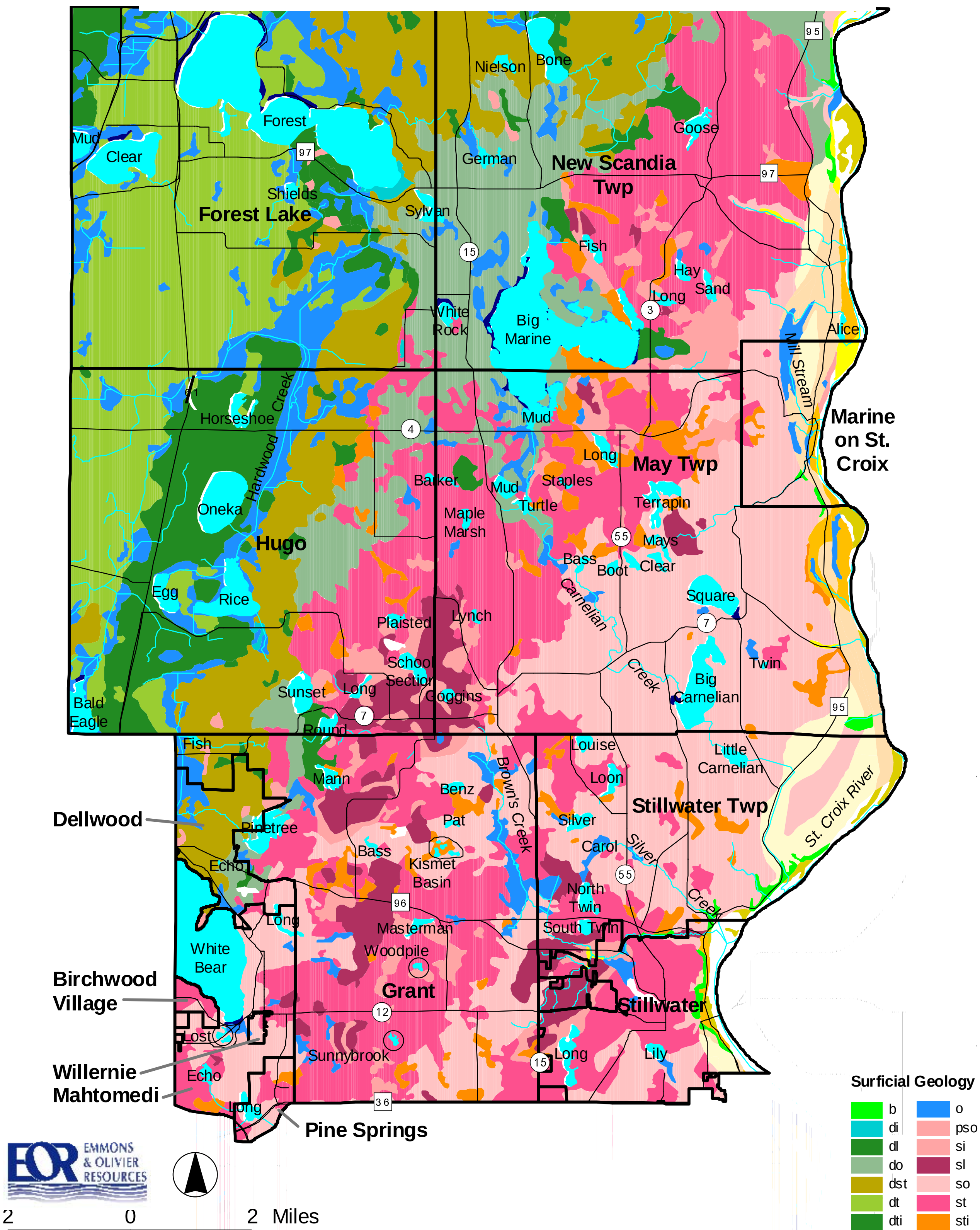


Geology:

The path of Hardwood Creek follows the trend of the St. Croix Moraine from Rice Lake to approximately 180th Street (Figure 3). The surficial geology of this area is composed of outwash of both Grantsburg Sublobe Deposits of the Des Moines Lobe and Superior Lobe Deposits. Superior Lobe deposits are shown in pinks and reds on the Quaternary Surficial Geology Map (Figure 3). Des Moines Lobe deposits are shown in green tones.

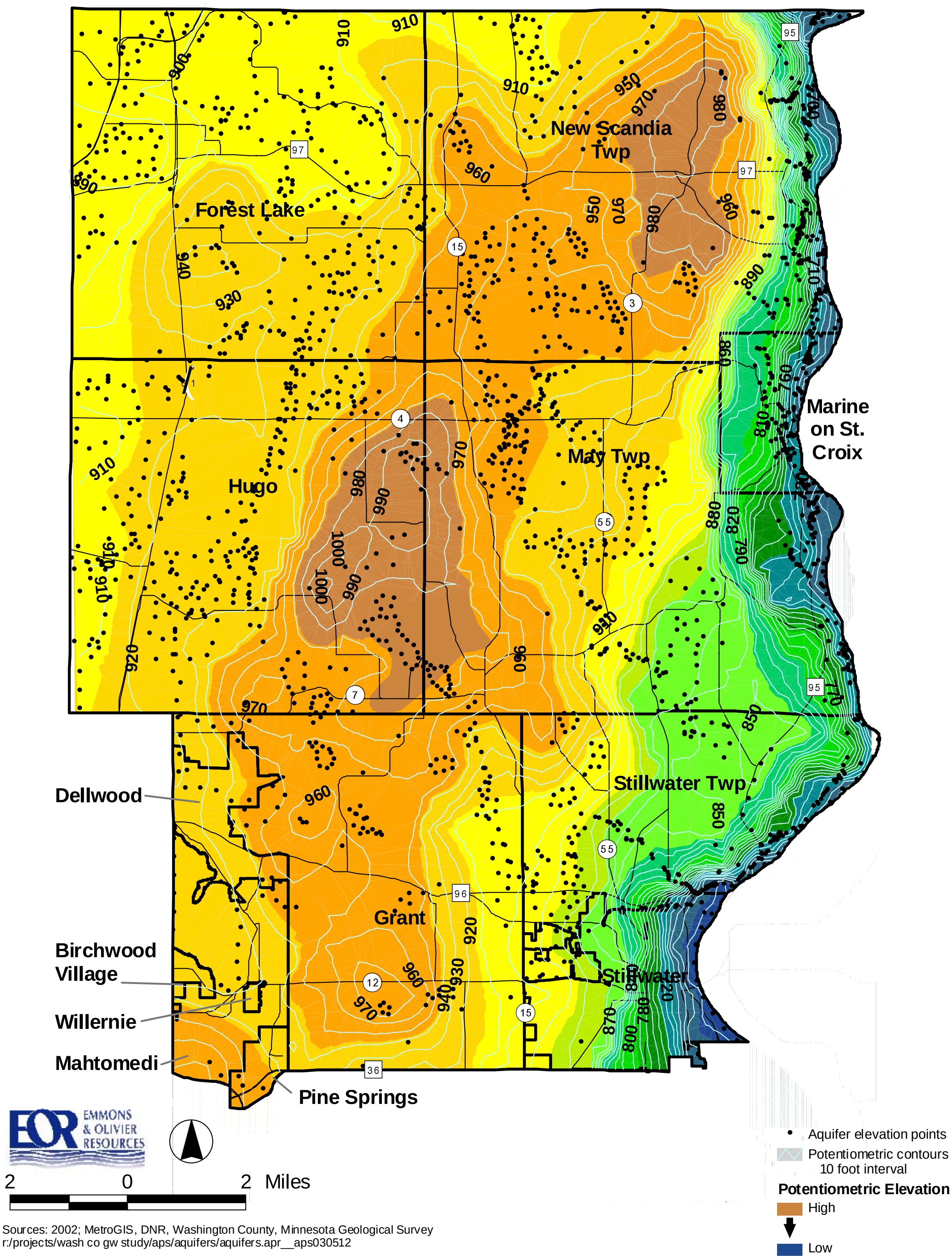
Quaternary groundwater contours developed as part of the Integrating Groundwater and Surface Water Management Study for Northern Washington County indicate that the recharge area for Hardwood Creek mainly comes from Superior Lobe outwash and tills to the east (Figure 4). Waters emerging from several well-developed peat lands to the north and east of Rice Lake contribute to the flow of Hardwood Creek.

Figure 3. Surficial Geology of Northern Washington County, MN



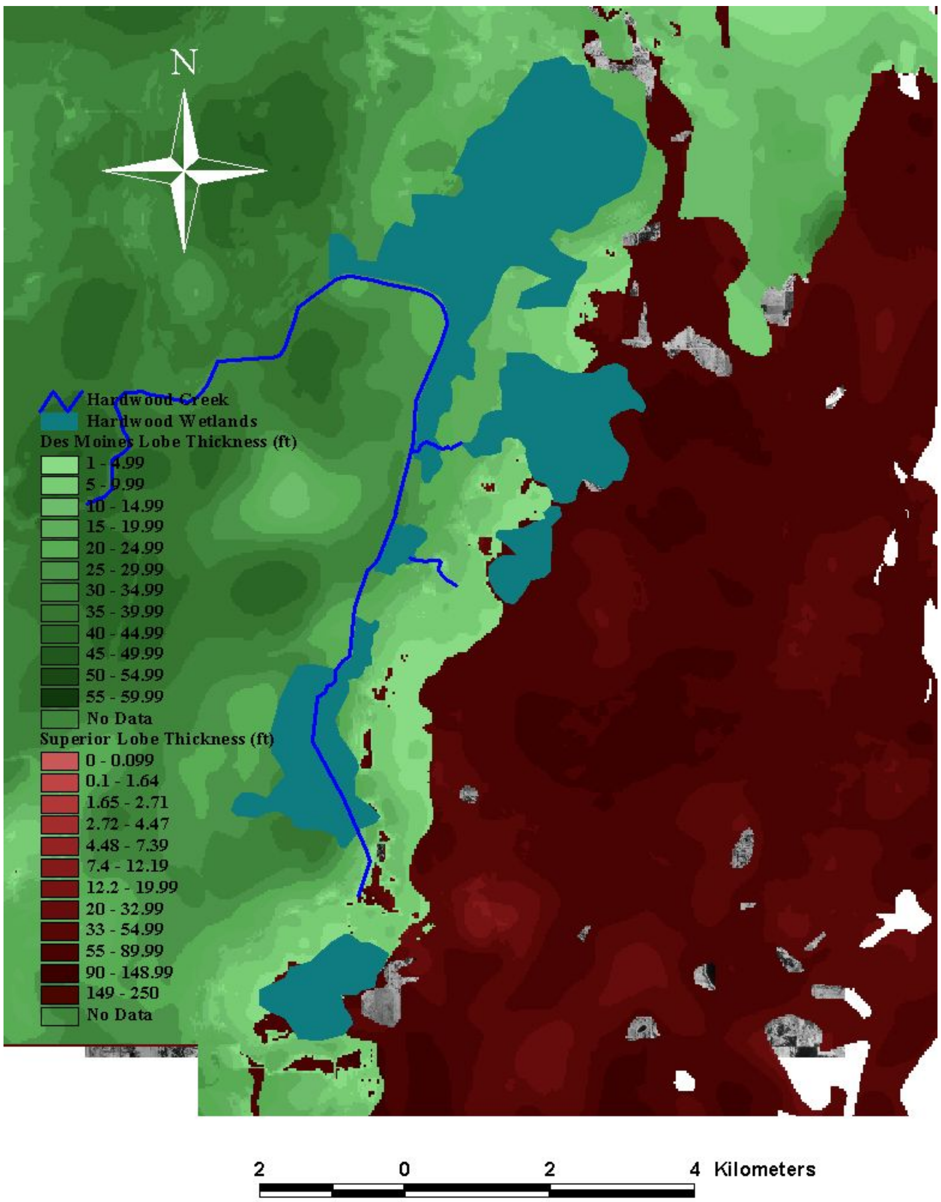
Source: 2002; Minnesota Geological Survey, DNR, Washington County, MetroGIS
r:/projects/wash co gw study/final_report_maps.apr__jlo030429

Figure 4. Quaternary Aquifer Groundwater Contours of Northern Washington County.



A till thickness map was generated with data from the Minnesota Geologic Survey as part of the Northern Washington County Study (Figure 5). Large wetlands, shown as gray areas in Figure 5, associated with Hardwood Creek originate near areas of thin glacial tills. The thin glacial tills hosting the wetlands are shown as light green areas on the figure. High permeability sands in these thin glacial tills support wetlands around Rice Lake, Tingley Springs and the Paul Hugo Wildlife Management Area. A large hydraulic gradient through the Des Moines Lobe tills and peat deposits in the area supports a number of springs between 157th and 165th Streets. Peat deposits in this reach of Hardwood Creek are up to 30 feet thick (EOR, 2004).

Figure 5. Till thickness near Hardwood Creek, MN



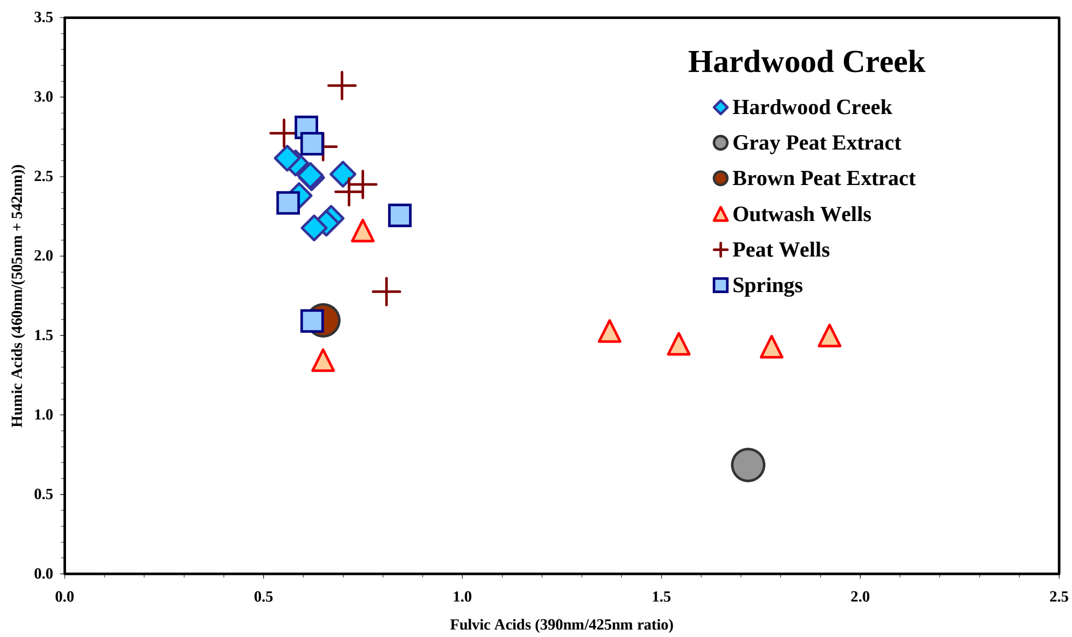
Organic Chemistry:

Sub-samples of the chemical analyses were analyzed on a Shimadzu RF-5000 scanning spectrofluorophotometer. Fluorescent intensity was measured at a Δλ of

75 nm with 5 nm bandwidths for both excitation and emission wavelengths. Peak areas were compared to a Nordic Reservoir NOM (Natural Organic Matter) standard reference sample obtained from the International Humic Substances Society. The ratios of peak area for the two main fulvic acid peaks at 390 nm and 425 nm were compared to the main humic acid peaks at 460 nm to 505 nm plus 542 nm (Figure 7).

Two representative peat samples, a dark reddish brown (5YR 3/2) upper layer peat and a gray (10 YR 5/1) deeper reduced layer peat, were collected at a site near Harrow Avenue. Samples of peat deposits removed near Harrow Avenue were extracted with a 0.1M KCl solution in de-ionized water for comparison. The deeper gray peat extract sample has a fulvic to humic acid ratio similar to outwash wells sampled near Hardwood Creek (Figure 7). This similar signature demonstrates that these "gray peat" organics may be derived from recharge areas on the adjacent Superior Lobe Moraine. The cluster of data points visible on the left side of the figure illustrate that the Hardwood Creek and peat well samples show similar chemical signatures to the brown peat extract sample. These data reveal that a significant fraction of the organic material in Hardwood Creek is derived from the peat deposits immediately below the creek.

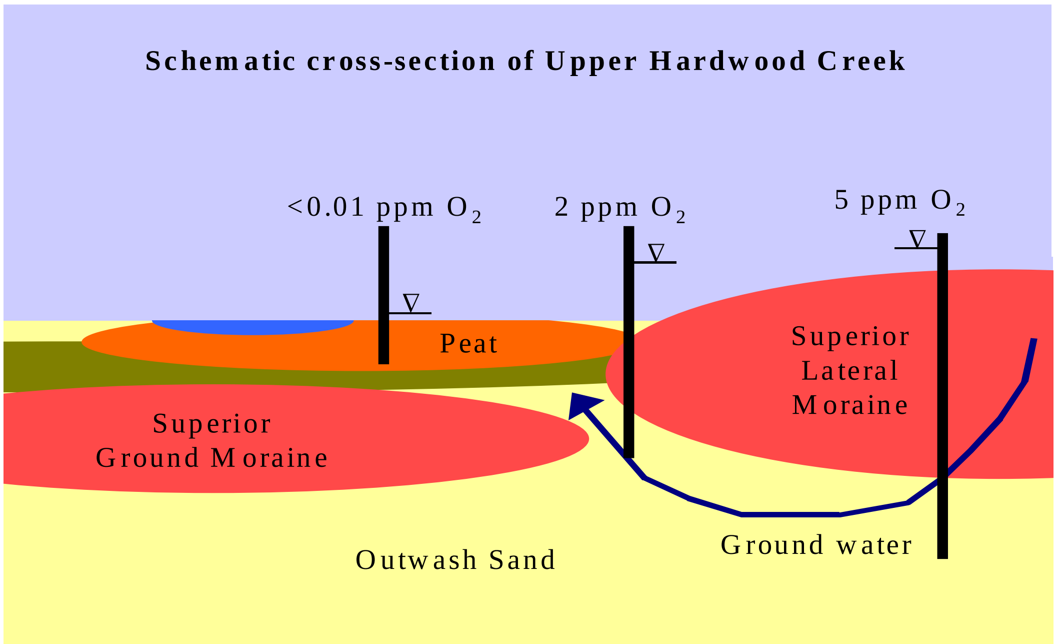
Figure 7. Ratios of Fulvic to Humic Acid in Hardwood Creek, MN



Conceptual Diagram and Description:

Poorly oxygenated waters originating on the Superior Lobe moraine flow westward along a gradient to Hardwood Creek. Waters recharging Hardwood Creek flow through deep outwash deposits, Des Moines Lobe sediments, and more recent peat deposits where they are stripped of any residual oxygen by organic carbon. This low in dissolved oxygen water helps preserve the extensive peat deposits and supports the base level water flow in Hardwood Creek (Figure 6).

Figure 6. Schematic cross-section of Upper Hardwood Creek, MN



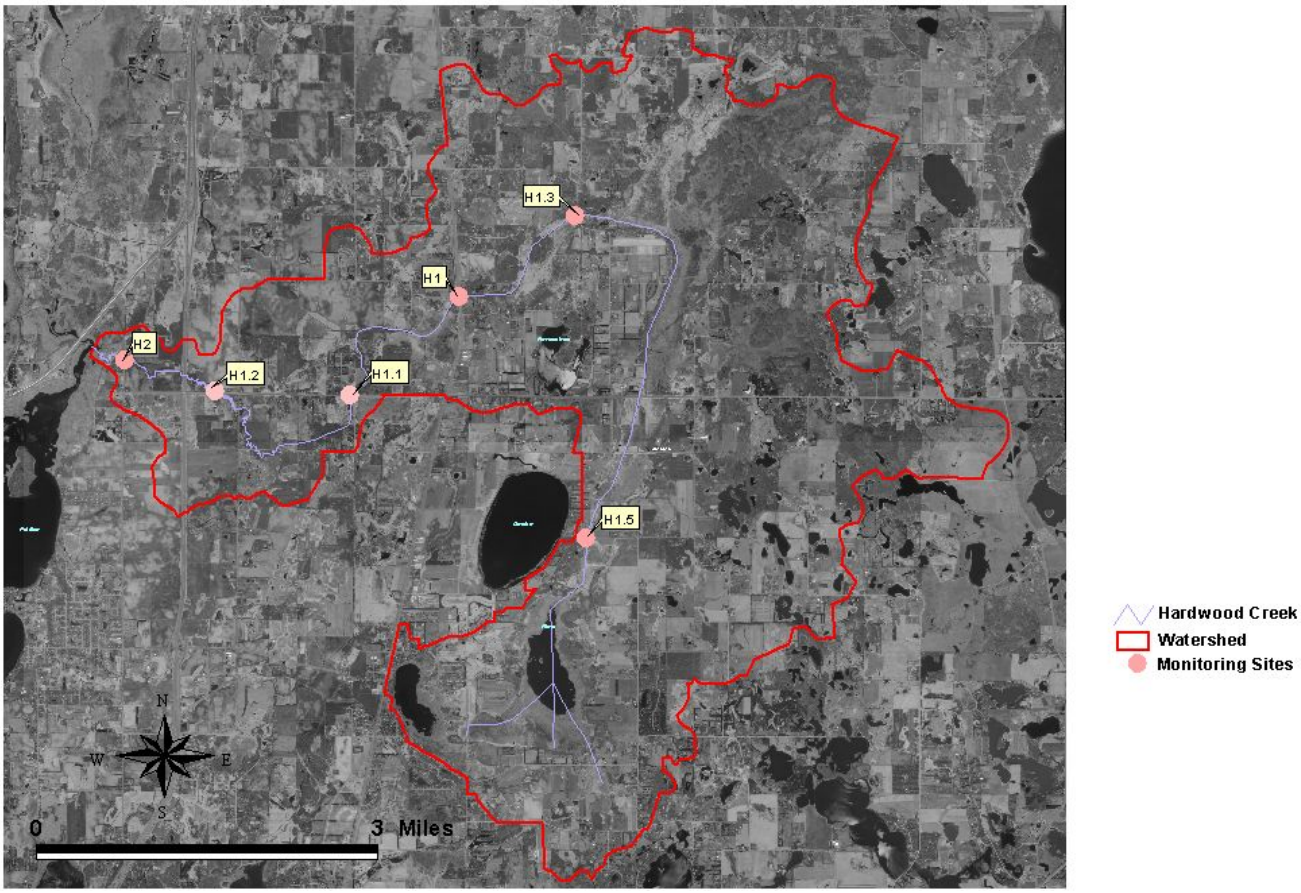
Ground Water Conclusions:

- Release of organics from underlying peat deposits is a natural process.
- Low oxygen levels are related to low flow periods in Hardwood Creek during the summer.
- Warm temperatures in the summer increase the natural release of organics creating higher oxygen demands within Hardwood Creek.
- Lower water levels expose more of the peat deposits to atmospheric oxygen further increasing the rate of decomposition.
- In winter water can adsorb atmospheric oxygen more readily due to the higher solubility of oxygen in cold water, although this process may be restricted by ice cover. Cold temperatures in the winter reduce the rate of organic decomposition slowing the release of organic carbon and therefore reducing oxygen demand in-stream.
- Ditching efforts to lower water levels could create additional impacts on oxygen levels in Hardwood Creek.

Surface Water Data

Water quality monitoring was conducted at six sites along Hardwood Creek in 2004 (Figure 8).

Figure 8. 2004 Water Quality Monitoring Sites along Hardwood Creek

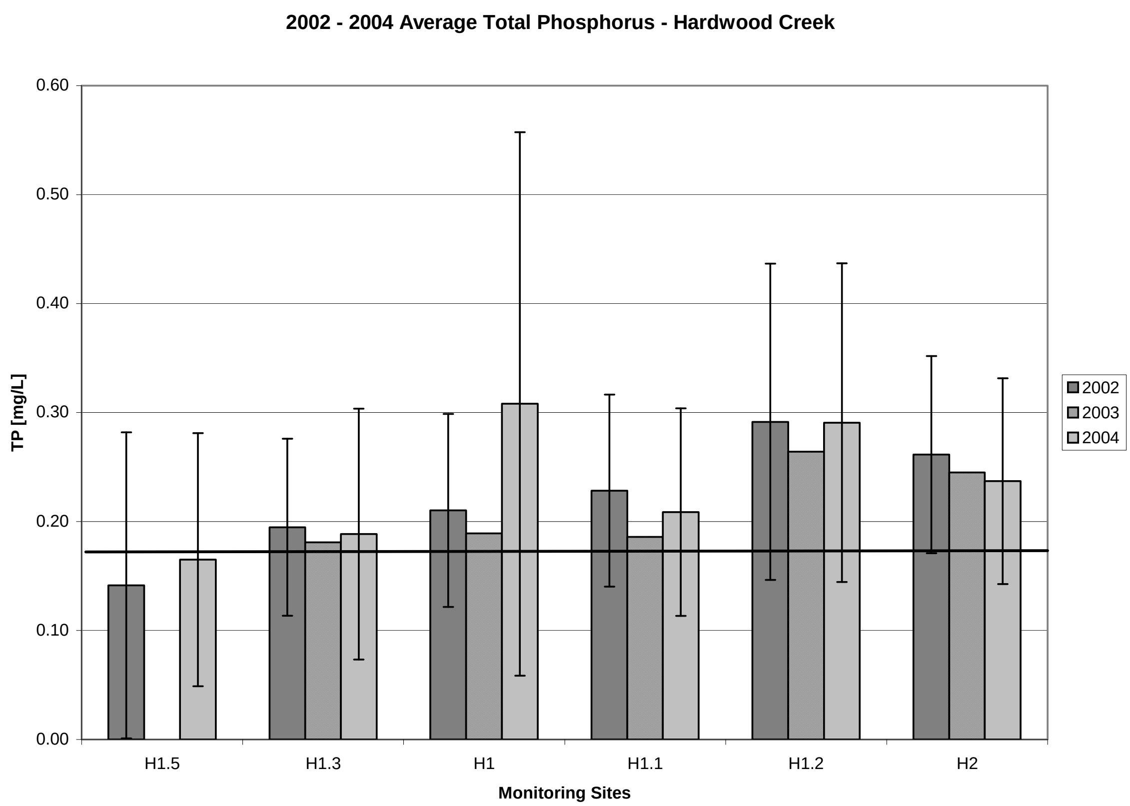


Monitoring at the six sampling sites began on ice out which was March 24, 2004. Due to the nature of this report, only total phosphorus, nitrite/nitrate, ammonia, dissolved oxygen (DO) and biological oxygen demand (BOD) are discussed. Chlorophyll-a was not collected on direction from the Technical Advisory Committee and personal communication with Steve Heiskary (2003).

Phosphorus

Concentrations of total phosphorus were compared to historic data collected on Hardwood Creek as well as to ecoregion expectations (McCollor and Heiskary, 1993), which are defined as the 75th percentile of data collected from 1970-92 (.17mg/L) at designated minimally impacted sites in the North Central Hardwood Forest Ecoregion. For the months of June – October, all monitoring sites had concentrations similar to previous years. However, all sites with the exception of H1.5 exceeded the ecoregion expectation (Figure 9).

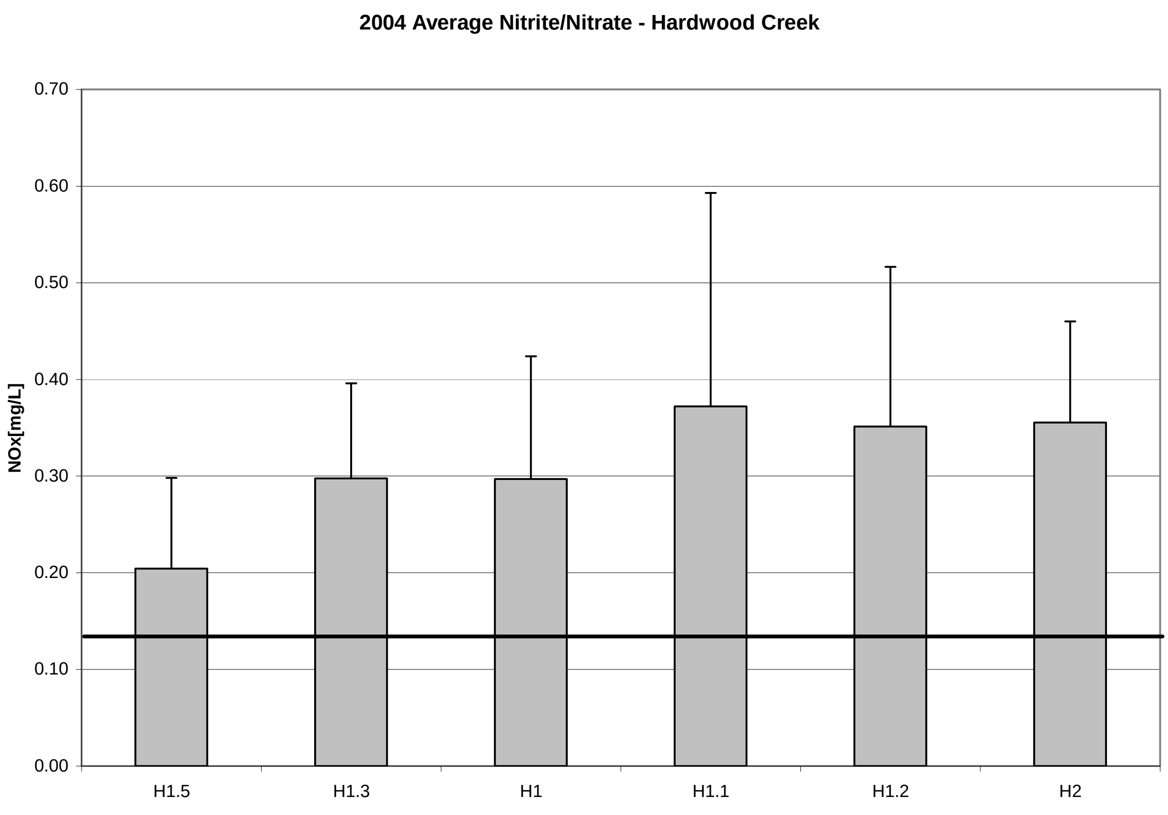
Figure 9. Average Total Phosphorus Concentrations in Hardwood Creek, MN



Nitrogen

Concentrations of nitrate + nitrite nitrogen (NO_2+NO_3) were compared to ecoregion expectations (McCollor and Heiskary, 1993). All monitoring sites exceeded the ecoregion expectation of 0.12mg/L of NO2+NO3 (Figure 10). The water quality standard for un-ionized ammonia for Hardwood Creek is 40 µg/L. None of the monitoring stations exceeded this water quality standard.

Figure 10. Average Nitrite/Nitrate Concentrations in Hardwood Creek, MN



Dissolved Oxygen

YSI continuous flow meters were installed at monitoring sites H1.5, H1.3, and H2. The average daily DO readings are displayed in Figures 11-13. Probes were cleaned and calibrated on a bimonthly basis. Results indicate that during the summer months, dissolved oxygen is below the standard of 5 mg/L at monitoring sites H1.5 and H1.3. This is consistent with the groundwater data for this area indicating that organic loading from the peats is high. A monitoring station H1.5, dissolved oxygen reached a daily average of less than 1 mg/L during the month of August. RCWD did perform minor maintenance from Rice Lake to H1.5 during the winter of 2004. This effort could have exacerbated already low oxygen levels in this section of the creek. At monitoring site H2, dissolved oxygen occasionally fell below the standard during the months of August and September.

Figure 11. Daily Average Dissolved Oxygen at H1.5 along Hardwood Creek, MN

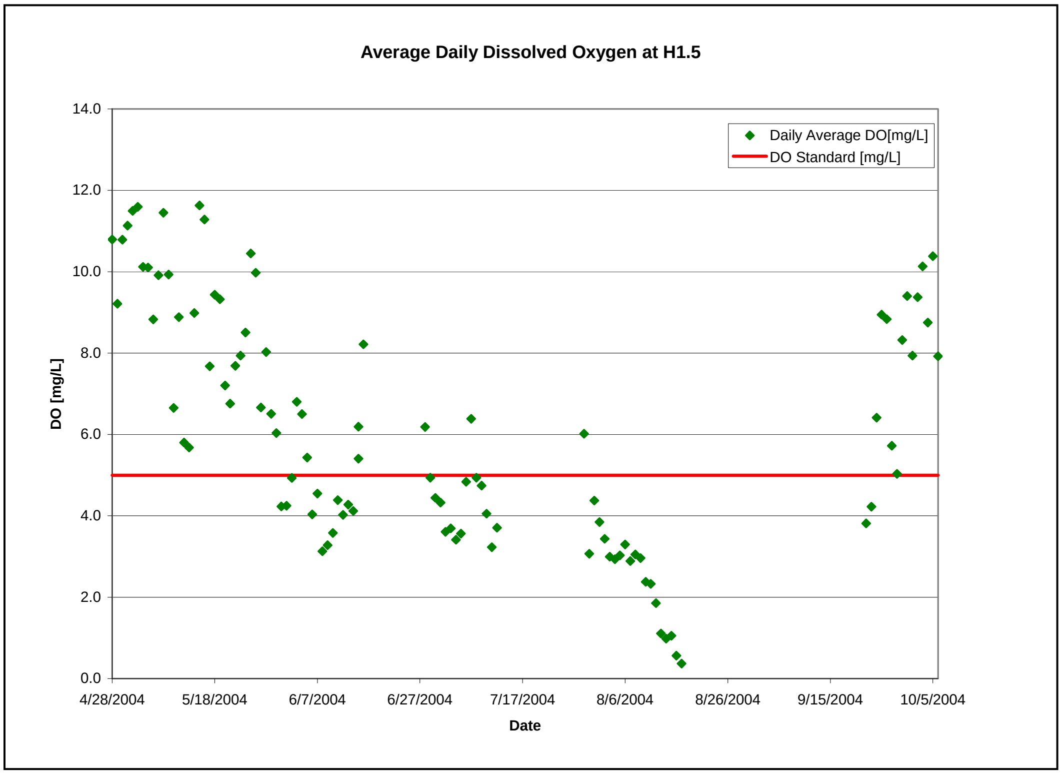


Figure 12. Daily Average Dissolved Oxygen at H1.3 along Hardwood Creek, MN

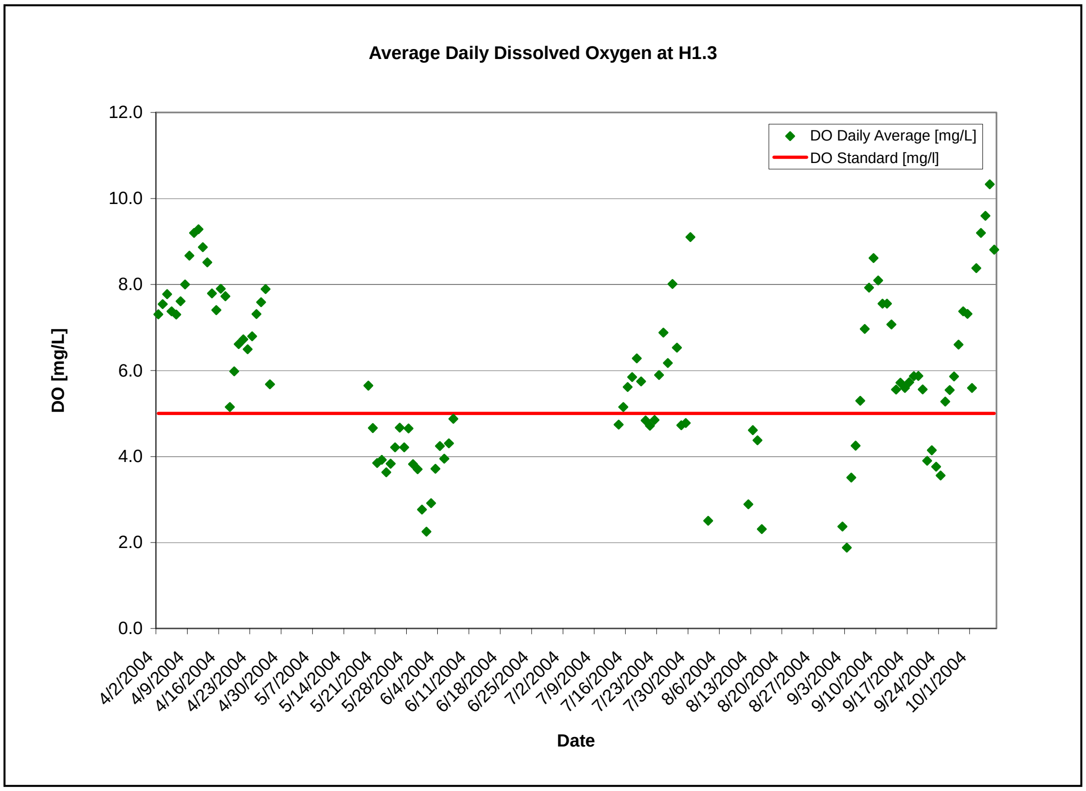
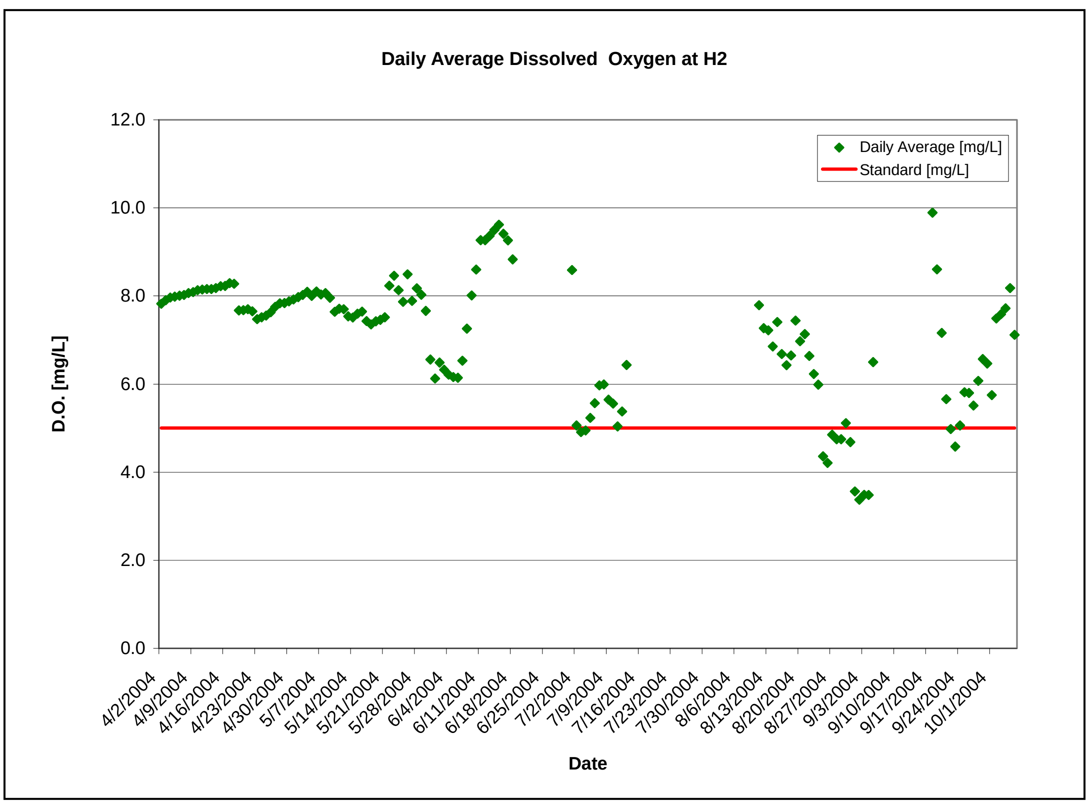
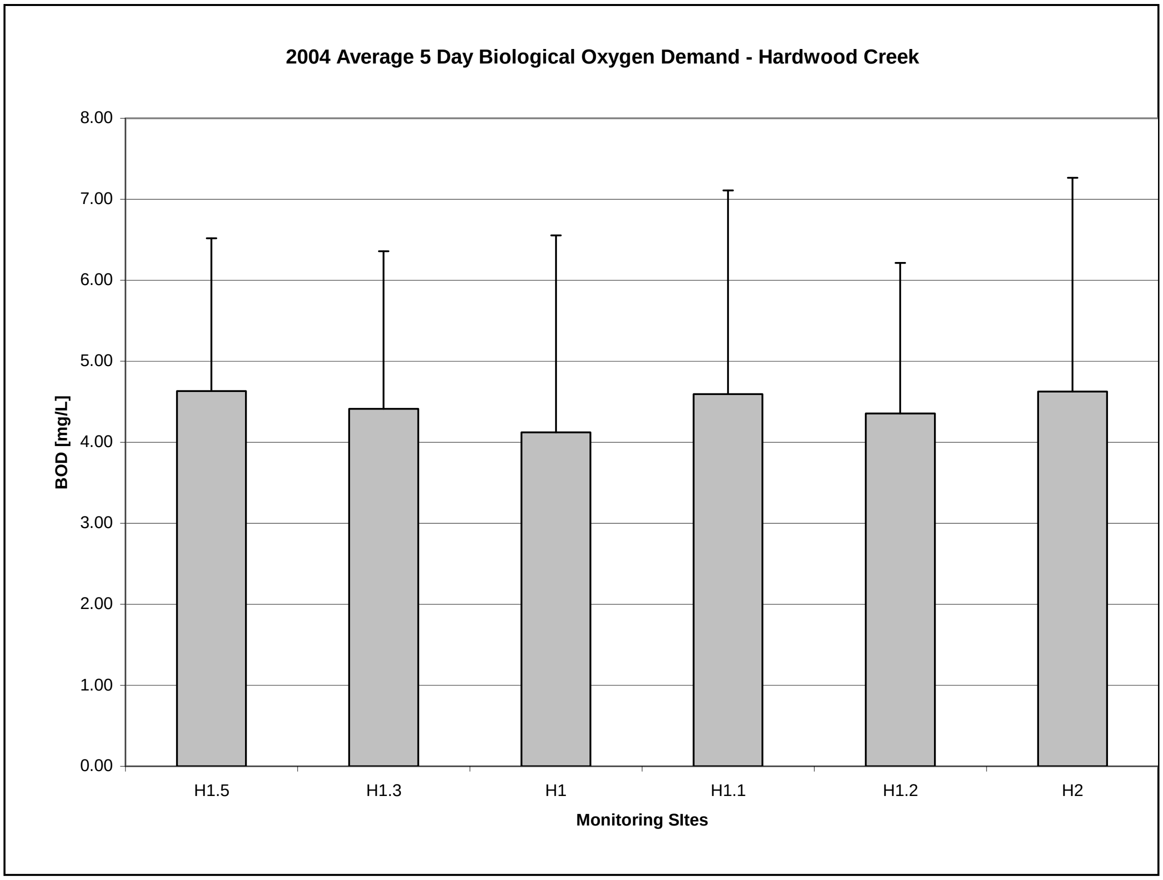


Figure 13. Daily Average Dissolved Oxygen at H2 along Hardwood Creek, MN



BOD measurements were taken at each monitoring site. Concentrations of BOD were compared to ecoregion expectations (McCollor and Heiskary, 1993). All monitoring sites exceeded the ecoregion expectation of 3.3 mg/L at least 50% of the time (Figure 14). This number is based on 7 samples per site with no samples taken during the months of July or August.

Figure 14. 2004 Average BOD_5 for Hardwood Creek, MN



Surface Water Conclusions

- Nutrient concentrations are high at all monitoring stations along Hardwood Creek. The trend is for concentrations to increase with each downstream monitoring site until H-2.
- In 2004, dissolved oxygen was below the 5mg/L standard 46% of the time at H1.5, 36% of the time at H1.3 and 10% of the time at H2.
- Biological oxygen demand was above the ecoregion expectation of 3.3 mg/L at least 50% of the time at all monitoring sites indicating that there is organic enrichment in Hardwood Creek.

Biological Data – Len Ferrington

Surface Floating Pupal Exuviae and Macroinvertebrates

Dr. Len Ferrington from the University of Minnesota Department of Entomology was contracted to evaluate Chironomidae in Hardwood Creek. Dr. Ferrington collected surface floating pupal exuviae (SFPE) that were left behind on the water surface after adults emerge from the water. This method is not routinely employed in the United States for water quality assessments and therefore is explained in detail in Attachment 1. In addition to collecting SFPE, Dr. Ferrington also worked with a graduate student, Adam Sealock, who collected macroinvertebrates along Hardwood Creek using a dip net. The data used for this analysis were generated using a standard, rapid bioassessment field methodology. The method uses dip-nets (DN) employed in a consistent manner and is also described in Attachment 1.

Detailed explanations are provided for metrics that were calculated from the SFPE and DN samples. Information in this report summarizes interim results for SFPE samples collected in April, June and September 2004 and DN samples collected in June, 2004. Consequently, the results provided in this interim report, although based on extensive data sets, should be considered as preliminary in scope. Raw data by sample site and sample date are available upon request.

Metrics Calculated from Collections of SFPE and DN

The following eight metrics for each of the sample sites investigated in this project were calculated: (1) cumulative species richness by sample site (SFPE and DN); (2) Brillouin's Diversity Index (based on cumulative totals of all samples per site- SFPE and DN); (3) biotic index values primarily based on species tolerances used for the Midwest (Ohio) or Upper Midwest (WI) (SFPE and DN); (4) the ratio of total specimens of Chironomini to Orthocladiinae (SFPE); (5) the percentage of taxa per site that are considered to be primarily lotic in terms of habitat preference, primarily lentic in terms of habitat preference or are considered to be habitat generalists (SFPE); (6) the percentage of EPT (DN); (7) the percentage of Chironomidae (DN); and (8) percent dominance (DN). Definitions and results of all the above metrics are provided below.

Cumulative Species Richness - Cumulative species richness represents the total number of species present in all three DN samples for a given sample site. This metric is sensitive to the seasonal changes in Chironomidae emergence and macroinvertebrate life cycles and could change when samples for other months are included in the final data set.

For SFPE samples, the species richness of sites in the upper portion of Hardwood Creek is consistently and markedly lower than the species richness detected at sites in the lower portion of the creek. For DN samples, species richness is higher in the upper portion of Hardwood Creek than in the lower portion (Table 1). The higher richness values at the sites in the upstream portion of the Hardwood Creek largely result from the greater numbers of leeches and mollusks at these sites. For instance, only two species of leeches, *Glossiphonia complanata* and *Helobdella stagnalis,* were found in sites in the lower reach of Hardwood Creek. In contrast, six species of leeches occurred at sites in the upstream portion of the creek.

Table 1. Cumulative Species Richness of SFPE and DN samples - Hardwood Creek, MN

Sample Site	Numbers of Specimens Collected	Cumulative Species Richness for SFPE	Cumulative Species Richness for DN
Site H-2	206	36	14
Site H-1.2	152	34	11
Site H-1.1	155	40	14
Site H-1	699	47	18
Site H-1.3	84	23	15
Site H-1.5	1578	26	28

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 (Table 2).

For purposes of interpretation, empirical results from numerous studies using DN collections (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 streams with excellent to very good water quality. Values of less than 1.000 nats generally occur only when very significant alterations of macroinvertebrate 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. We are not aware of any comprehensive empirical data sets from a wide array of streams near our sample sites that report species diversity values for multiple samples at several sites. Consequently the cut-off values used for streams in Kansas are used as reference levels for interpreting the diversity values provided in this report.

SPFE results show that the three highest Brillouin's Diversity Index values are for sites in the lower portion of Hardwood Creek, and are indicative of excellent to very good water quality when applying the interpretive standards for streams in Kansas. The Brillouin's Index value for Site H1.5 is unexpectedly high and, according to the standards applied for interpreting this index in Kansas streams, indicates excellent to very good water quality. Closer inspection, however, of the species collected at this site show that several species are more characteristic of lentic habitats, are habitat generalists, or are semi-terrestrial species that or likely to be more common in boggy habitats. The combination of these species with a subset of predominantly lotic species results in the elevated index values.

Analysis of DN samples show that the Brillouin's Diversity Index values for all sites in Hardwood Creek are low. It is likely that the consistently low values of this metric are related to the sampling approach that uses stratification units and single dips rather than multiple dips from an array of microhabitats that are combined into one large sample. As samples from other stratification units are processed for this project, the resulting data can then be sequentially amalgamated into successively larger "composited samples" and the influence that stratification units and multiple dips have on this metric can be determined.

Table 2. Brillouin's Diversity Index of SFPE and DN samples - Hardwood Creek, MN

Sample Site	Numbers of Specimens Collected	Brillouin's Diversity Index for SFPE (nats)	Brillouin's Diversity Index for DN (nats)
Site H-2	206	2.742	1.325
Site H-1.2	152	1.475	1.363
Site H-1.1	155	2.836	1.660
Site H-1	699	2.776	1.422
Site H-1.3	84	1.395	1.7
Site H-1.5	1578	1.329	1.234

Biotic Index - Individual species- level or genus- level tolerances are required to calculate biotic index values for collections of macroinvertebrates. Barbour et al. (1999) discuss the concepts and underlying assumptions related to calculating biotic indices, and provide lists of taxa and their associated tolerance values for organic enrichment that have been developed for several regions of the United States. Two regions, the Midwest Region and Upper Midwest Region, are close to our project area and values for taxa in these two regions can logically serve as estimates of tolerance that should be appropriate for our biota. The values for the Midwest were developed in Ohio and those for the Upper Midwest primarily derive from research by William Hilsenhoff working on streams and rivers in Wisconsin. On the basis of geographic proximity the values for the Upper Midwest would seem to be the most appropriate, however several of the taxa that occur in Hardwood Creek are considered as more tolerant of organic enrichment in the scheme developed by Hilsenhoff compared to the tolerance values provided for Ohio. Because of this disparity in the two schemes, the biotic index values are calculated using the tabled species' tolerance values for the Midwest or for the Upper Midwest that seem most appropriate based on best professional judgment and two Biotic Index values are provided for each sample site.

Hilsenhoff (1987) provided a table for interpreting biotic index values. According to his scheme, index values between 0.00 and 3.50 are considered to represent excellent water quality. Index values between 3.51 and 4.50 are considered to represent very good water quality, with possible slight organic enrichment. Index values between 4.51 and 5.50 are considered to represent good water quality, with some organic enrichment. Index values between 5.51 and 6.50 are considered to represent fair water quality, with fairly significant organic enrichment. Index values between 6.51 and 7.50 are considered to represent fairly poor water quality, with significant organic enrichment. Index values between 7.51 and 8.50 are considered to represent poor water quality, with very significant organic enrichment. Index values between 8.51 and 10.00 are considered to represent very poor water quality, with severe organic enrichment.

For SFPE samples, the two sets of Biotic Index (BI) values show similar trends but substantially different magnitudes. When comparing BI scores between SFPE and DN samples, SFPE samples indicate that Hardwood Creek has good water quality with slight organic enrichment. DN samples indicated that Hardwood Creek has fair water quality with fairly significant organic enrichment. In both cases, no site along Hardwood Creek stands out as significantly more enriched than another. However, in both cases site H1.5 does have one of the highest BI values. That these higher values could be exacerbated by the minor maintenance of this stretch that occurred during the winter of 2004. In all instances, the BI indicates that all sites along Hardwood Creek are experiencing some organic enrichment.

Table 3. Biotic Index of SFPE and DN samples - Hardwood Creek, MN

Sample Site	Numbers of Specimens Collected	Biotic Index for SFPE samples based on tolerances to organic enrichment		Biotic Index for DN samples based on tolerances to organic enrichment	
		OH	**(WI)**	**OH**	**(WI)**
Site H-2	206	4.24	(6.33)	6.07	(6.20)
Site H-1.2	152	4.65	(6.07)	5.91	(6.16)
Site H-1.1	155	4.16	(6.13)	5.77	(5.95)
Site H-1	699	3.91	(6.01)	6.28	(6.38)
Site H-1.3	84	3.66	(6.21)	6.44	(6.49)
Site H-1.5	1578	4.45	(8.55)	7.63	(7.63)

Ratio of Chironomini to Orthocladiinae - The family Chironomidae is divided into eleven subfamilies that are further divided into tribes, genera and species. Oliver et al. (1990) recorded 205 genera and 1051 species for North America, but recent descriptions of new species and revisionary monographs increase the total to approximately 1200 species. The species belong to seven subfamilies and 14 tribes. Several species of some of the subfamilies are restricted to aquatic habitats that are high in average oxygen concentrations and these species are conspicuously absent or reduced in number in habitats that have lower oxygen concentrations, either naturally or as a result of organic loading. Examples of these subfamilies are Diamesinae, Prodiamesinae and Orthocladiinae. In contrast, one of the subfamilies, Chironominae, contains several species that have high concentrations of hemoglobins as larvae and, consequently, can survive lowered concentrations of dissolved oxygen in surface waters. Many of the species within the tribe Chironomini, which is one of three tribes of the subfamily Chironominae, often predominate in low oxygen habitats and can dominate the chironomid community in streams that are organically enriched (e.g., Ferrington 1987, 1989, 1990; Ferrington and Crisp 1989). Consequently it is helpful to determine the percent of species and specimens of Chironomini and Orthocladiinae for each sample site when evaluating water quality conditions using collections of SFPE to assess Chironomidae.

In Minnesota species of Chironomidae that are classified into two other tribes of Chironominae, the tribe Tanytarsini and the tribe Pseudochironomini, are known to occur. The tribe Pseudochironomini consists of only one genus in North America, Pseudochironomus, and the species typically are not common in habitats similar to the ones investigated in this project. Species of the other Tribe, Tanytarsini, commonly occur in springs and small streams with higher oxygen concentrations so they can be considered, along with Orthocladiinae, as indicators of habitats that lack increased levels of organic enrichment.

Orthocladiinae generally comprise about 50% of taxa and usually a majority of specimens (>50%) in unimpacted small order streams similar to Hardwood Creek. However, the actual values are influenced by type of substrate, velocity and time of year that samples are collected. Repeated collections on at least monthly intervals generally provide adequate resolution of the composition and relative abundances of Orthocladiinae and Chironomini. Slower velocities typically result in lower species and numbers of Orthocladiinae, combined with corresponding increases in Chironomini. Similarly, stream substrates that are predominantly sand and/or fine particulate organic matter or muds favor higher values for Chironomini and lower values for Orthocladiinae. Higher current velocities, more coarse substrates and/or well-developed riffles can result in higher values for Orthocladiinae and correspondingly lower values of Chironomini.

In small streams with excellent to very good water and habitat quality the ratios of Chironomini to Orthocladiinae are generally 1.0 or less when based on taxa and 3.0 or less when based on specimens. Streams that are stressed by higher levels of organic loading can see ratios exceed 3.0 and 30.0 respectively. None of the ratios found in Hardwood Creek suggest very high levels of organic loadings. However, compared to other sites sampled in the Twin Cities Metro Area such as Minnehaha Creek and Brown's Creek, organic loading is higher in Hardwood Creek (Table 4). In addition, according to these ratios there is no significant difference in organic enrichment between sites. This is consistent with the BI results and indicates that what enrichment there is has little recovery throughout the system.

Table 4. Ratio of Chironomini to Orthocladiinae Taxa in Hardwood Creek, MN

Sample Site	Orthocladiinae Species and (% Specimens)	Chironomini Species and (% Specimens)	Tanytarsini Species and (% Specimens)	Ratio of Chironomini to Orthocladiinae Taxa (Specimens)
Site H-2	14 (34.8%)	12 (29.0%)	8 (33.5%)	0.86 (0.83)
Site H-1.2	13 (85.8%)	8 (2.0%)	8 (11.5%)	0.62 (0.02)
Site H-1.1	12 (39.3%)	15 (21.7%)	6 (30.9%)	1.25 (0.55)
Site H-1	15 (60.3%)	15 (8.8%)	9 (23.1%)	1.00 (0.15)
Site H-1.3	9 (84.3%)	4 (6.6%)	6 (7.6%)	0.44 (0.08)
Site H-1.5	6 (12.7%)	10 (74.2%)	6 (6.8%)	1.67 (5.86)
Minnehaha Creek	26 (49.0%)	19 (28.4%)	16 (19.8%0	0.73 (0.4)
Brown’s Creek	30 (87.3%)	3 (1.5%)	4 (0.2%)	0.10 (0.02)

Habitat Preferences - Aquatic insects have a variety of morphological and behavioral adaptations that enable them to persist in an array of different habitats and substrates, however individual species are often very strongly tied to narrow ranges of habitat, substrate and hydrology. Two general categories of habits, lentic and lotic, refer to standing water and flowing water habitats. In the upper portion of Hardwood Creek, where the area is flat, it can be expected that this stretch will have a greater proportion of species that are characteristic of lentic habitats compared to the insects in down stream sections that should have a greater proportion of species that are characteristic of lotic habitats. In order to test these assumptions, the percent of Chironomidae taxa collected at each site have been calculated based on whether they show a strong tendency to predominate in lotic or lentic habitats, or can be considered to be habitat generalists that are likely to persist in both types of settings.

Differences in physical habitat are clearly indicated by the habitat preferences of species of Chironomidae that occur at sites in the upper portion of Hardwood Creek (Table 5). The upper portion of Hardwood Creek is characterized by elongated stretches of slow-flowing water, relatively deeper channel conditions and predominance of fine-grained silt or silt/mud substrates. Chironomidae in these areas consists of a higher incidence of species that show a strong tendency to occur in lentic habitat or are considered to be habitat generalists. In addition, several species that are semi-aquatic or common in boggy or saturated soils also occurred at the upstream sites.

Table 5. Species and percent of specimens (in parens) of Chironomidae categorized by habitat preferences

Sample Site	Species that predominate lotic habitats	Species that predominate in lentic habitats	Species that are considered to be habitat generalist	Species that are semi-aquatic or common in bogs/saturated soils
Site H-2	15 (58%)	10 (16.1%)	11 (25.9%)	1 (<0.01%)
Site H-1.2	20 (88.9%)	7 (3.0%)	7 (8.1%)	0 (0.00%)
Site H-1.1	18 (52.9%)	11 (18.8%)	11 (28.3%)	0 (0.00%)
Site H-1	23 (57.0%)	12 (10.6%)	12 (32.4%)	0 (0.00%)
Site H-1.3	7 (79.2%)	7 (10.7%)	9 (10.2%)	1 (<0.01%)
Site H-1.5	6 (19.4%)	15 (62.5%)	8 (18.1%)	3 (0.04%)

Percent EPT - The percentage of Ephemeroptera, Plecoptera and Trichoptera (EPT) in dip-net samples is a common metric computed from collections of aquatic macroinvertebrates taken during water quality assessments (Barbour et al. 1999). We calculated EPT as (1) the cumulative percent of taxa at each site and (2) the cumulative percent of specimens at each site. Moderate to high values for the EPT metric are interpreted as representing better water quality/habitat quality and lower values as poorer quality.

The percentages of EPT at all sites in Hardwood Creek were low however, clear patterns in terms of both species and specimens are apparent when sites in the lower portion of Hardwood Creek are compared to sites in the upper portion of the stream. The average EPT at sites in the lower portion of the creek is 22% compared with 4.9% for sites in the upper portion. Similarly, EPT based on specimens in the lower portion of the stream averages 5.9% compared to 0.7% for sites in the upper portion of Hardwood Creek (Table 6).

Table 6. Percent EPT for DN samples in Hardwood Creek, MN

Sample Site	**Numbers of Specimens Collected**	Percent EPT Species and (Specimens)
Site H-2	206	23.2% (4.0%)
Site H-1.2	152	14.3% (8.9%)
Site H-1.1	155	32.1% (8.7%)
Site H-1	699	18.6% (2.2%)
Site H-1.3	84	4.8% (1.7%)
Site H-1.5	1578	8.3% (0.3%)

Percent Chironomidae - The percentage of Chironomidae specimens in dip-net samples is a common metric computed from collections of aquatic macroinvertebrates taken during water quality assessments (Barbour et al. 1999). We calculated Percent Chironomidae as the cumulative percent of specimens at each site. This metric generally is considered to be inversely related to water quality or habitat quality, with moderate to high values interpreted as representing poorer water quality/habitat quality and lower values as higher quality. There are, however, very common exceptions to this interpretation and it is better to interpret this metric at the subfamily or tribe level rather that at the family level. However, we have opted to include the metric based on family level determination in this report only because it is a more commonly reported metric and therefore provides better opportunity for comparisons to other projects.

The percent of Chironomidae shows substantial differences at sites in the lower portion of the stream compared with sites in the upper portion. The patterns are similar to those observed for EPT, with Chironomidae averaging 52.8% of all specimens for sites in the downstream portion of Hardwood Creek, but only 18.4% at sites in the upstream portion (Table 7). Normally decreases in percent Chironomidae are interpreted as indicating improvement in water or habitat quality. However, in Hardwood Creek the declines in percent composition of Chironomidae are paralleled by declines in percent EPT and increases in percent of macroinvertebrates that are leeches and mollusks. In this study, the decline in percent Chironomidae must be interpreted as representing declining water and/or habitat quality.

Table 7. Percent Chironomidae Species for DN samples in Hardwood Creek, MN

Sample Site	Numbers of Specimens Collected	Percent Chironomidae Species
Site H-2	206	56.5%
Site H-1.2	152	67.9%
Site H-1.1	155	46.6%
Site H-1	699	52.4%
Site H-1.3	84	40.1%
Site H-1.5	1578	3.7%

Percent Dominance - The percentage of the three most abundant species in dip-net samples is a common metric computed from collections of aquatic macroinvertebrates taken during water quality assessments (Barbour et al. 1999). We calculated Percent Dominance based on the cumulative specimens in all three dip-net samples at each individual site. This metric generally is considered to be inversely related to water quality or habitat quality, with moderate to high values interpreted as representing poorer water quality/habitat quality and lower values as higher quality.

All sample sites have high dominance among macroinvertebrates, ranging from a low value of 72.9% at Site H-1.1 to the highest value of 86.8% at Site H-1. The average percent dominance of macroinvertebrates in SBSU at sites in the lower portion of the stream is 82.3%, whereas the average for sites in the upper portion of the creek is only 77.7%. Although no consistent pattern is apparent for the different portions of Hardwood Creek, it should be noted that the highest values of percent dominance were calculated at Site H-1 and Site H-1.5.

Sample Site	Numbers of Specimens Collected	Percent Dominance of Three Most Abundant Taxa
Site H-2	206	84.5%
Site H-1.2	152	84.9%
Site H-1.1	155	72.9%
Site H-1	699	86.8%
Site H-1.3	84	71.4%
Site H-1.5	177	87.0%

SFPE and DN Conclusions

- There is a difference between the physical structure of Hardwood Creek upstream and downstream of Highway 61. Downstream of Highway 61 stream substrates consist predominately of clean sands. Upstream of Highway 61 stream substrates consist predominately of soft, unconsolidated silts and mud.
- There is a difference on oxygen levels between the reach of Hardwood Creek upstream of Highway 61 and the reach downstream of Highway 61.
- Metrics calculated for SFPE showed a difference between Chironomidae communities found in the upstream portion of Highway 61 and those found in the downstream portion of Highway 61.
- Metrics calculated for DN showed a difference between Chironomidae communities found in the upstream portion of Highway 61 and those found in the downstream portion of Highway 61.
- Metrics calculated showed a difference in monitoring site H1.5 which was just downstream of a reach that had minor maintenance conducted in winter of 2004.

<u>References</u>:

Allen, JD. 1005. Stream Ecology. Kluwer.

Barbour, Michael T., Jeroen Gerritsen, Blaine D. Snyder and James B. Stribling. 1999. *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish*, Second Edition. Office of Water, U. S. EPA. Document # EPA 841-B-99-002, July 1999.

Barton, David R., Donald R. Oliver and Mary E. Dillon. 1995. A comparison of pupal exuviae and larval Chironomidae for biomonitoring of the impacts of agricultural practices on surface water quality. Pp. 125-132. In: *Chironomids: From Genes to Ecosystems.* Peter S. Cranston (Ed.). CSIRO Publications, Melbourne 482 pp.

Blackwood, Mary Anne, Sara M. Hall and Leonard C. Ferrington, Jr. 1995. Emergence of Chironomidae from Springs in the Central High Plains Region of the United States. Pp 132-151, In *Biodiversity of Aquatic Insects and Other Invertebrates in Springs*. L. C. Ferrington, Jr. (Ed.). Special Publication No. 1 of the Journal of the Kansas Entomological Society, 165 pp.

Boerger, Hans. 1981. Species composition, abundance and emergence phenology of midges (Deiptera[sic]: Chironomidae) in a brown-water stream of west-central Alberta, Canada. Hydrobiologia 80: 7-30.

Brundin, Lars. 1966. Transantarctic relationships and their significance, evidenced by chironomid midges. With a monograph of the subfamilies Podonominae and Aphroteniinae and the austral ***Heptagyiae*.** K. Svenska Vetensk Akademie Handlungen. 11: 1-472.

Chou, Ronald, Y. M., Leonard C. Ferrington Jr., Barbara L. Hayford and Heidi M. Smith. 1999. Composition and phenology of Chironomidae (Diptera) from an intermittent stream in Kansas. Archives für Hydrobiologie 141(1): 35-64.

Coffman, William P. 1973. Energy flow in a woodland stream ecosystem: II. The taxonomic composition and phenology of the Chironomidae as determined by the collection of pupal exuviae. Archives für Hydrobiologie 71: 281-322.

Coffman, William P. 1974. Seasonal differences in the diel emergence of a lotic chironomid community. Entomologica Tidskre Supplement 95: 42-48.

Coffman, William P. and Leonard C. Ferrington, Jr. 1984. Chironomidae, Chapter 25. Pp. 551-652, <u>In</u> *An Introduction to the Aquatic Insects of North America, Second Edition,* R. W. Merritt and K. W. Cummins, (Eds.). Kendall/Hunt Publishing Company, Dubuque, Iowa. 722 pp.

Coffman, William P. and Leonard C. Ferrington, Jr. 1995. Chironomidae, Chapter 26. Pp. 635-748, <u>In</u> *An Introduction to the Aquatic Insects of North America, Third Edition*, R. W. Merritt and K. W. Cummins, (Eds.). Kendall/Hunt Publishing Company, Dubuque, Iowa.

862 pp.

Coler, Barbara C. 1984. Community responses of Chironomidae (Diptera) to organic enrichment in a small Kansas stream. Unpublished Master's Thesis, University of Kansas. Lawrence, Kansas. 81 pp.

Cranston, Peter S., P. D. Cooper, Rod A. Hardwick, C. L. Humphrey and Peter L. Dostine. 1997. Tropical acid streams- the chironomid (Diptera) response in northern Australia. Freshwater Biology 37: 473-483.

Emmons and Oliver Resource, Inc. 2003. Integrating Groundwater and Surface Water Management in Northern Washing County.

Emmons and Olivier Resources, Inc. 2004. Rehabilitation/Engineer's Repair Report Hardwood Creek/Washington County JD2. Rice Creek Watershed District. http://www.ricecreek.org/projects/hwc/

Ferrington, Leonard C. Jr. 1987. Collection and Identification of Floating Pupal Exuviae of Chironomidae for Use in Studies of Surface Water Quality. Prepared for U. S. EPA, Region VII, Kansas City, KS as SOP No. FW130A. 39 pp. + appendix.

Ferrington, Leonard C., Jr. 1990. Abundance and Longitudinal Distribution of *Chironomus riparius* near the Middle Basin WWTP in Johnson County, Kansas. Grant Completion Report for Johnson County Wastewater District.

Ferrington, Leonard C., Jr. 1993. Water Chemistry, Sediment Chemistry, Fish and Macroinvertebrate Communities of the Galena Superfund Subsite of the Tri-State Mining District. Report Number 56. Kansas Biological Survey, Lawrence, Kansas.

Ferrington, Leonard C. Jr. 1998. Generic Composition of the chironomid fauna in springs of North America. Pp. 141-156. In: *Studies in Crenobiology: The biology of springs and springbrooks*, L. Botosaneanu (ed.). Backhuys Publishers, Leiden 261 pp.

Ferrington, Leonard C. Jr. 2000. Hibernal emergence patterns of Chironomidae in lotic habitats of Kansas versus ambient air and water temperatures. Pp. 375-382. In: *Late Twentieth Century Research on Chironomidae: An Anthology from the 13th International Symposium on Chironomidae.* Odwin Hoffrichter (ed.). Shaker Verlag, Aachen, 661 pp.

Ferrington, Leonard C., Jr. Mary Anne Blackwood, Christopher A. Wright, Norman H. Crisp, Jeffry L. Kavanaugh and Franz J. Schmidt. 1991. A Protocol for Using Surface-Floating Pupal Exuviae of Chironomidae for Rapid Bioassessment of Changing Water Quality. Pp.181-190. In: *Sediment and Stream Water Quality in a Changing Environment: Trends and Explanations*. IAHS Publication Number 203. 374 pp.

Ferrington, Leonard C., Jr. and Norman H. Crisp 1989. Water chemistry characteristics of receiving streams and the occurrence of *Chironomus riparius* and other Chironomidae in

Kansas. Acta Biologica Debrecina Supplementum OecoIogica Hungarica 3: 115-126.

Ferrington, Leonard C. Jr., Rathi G. Kavanaugh, Franz J. Schmidt and Jeffry L. Kavanaugh. 1995. Habitat Separation Among Chironomidae (Diptera) in Big Springs. Pp. 152-165, In: *Biodiversity of Aquatic Insects and Other Invertebrates in Springs*. Leonard C. Ferrington, Jr. (Ed.). Special Publication No. 1 of the Journal of the Kansas Entomological Society, 165 pp.

Hardwick, Rod A., P. D. Cooper, Peter S. Cranston, C. L. Humphrey and Peter L. Dostine. 1995. Spatial and temporal distribution patterns of drifting pupal exuviae of Chironomidae (Diptera) in streams of tropical northern Australia. Freshwater Biology 34: 569-578.

Humphries, C. F. 1938. The chironomid fauna of the Grosser Ploner See, the relative density of its members and their emergence periods. Archives für Hydrobiologie 33: 535-584.

Karr, James R. and Ellen W. Chu. 1999. *Restoring Life in Running Waters: Better Biological Monitoring*. Island Press, Washington, D. C. 206 pp.

Kavanaugh, Jeffry L. 1988. Community composition and emergence phenology of Chironomidae (Diptera) jn prairie streams of different flow regimes. Unpublished Master's thesis, University of Kansas. Lawrence, Kansas. 77 pp.

Kavanaugh, Rathi C. 1988. Decomposition studies of Chironomidae pupal exuviae (Chironomidae: Diptera). Unpublished Master’s thesis, University of Kansas, Lawrence, Kansas 104 pp.

Langton, P.H. 1991 A key to pupal exuviae of West Palaearctic Chironomidae. 386pp. Privately published at 3 St Felix Road, Huntingdon, Cambridgeshire, PE17 1YH, UK.

Lehman, Jens. 1971. Die Chironomiden der Fulda. Archives für Hydrobiologie, Supplement 37: 466-555.

McGill, J. D., R. S. Wilson, & A. M. Brake. 1979. The use of chironomid pupae exuviae in the surveillance of sewage pollution within a drainage system. Water Research 13: 887-894.

National Academy of Sciences. 2001. *Assessing the TMDL Approach to Water Quality Management*. National Academy Press, Washington, D. C. 102 pp. + appendices.

Plafkin, James L., Michael T. Barbour, K. D. Porter, Sharon K. Gross and R. M. Hughes. *Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish.* U. S. EPA, Document # EPA 440-4-89-001.

Reiss, Friedrich 1968. Okologische und systematische Untersuchungen an Chironomiden (Diptera) des Bodensees. Ein beitrag zur lakustrischen Chironomidenfauna des nordlichen

Alpenvorlandes. Archives für Hydrobiologie 64: 176-323.

Ruse, Leslie P. 1993. Correlations between chironomid pupal skin collections and habitats recorded from a chalk stream. Netherlands Journal of Aquatic Ecology 26: 411-417.

Ruse, Leslie P. 1995a. Chironomid community structure deduced from larvae and pupal exuviae of a chalk stream. Hydrobiologia 315: 135-142.
Ruse, Leslie P. 1995b. Chironomid emergence from a chalk stream during a three year period. Archives für Hydrobiologie 133: 223-244.

Ruse, Leslie P., Scott J. Herrmann and James E. Sublette. 2000. Chironomidae (Diptera) species distribution related to environmental characteristics of the metal-polluted Arkansas River, Colorado. Western North American Naturalist 60(1): 34-56.

Ruse, Leslie P. and Ronald S. Wilson. 1984. The monitoring of river water quality within the Great Ouse Basin using the chironomid exuvial analysis technique. Water Pollution Controls 83: 116-135.

Thienemann, August. 1910. Das Sammeln von Puppenhauten der Chironomiden Eine bitte um Mitarbeit. Archives für Hydrobiologie 6: 2-214.

Thienemann, August. 1954. *Chironomus. Leben, Verbreitung und wirtschaftliche Bedeutung der Chironomidae*. Binnegewässer 20: 1-834.

Wartinbee. David C. and William P. Coffman. 1976. Quantitative determination of chironomid emergence from enclosed channels in a small lotic ecosystem. American Midland Naturalist. 95: 479-485.

Wiederholm, Torgney (Ed.). 1986. Chironomidae of the Holarctic Region: Keys and diagnoses. Part 2. Pupae Entomologica scandinavica Supplement 28: 1-482.

Wilson, Ronald S. 1977. Chironomid pupal exuviae in the River Chew. Freshwater Biology. 7(l): 9-17.

Wilson, Ronald S. 1980. Classifying rivers using pupal exuviae. Pp.209-216. In: *Chironomidae Ecology, Systematics, Cytology and Physiology*, D. A. Murray (ed.). Proceedings of the 7th International Symposium on Chironomidae. Pergammon Press, Dublin. 354 pp.

Wilson, Ronald S. 1987. Chironomid communities in the River Trent in relation to water chemistry. Entomologica Scandinavica Supplement 29: 387-393

Wilson, Ronald S. 1989. The modification of chironomid pupal exuvial assemblages by sewage effluent in rivers within the Bristol Avon catchment, England. Acta Biologica Debrecina Supplementum OecoIogica Hungarica 3: 367-376.

Wilson, Ronald S. and P. L. Bright. 1973. The use of chironomid pupal exuviae for characterizing streams. Freshwater Biology. 3: 283-302.

Wilson, Ronald S. and J. D. McGill. 1977. A new method of monitoring water quality in a stream receiving sewage effluent, using chironomid pupal exuviae. Water Research. 11: 959-962.

Wilson, Ronald S. and J. D. McGill. 1982. A practical key to the genera of pupal exuviae of the British Chironomidae (Diptera, Insecta). University of Bristol Press. UK. 62 pp.

Wilson, Ronald S. and S. E. Wilson. 1983. A reconnaissance of the River Rhine using Chironomidae pupal exuviae (Insecta: Diptera). Memoirs of the American Entomological Society 34: 361-385.

Wright, Christopher A. and Leonard C. Ferrington, Jr. 1996. Analysis of Chlordane-impacted streams using chironomid pupal exuviae (Diptera: Chironomidae). Hydrobiologia 318: 69-77.

Attachment 1:
Methodology for collecting Surface Floating Pupal Exuviae (SFPE) and Dip Net (DN) samples in Hardwood Creek MN

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.

Chironomidae 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.

Methodology for Collecting Dip-Net (DN) Samples

Dip-net sampling is a common method for collecting aquatic macroinvertebrates for water quality assessments (Barbour et al. 1999). Several different variations of field protocols exist, but a commonly accepted approach is to sample sites according to a standardized procedure consisting of a pre-determined number of dips or “jabs” into each microhabitat present in a reach of stream. The dips are composited into a single sample that is then evaluated. In this approach, it is assumed that species from each microhabitat will be proportionally represented in the composited sample. Typical microhabitats that are sampled include riffles, pools, bedrock, undercut banks, wood substrates or snags. A given sample site may be lacking one or more of the microhabitats and, unfortunately, with this approach it is not possible to determine the affect that the lack of the microhabitat(s) has on the metrics that are calculated from the composited sample.

In this analysis, we used a modified dip-net sampling protocol. Our field protocol stipulated that individual microhabitats be sampled, with each dip of the net into a given microhabitat resulting in a single sample. In this approach, it is necessary to perform a visual reconnaissance of each site before samples are collected in order to determine the microhabitats that are present. Each microhabitat is considered as a stratification unit for the site and is sampled three times. Any given site can therefore have from one to many stratification units.

Our approach is extremely well suited for Hardwood Creek. Due to ditching activities, the lower portions of Hardwood Creek have considerably greater microhabitat heterogeneity than in the upper portions of the creek. Consequently, we defined stratification units as (1) stream bottom, (2) stream bank, (3) riffle, and (4) wood substrates. The stream bottom stratification unit (SBSU) was located in the deeper portions of a reach, and at downstream sites consisted of deeper areas of pools. In the upper portion of the stream the SBSU sampled was the midpoint between banks of the ditched channel. Although sites in the downstream potion of Hardwood Creek contain all four stratification units, virtually no riffle microhabitat occurs in ditched areas of the upper portion of Hardwood Creek, and very little wood substrates are present. Consequently, only stream bottom and stream bank microhabitats are present at all eight sample sites. The data for this interim report are derived from the three dip-net samples collected from the SBSU of each the eight sample sites, and data across sites are directly comparable.

Appendix B. Stressor Identification and Pollutants of Concern

Table of Contents

1. Introduction

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

Although biological assessments are useful for identifying biological impairments, they do not identify the cause of impairment. Linking biological effects with their causes is complex, particularly when multiple stressors impact a waterbody. Investigation procedures are needed that can successfully identify the stressor(s) and lead to appropriate corrective measures through habitat restoration and point/non-point source controls. The Stressor Identification (SI) process developed by U.S. EPA is a formal method for analyzing available evidence such as biological, physical and chemical data, as well as land use and habitat data, and identifying the causes of biological impairment of aquatic systems through a step-by-step procedure (Figure 1). These steps include detecting biological impairment, assembling available data, listing candidate causes, analyzing the lines of evidence for each candidate cause, and characterizing the probable cause(s).

2. List candidate causes

DESCRIPTION OF THE IMPAIRMENT

The impairment on Hardwood Creek was characterized by a low Index of Biotic Integrity (IBI) score. However, during the course of this study, Hardwood Creek was also listed for low dissolved oxygen. Even though both impairments were observed at only the most downstream monitoring site (H2, Figure 2), the entire stream length (13.38 miles) was originally listed on the 303(d) list of impaired waters, and therefore the scope of the study included the entire stream length from the headwaters to the mouth. However, on April 12, 2005, the MPCA split Hardwood Creek into two reaches: upstream from Highway 61 (8.33 miles) and downstream of Highway 61(5.05 miles) based on technical information presented in the document entitled "Request to MPCA Professional Judgment Group to split Hardwood Creek into two reaches at Highway 61" (Appendix A of the TMDL report).

The reason for splitting Hardwood Creek into two reaches was based upon best professional judgment. The upper stretch of Hardwood Creek (from Rice Lake to Highway 61) has naturally occurring low dissolved oxygen due to the release of organics from underlying peat deposits and poorly oxygenated groundwater. Upon analyzing groundwater data, surface water data, and biological data, it was determined that changes in land use activities or changing the stream configuration could not achieve dissolved oxygen levels that would be above the Minnesota Class 2B standard of 5 milligrams per liter (mg/L) for this upper section of the creek. Because the case has been made that dissolved oxygen levels in the upper portion of the creek can only be expected to meet natural background conditions, the MPCA de-listed the upper portion of the creek for the fish IBI. The MPCA does not have tools to properly assess a biological community that resides in an environment where DO levels are below 5 mg/L. However, this upstream section of the creek does have an impact on downstream water quality and in-stream habitat. Therefore, this stressor identification process has been modified to focus only on the reach downstream of Highway 61. However, data collected upstream of Highway 61 are still included in all analyses in order to provide a holistic view of the watershed.

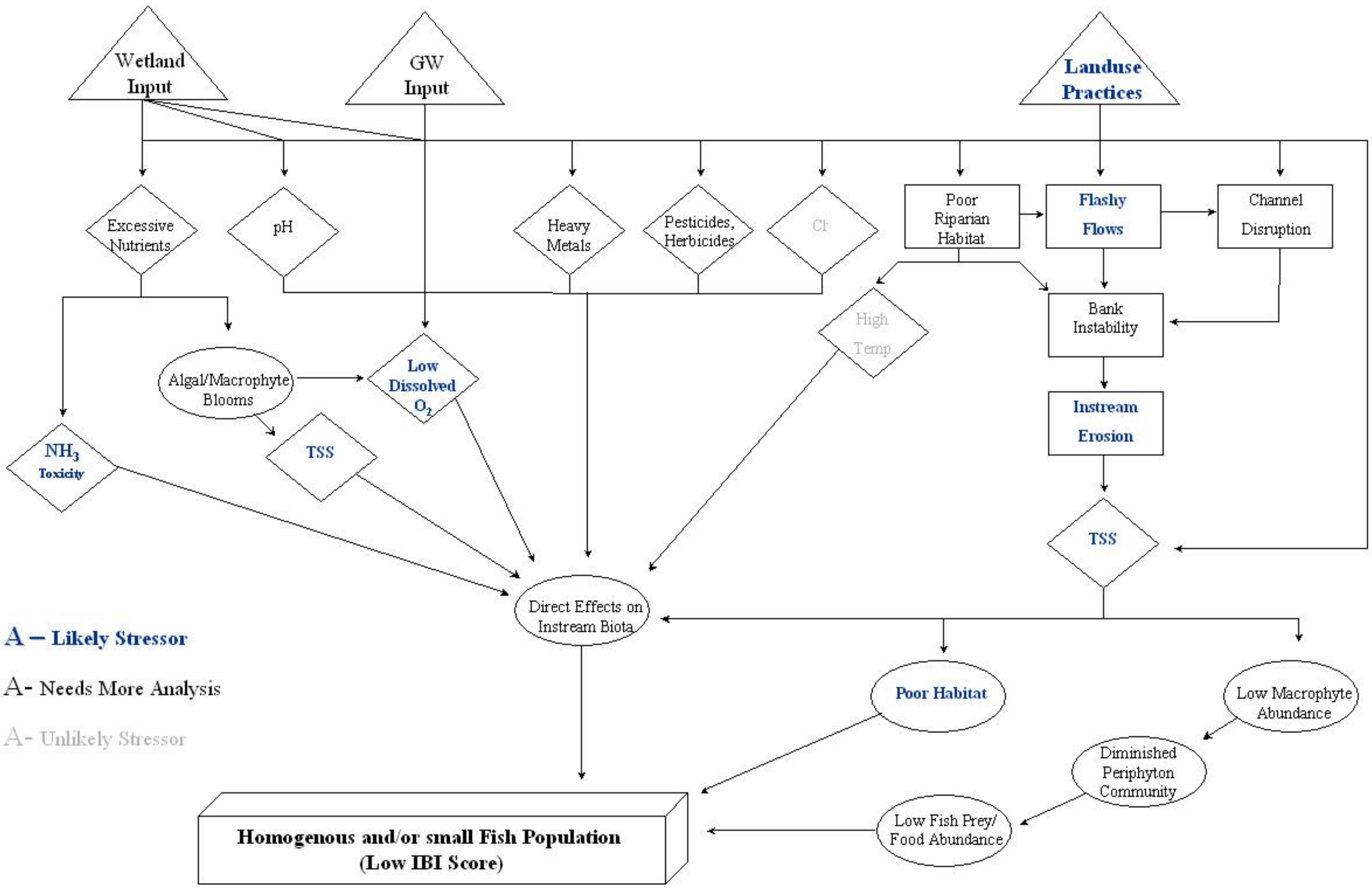


Figure 1. Simplified Conceptual Model of Potential Stressors impairing the biological community in Hardwood Creek

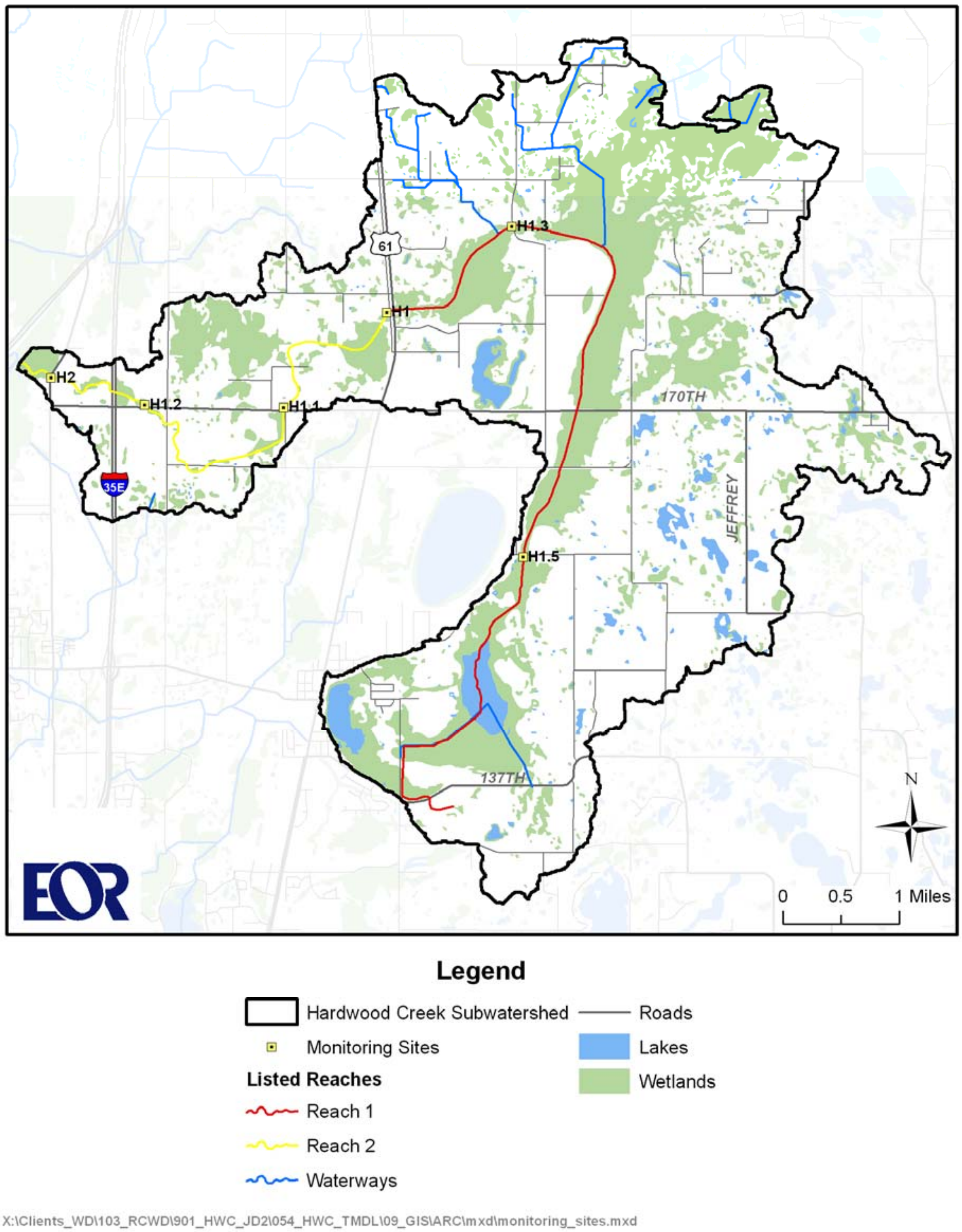


Figure 2. Monitoring Sites

NARROWING THE LIST OF POTENTIAL STRESSORS

To determine the list of candidate causes to be considered as stressors for the biotic impairment of Hardwood Creek, all historical monitoring data (Section 6A: Historical Monitoring Data) was reviewed. Where possible, flow duration curves were created (Section 6B: Flow Duration Curves). A simplified conceptual model of all possible stressors in Hardwood Creek is shown in Figure 1. From initial review of the historical monitoring data, pH, chloride, and high water temperatures were ruled out as likely stressors impacting Hardwood Creek. All other potential stressors were identified as either needing further analysis or as being likely stressors. Based on this initial exercise, the 2004 monitoring program was established. Water quality stations coupled with continuous flow meters were installed at the six historic monitoring sites, from the headwaters to the mouth. Water quality parameters measured were total suspended solids (TSS), volatile suspended solids (VSS), ammonia, nitrates and nitrites (NOx), total Kjeldahl nitrogen (TKN), total phosphorus (TP), soluble reactive phosphorus (SRP), dissolved oxygen, biological oxygen demand, and chemical oxygen demand. MPCA staff recommended that chlorophyll-*a* not be measured in this stream due to its small size. After discussions with MPCA staff and the TAC, it was determined that a pesticide, herbicide, and heavy metal screening should also be conducted at each monitoring site. In addition, three continuous YSI dissolved oxygen meters were installed at monitoring sites H1.5, H1.3 and H2. To aid in the causal analysis, a Rosgen Level III analysis was performed along five reaches. In addition, Chironomidae data and macroinvertebrate data were collected at each monitoring site by the University of Minnesota.

LIST THE CANDIDATE CAUSES

The candidate causes analyzed for the stressor identification process for Hardwood Creek were:

- Sedimentation
- Low dissolved oxygen
- Nutrient enrichment (phosphorus and nitrogen)
- PAHs, heavy metals, and pesticides

Sedimentation

Altered Habitat

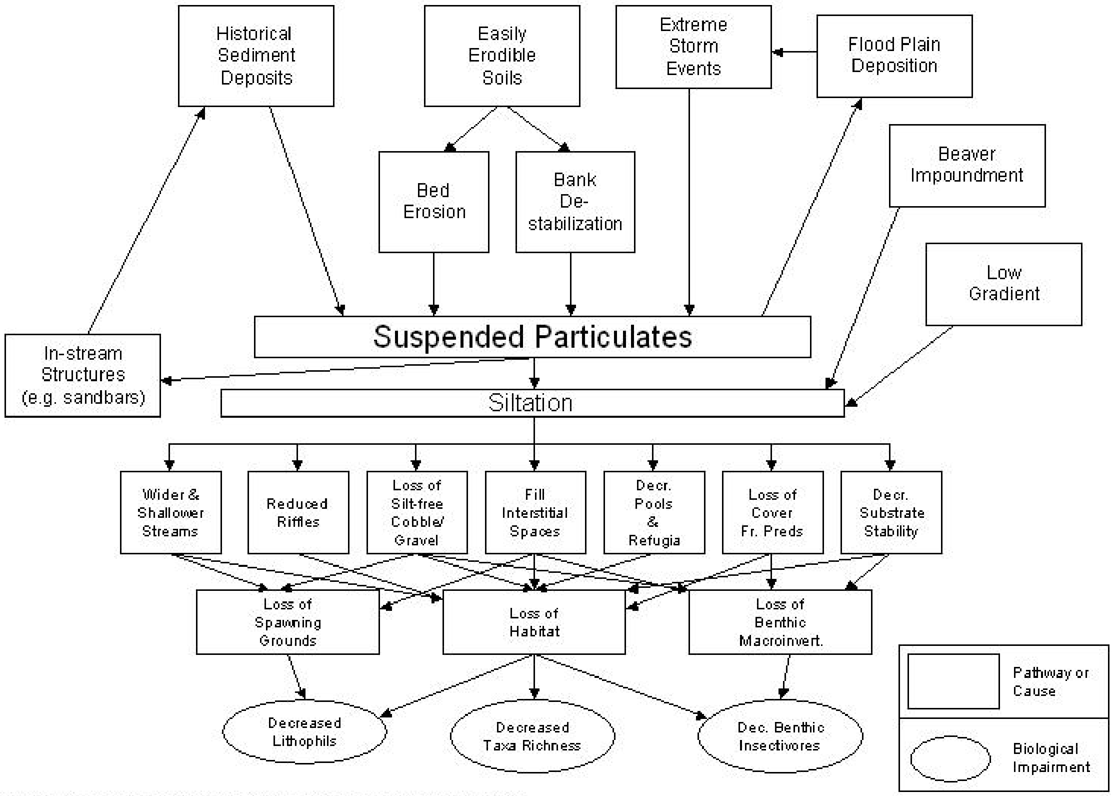
Loss of reproduction, feeding, or refugia habitat associated with unstable or unsuitable geological substrates is a common disturbance in stream systems and can occur due to excess silt and sediments entering the stream (Figure 3). Exterior sources of silt and sediment include bank erosion due to altered hydrology, farming activities, roads and urban runoff, and dirt and gravel road systems in the drainage area. Naturally occurring stream features and landscape characteristics within the Hardwood Creek Watershed may also affect stream sediment conditions, potentially altering the occurrence of suitable gravel substrates. Examples are beaver dams and low gradients, which decrease flow, causing particulates to settle and remain trapped Another example in Hardwood Creek is that the lower portion of system runs through the geologic area known as Anoka Sand Plain, which is linked to the sandy soils found along the bank of the creek.

The result of this excess sediment is the covering/filling of cobbles and gravel substrate and interstitial spaces, decreasing pool depth, and the potential burial of larger coarse woody debris. In addition, excess sediment can affect stream aquatic use conditions by eliminating stable, coarse substrates that provide shelter during high flow events, thereby potentially affecting fry, smaller fish, and the macroinvertebrate communities. Sediment sources within a stream include materials eroded from banks and scoured off the stream bed.

A habitat assessment following MPCA protocol was conducted along a 1,000-foot stretch at monitoring site H2. In addition, two independent habitat assessments were conducted using the Qualified Habitat Evaluation Index (QHEI). The results of all three of these habitat assessments in this area indicate that sedimentation and channel instability were high. The low fish IBI scores in Hardwood Creek are likely a result of the stream's poor quality habitat. The relationship between high quality physical habitat and a healthy fish community in other systems is well documented (Gorman and Karr 1978; Allen and Flecker 1993; Allen et al. 1997; Saunders et al. 2002; Rhoads et al. 2003). Additional habitat assessments were conducted in the remaining Rosgen reaches using the EPA rapid bioassessment habitat protocol. Although the protocol is different than the one used by MPCA, these assessments also indicated that sedimentation and channel instability were high in these stretches.

Altered Hydrology

The upper two-thirds of Hardwood Creek (~10 miles) are channelized, or ditched. Ditching can produce more frequent higher peak flows downstream and can increase suspended sediments (Prévost et al. 1998), leading to poorer habitat quality. These phenomena have all been observed in Hardwood Creek. Higher peak flows result from less flow being attenuated in a channelized ditch and from watershed runoff being directed to the channel more quickly. Ditching can decrease local storage, and water that would have spread out onto the floodplain remains in the channel and is passed downstream more quickly (Brookes 1988; Saunders et al. 2002). Channelization can alter biological communities by changing both the physical structure of the stream and the flow characteristics of the water. Channelization ultimately lowers dissolved oxygen, increases siltation, and reduces substrate complexity. This complex suite of stressors also include decreased woody debris, which reduces available substrate and changes the energy source for consumers; decreased sinuosity, which changes flow characteristics; erosional patterns and substrates; increased channel depth; loss of pools that act as refugia; and loss of riffles that oxygenate water and transport sediment.



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

Figure 3. Conceptual Model of Candidate Cause 1: Sedimentation

Low Dissolved Oxygen/Organic Enrichment

Four mechanisms have been identified in Hardwood Creek that could be contributing to the low dissolved oxygen in the lower reach (Figure 4).

Organic Enrichment

Depletion of DO commonly occurs from organic enrichment. Organic enrichment is the most common cause of increased biological oxygen demand (BOD) and is commonly associated with wastewater treatment plants (Allan 1995). There are no point sources of organic enrichment in the Hardwood Creek watershed. However, there are several non-point sources within the watershed including a large peatland that constitutes the majority of the headwaters area and to lesser degree agricultural sources. There is one registered dairy operation immediately adjacent to the creek and several smaller farms with horses or livestock within 1,000 feet of creek. In addition, there are areas where row crop agriculture is farmed up to the banks of the creek with little or no riparian buffer.

High nutrient concentrations

High nutrient loadings entering a stream can accelerate primary production, allowing for increases in biological activities. When the plants and algae die, bacteria decomposing the plant tissue deplete DO while at the same time release nutrients into the water column. Since no chlorophyll-*a* or algal biomass data were collected in this study, the cause of low dissolved oxygen in Hardwood Creek was estimated from coupling continuous DO readings and BOD measured at the six monitoring stations with observational data.

Decreased canopy cover

Often associated with agricultural and urban development, decreased canopy cover can lower dissolved oxygen by increasing water temperatures, which subsequently decreases the solubility of oxygen in water and increases primary production due to more light and warmer water temperatures (Allan 1995).

Changes in channel geomorphology

As oxygen diffusion rates are generally highest in agitated waters, such as those flowing over riffles, changes to stream morphology that affect the number of riffles (e.g., channelization, increases in water depth, changes in surface area) also may affect dissolved oxygen concentrations.

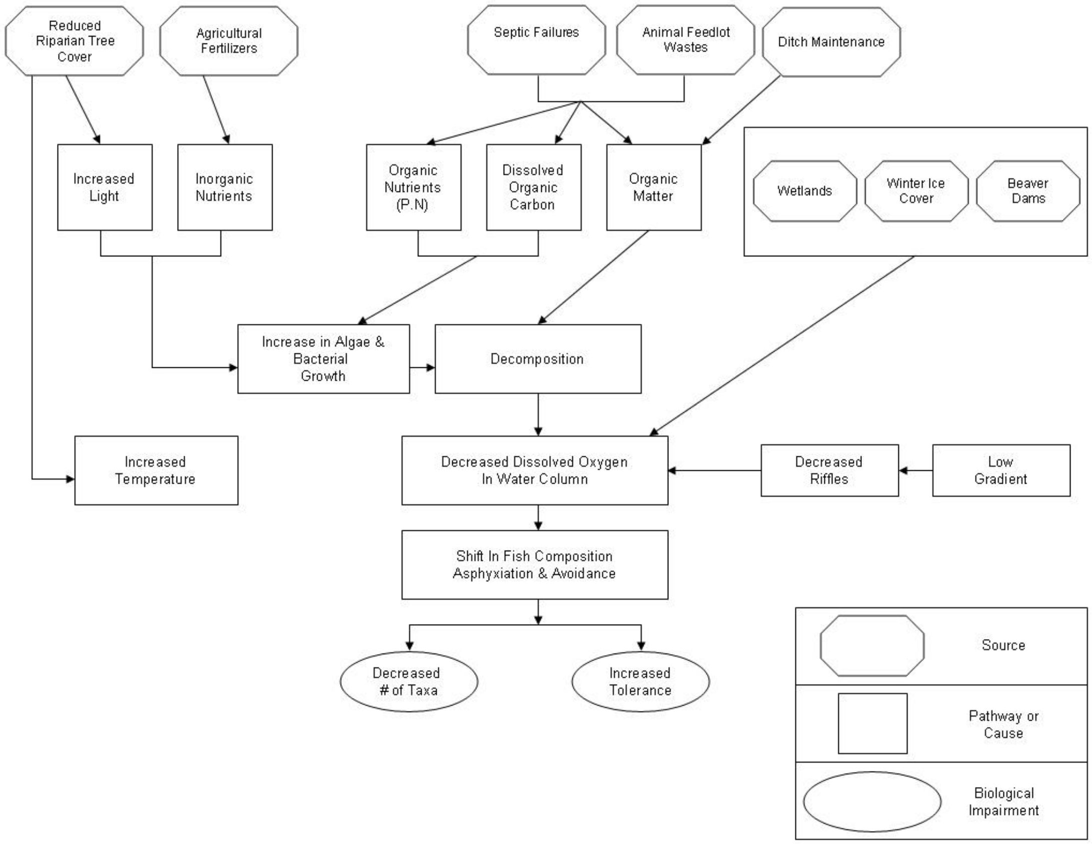


Figure 4. Conceptual Model of Candidate Cause 2: Dissolved Oxygen

Nutrient Enrichment Leading to Changes in Food Web

Nutrient enrichment can cause changes in fish and benthic macroinvertebrate assemblages, including changes in dominant species, and an increase in abundance and biomass of some species because excessive nutrient loading can alter food resources. Generalists, with a broad diet, are typically more tolerant of perturbations (Barbour et al. 1996). Some macroinvertebrate trophic guilds fare poorly after excessive nutrient loading, even with adequate oxygen, as excessive algal growth can decrease visibility, habitat complexity, and respiratory effectiveness. This change in macroinvertebrate abundances can affect fish through prey availability (Figure 5).

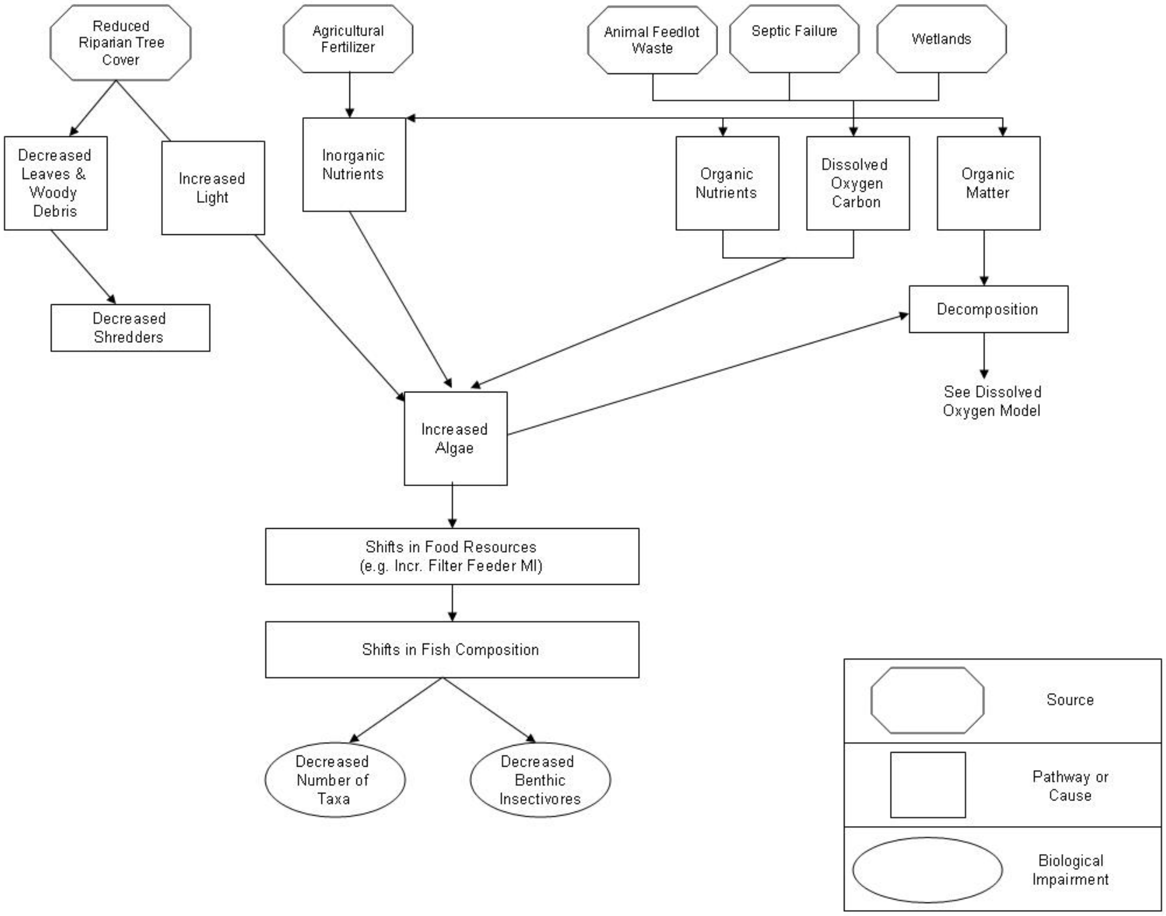


Figure 5. Conceptual Model of Candidate Cause 3: Nutrients

Exposure to PAHs, Heavy Metals, and Pesticides

Biological impairment can also be caused by toxic stress. Historically, the creek has not provided a means of waste disposal. However, since measurements have never been taken in the creek, these three candidate causes need to be further evaluated.

In summary, the candidate causes analyzed for the stressor identification process for Hardwood Creek were:

- Sedimentation
- Low dissolved oxygen
- Nutrient enrichment (phosphorus and nitrogen)
- PAHs, heavy metals, and pesticides

3. Analyze evidence

The association between candidate causes and effects was analyzed by evaluating data at the location of the impairment with all monitoring data for that site including biological data, habitat quality data, and water chemistry data. The first objective of the analysis was to determine if there was evidence that the candidate cause occurred at the same place as the impairment. The second objective was to determine if the cause increased compared to the nearest upstream location. Statistical analyses were not used to determine an increase because the power would be very weak due to small sample sizes. Even a small increase was accepted since it might represent a threshold for the effect. Data available for the examination of spatial co-occurrence came from 2002, 2003, and 2004.

PHYSICAL DATA

Habitat Evaluation

Data on the spatial location of habitat alteration were obtained by using the MPCA protocol for habitat assessment and conducting Rosgen Level II assessments in five reaches. The MPCA protocol for habitat assessment quantitatively measures or visually estimates key components of the physical habitat structure that influence stream ecology. Key components include channel morphology, substrate, cover, and riparian condition. This information was then converted into the Qualitative Habitat Evaluation Index (QHEI). This index uses five interrelated metrics based on the above key components. Based on these metrics, a total score is assigned to a stream reach out of a possible 100 points, with greater scores indicating higher quality. Values for the QHEI and its component metrics are given in Table 1.

Table 1. QHEI results for Hardwood Creek

Metric	Metric Component	Best Possible Score	Hardwood Creek at H2
1. Adjacent Land Use	Type	5	2
2. Riparian Zone	Width, Quality, Bank Erosion	15	7.5
3. In-stream Zone	Substrate Amount and Type, Embeddeness, Water Color and Clarity	27	10
4. Cover Type	Type and Amount	17	7
5. Channel Morphology	Pool Max. Depth, Riffle Depth, Channel Stablity, Sinuosity, Channel Development, Velocity, Water level, Gradient	36	6
	Total	100	32.5

Rosgen Assessment

A Rosgen Level I and II stream assessment was conducted along five reaches of Hardwood Creek (Section 6C: Rosgen Stream Assessment). Some key parameters of the Level III assessment were also included in this assessment. The average slope of Hardwood Creek from Rice Lake to the Highway 61 crossing is 0.03%. Downstream of Highway 61, gradient does increase. The stream channel is incised, with high channel shear and weak point shear on the stream bed and banks. Highly incised channels do not have ready access to flood plains, thus water energies are not abated by flood plain vegetation and structure, but concentrated in the channel. In addition, fine silt is not deposited in the flood plain but remains within the channel. Weak point shear stress on stream bed and banks suggests that bed and bank materials are easily eroded by low water energies, and greatly eroded by high energies, which was confirmed with observational data. The bed substrate was composed of fine materials and a low percentage of coarse substrate or cobbles.

CHEMICAL DATA

There are six ambient water quality monitoring stations (see Figure 5 of the TMDL report) located on the mainstem of Hardwood Creek on or above the biologically impaired segment. In-stream chemistry data were used to evaluate the spatial distribution of the potential candidate causes. Parameters analyzed were total suspended solids (TSS), volatile suspended solids (VSS), ammonia, nitrates and nitrites (NO_x), total Kjeldahl nitrogen (TKN), total phosphorus (TP), soluble reactive phosphorus (SRP), dissolved oxygen, biological oxygen demand, and chemical oxygen demand. Results of chemical analyses are presented in Figure 6 through Figure 8. Only those water quality parameters with standards or recommended concentration guidelines from the MPCA are shown.

Phosphorus

Concentrations of total phosphorus were compared to previous data collected on Hardwood Creek as well as to ecoregion expectations (McCollor and Heiskary 1993), which are defined as the 75th percentile of data collected from 1970-1992 (0.15 mg/L) at designated minimally impacted sites in the North Central Hardwood Forest Ecoregion. All monitoring sites had concentrations similar to previous years. However, the average TP at all sites, with the exception of H1.5, did not meet the ecoregion expectation.

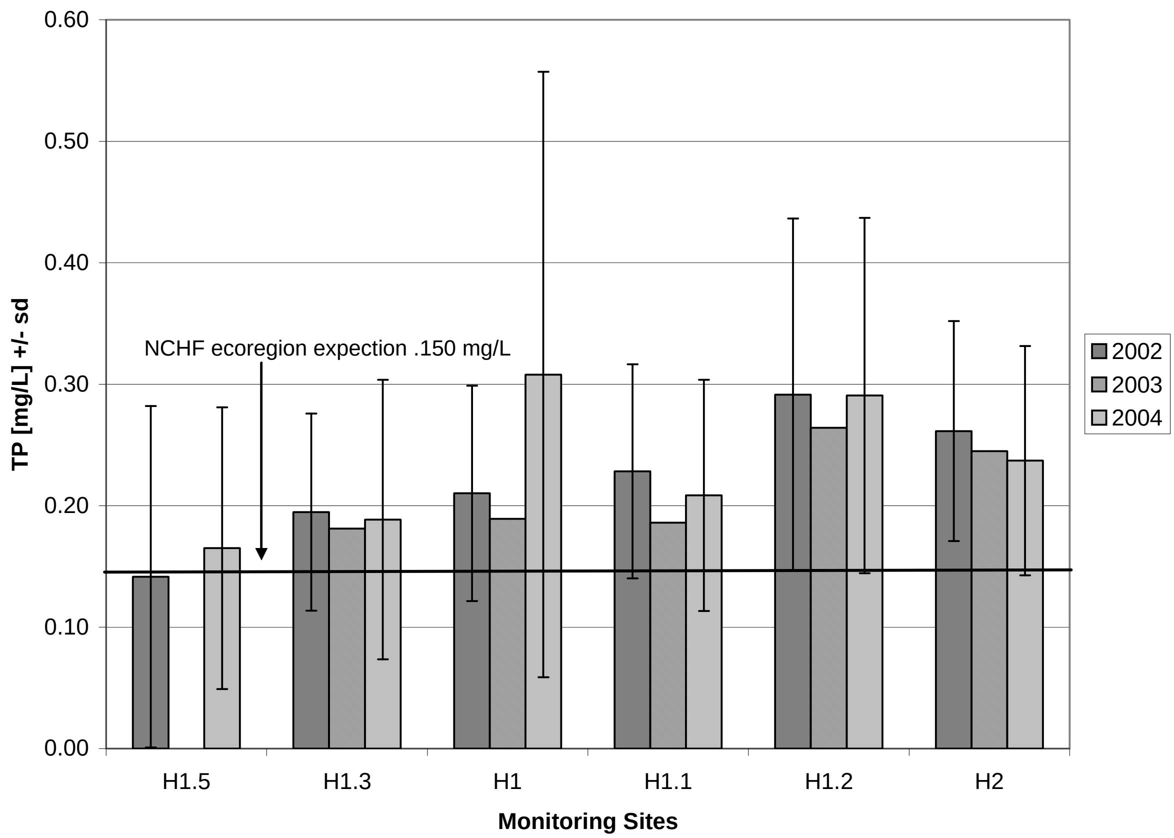


Figure 6. Annual Average Total Phosphorus Concentration along Hardwood Creek

Nitrogen

Concentrations of nitrite and nitrate-nitrogen (NO_2^-+NO_3^-) were compared to ecoregion expectations (McCollor and Heiskary 1993), which are defined as the 75th percentile of data collected from 1970-1992 (0.26 mg/L) at designated minimally impacted sites in the North Central Hardwood Forest Ecoregion. All monitoring sites, with the exception of H1.5, did not meet the ecoregion expectation of 0.26 mg/L of NO_2^-+NO_3^-.

The water quality standard for un-ionized ammonia for Hardwood Creek is 40 µg/L. None of the monitoring stations exceeded this water quality standard in 2004. Due to the low concentration of un-ionized ammonia, nitrogenous BOD was not considered a likely cause of low dissolved oxygen in Hardwood Creek.

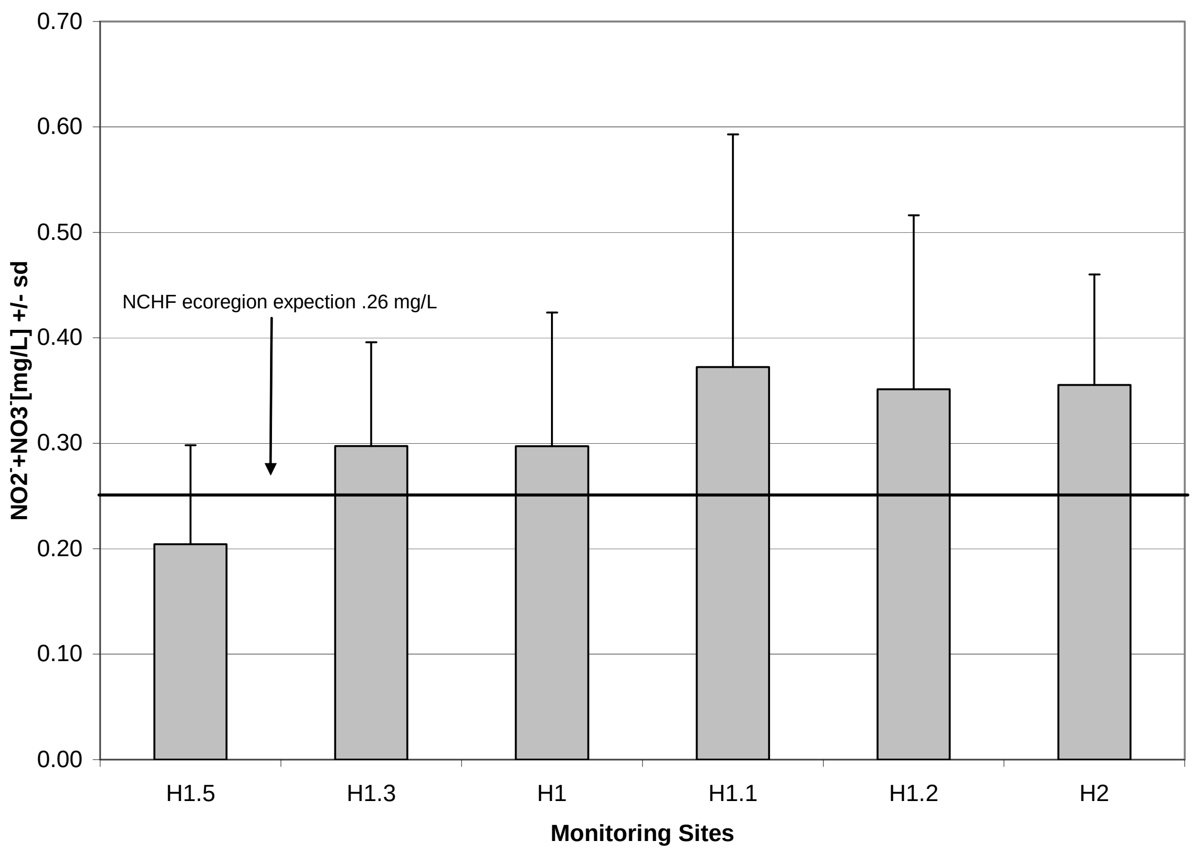


Figure 7. Annual Average Nitrate/Nitrite Concentration along Hardwood Creek

Total Suspended Solids (TSS)

Concentrations of TSS were compared to previous monitoring data and to ecoregion expectations (McCollor and Heiskary 1993), which are defined as the 75th percentile of data collected from 1970-92 (16 mg/L) at designated minimally impacted sites in the North Central Hardwood Forest Ecoregion. All monitoring sites had higher TSS concentrations in 2004 than in previous years. The was due to the minor maintenance of Judicial Ditch 2 that was conducted on the upstream portion of the creek during the winter of 2004. The maintenance activity caused nutrient and sediment concentrations to increase significantly during winter snowmelt. A more detailed documentation can be found in the "Report to MPCA on Minor Maintenance occurring on Judicial Ditch 2, Winter 2004 (Feb. – Mar.)" (found in Appendix D of the Washington County Judicial Ditch #2 Repair Report, which is Appendix D of the HWC TMDL report). Monitoring sites H1.5 and H1.3 met the ecoregion expectation of 16 mg/L for all monitoring years.

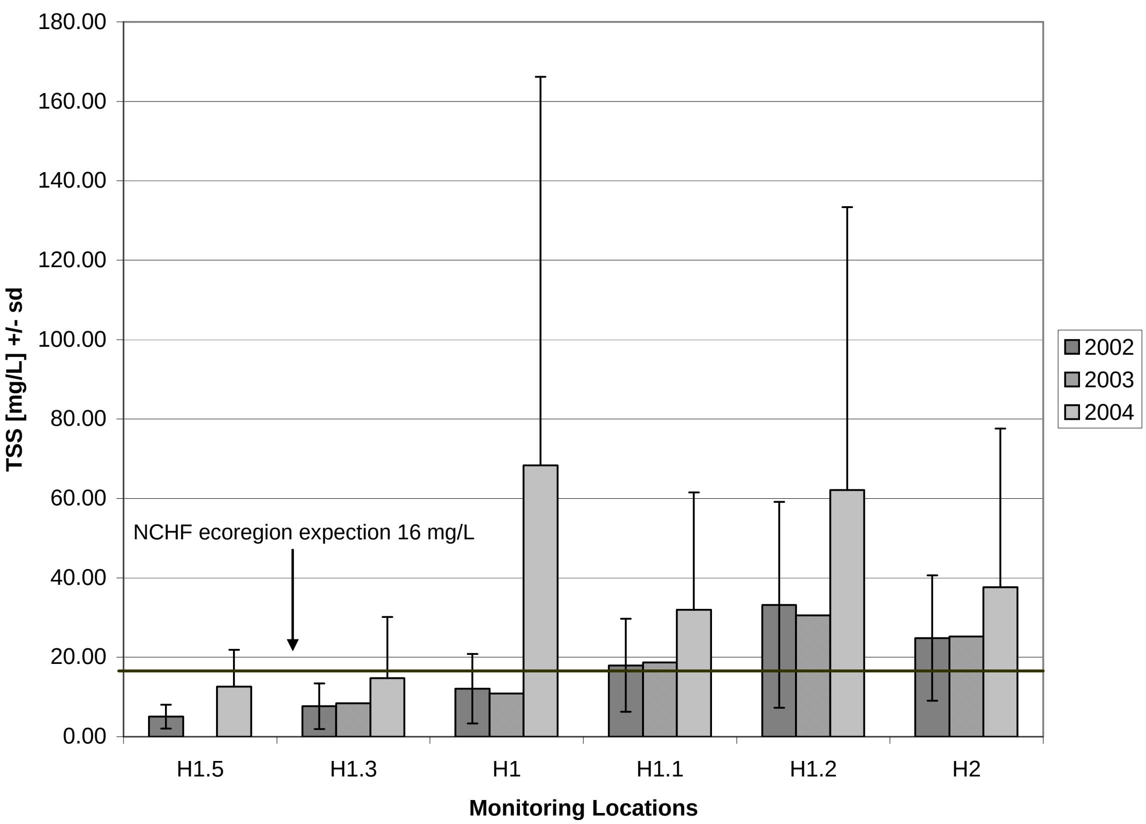


Figure 8. Annual Average Total Suspended Solids Concentration along

Dissolved Oxygen

Hardwood Creek was listed on the 303(d) list in 2004 for low dissolved oxygen. In the upper reaches of Hardwood Creek (from Rice Lake to Highway 61), data from the Northern Washington Groundwater Study (Washington County 2003) suggest that the low DO levels are influenced by the discharge of groundwater to the creek. In contrast, the low oxygen in the lower reaches is thought to be due to anthropogenic sources. To verify this hypothesis, direct measurements of groundwater into the upper portion of Hardwood Creek were taken in February 2004 and during spring and summer of 2005. In addition, water samples were taken to gain a better understanding of the physical and chemical processes that influence dissolved oxygen levels in groundwater and the creek. In addition to dissolved oxygen measurements the following parameters were analyzed:

- Major anions and cations, especially Fe^{2+} and Mn^{2+}
- Redox and eH potential
- Total organic carbon
- Organic carbon loading to the creek from groundwater
- Sources of organic carbon by fluorometric and/or isotopic methods

Results from these analyses indicate that the low dissolved oxygen in the upper reach of Hardwood Creek is due to organic loading naturally occurring in the peat sediments (Appendix A).

In addition, three continuous YSI dissolved oxygen probes were installed at H1.5, H1.3, and H2 for the duration of the summer. Probes were cleaned and calibrated on a bimonthly basis. Results indicate that during the summer months, dissolved oxygen drops below the standard of 5 mg/L at monitoring sites H1.5 and H1.3 (Figure 9 and Figure 10). At monitoring site H2, dissolved oxygen occasionally fell below this standard during the summer low flow period (Figure 11).

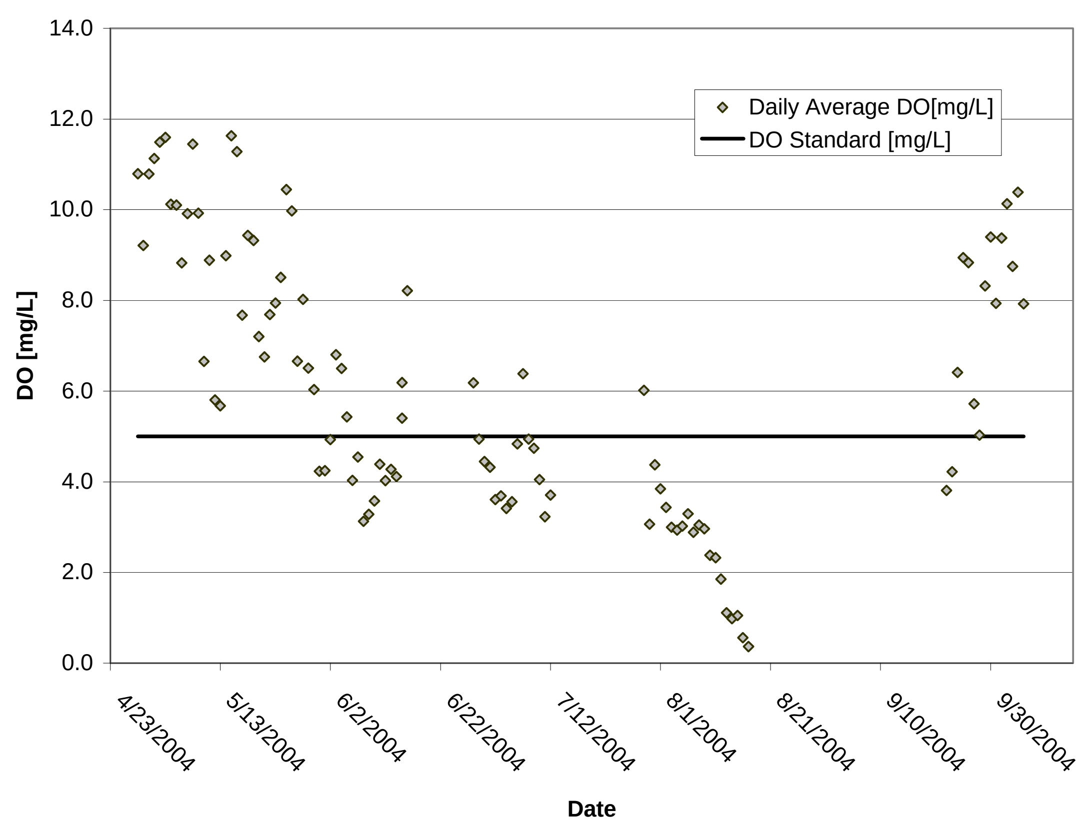


Figure 9. Daily Average Dissolved Oxygen Concentrations at monitoring site H1.5

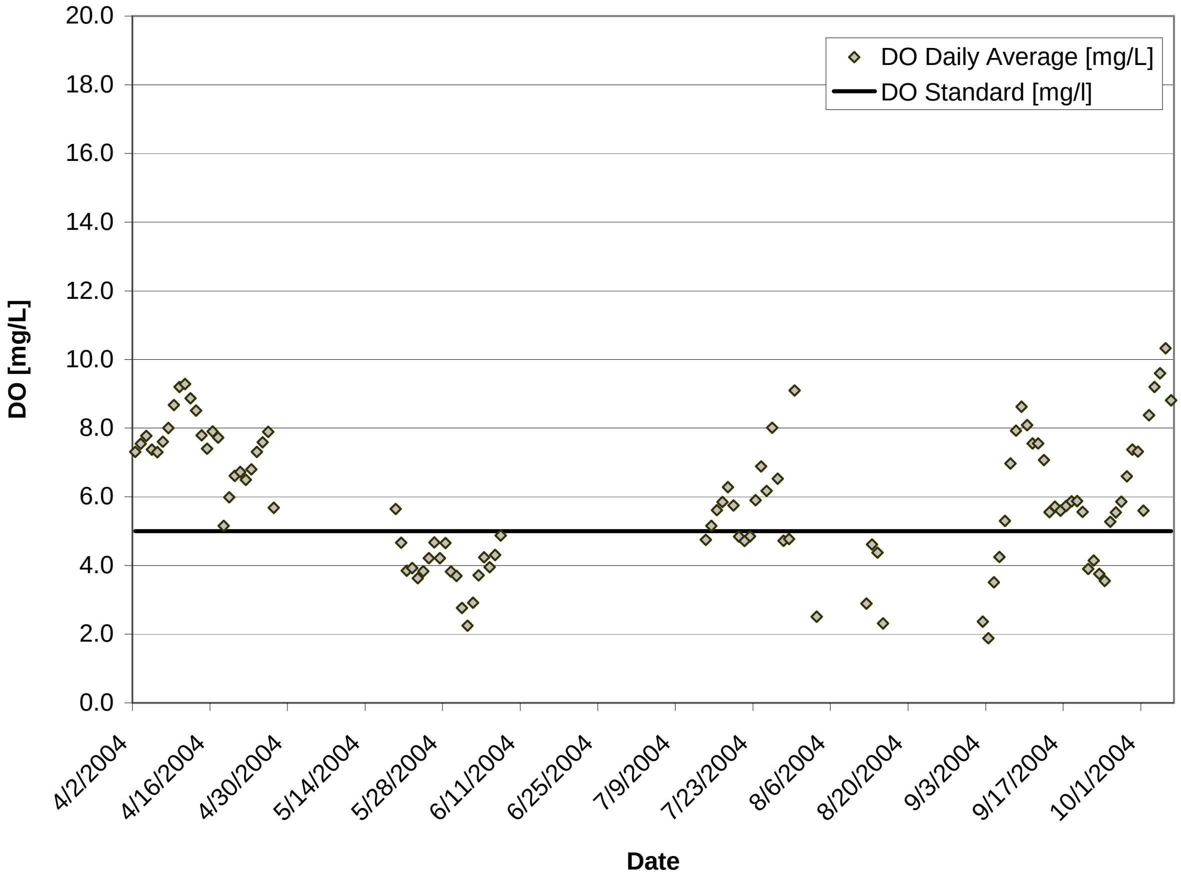


Figure 10. Daily Average Dissolved Oxygen Concentrations at monitoring site H1.3

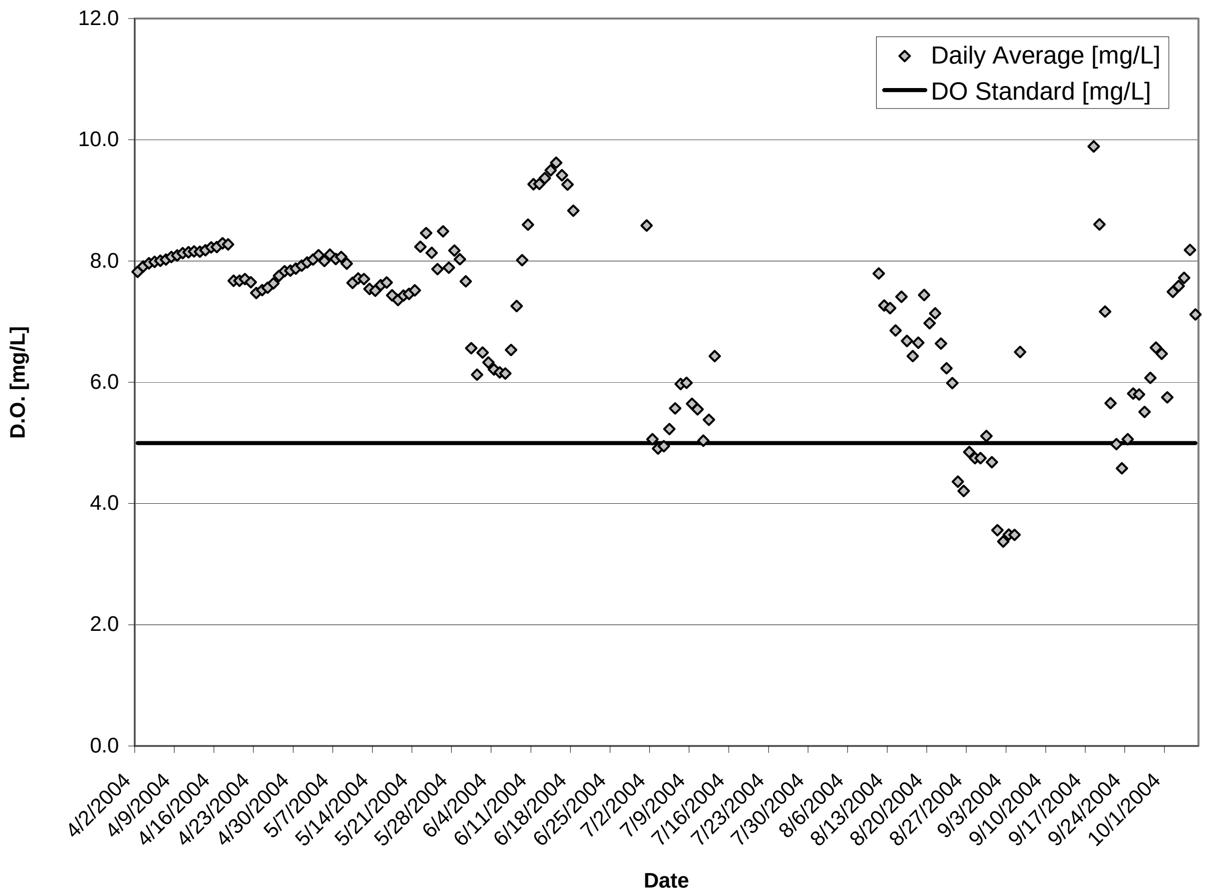


Figure 11. Daily Average Dissolved Oxygen Concentrations at monitoring site H2

Biological Oxygen Demand

Biological oxygen demand (BOD) was also analyzed at each monitoring site. Concentrations of BOD were compared to ecoregion expectations (McCollor and Heiskary 1993) which are defined as the 75th percentile of data collected from 1970-1992 (3.2 mg/L) at designated minimally impacted sites in the North Central Hardwood Forest Ecoregion. There are no historical BOD data, thus a comparison to previous years cannot be made. From the data collected, little recovery is seen through the Hardwood Creek system (Figure 12) indicating that upstream organic loadings likely affect downstream reaches. However, due to the maintenance that occurred in 2004, it is uncertain if these are the common conditions in Hardwood Creek. Additional monitoring needs to be collected to be able to sufficiently determine if the 2004 BOD concentrations were high due to maintenance or if they are reflective of common conditions in Hardwood Creek.

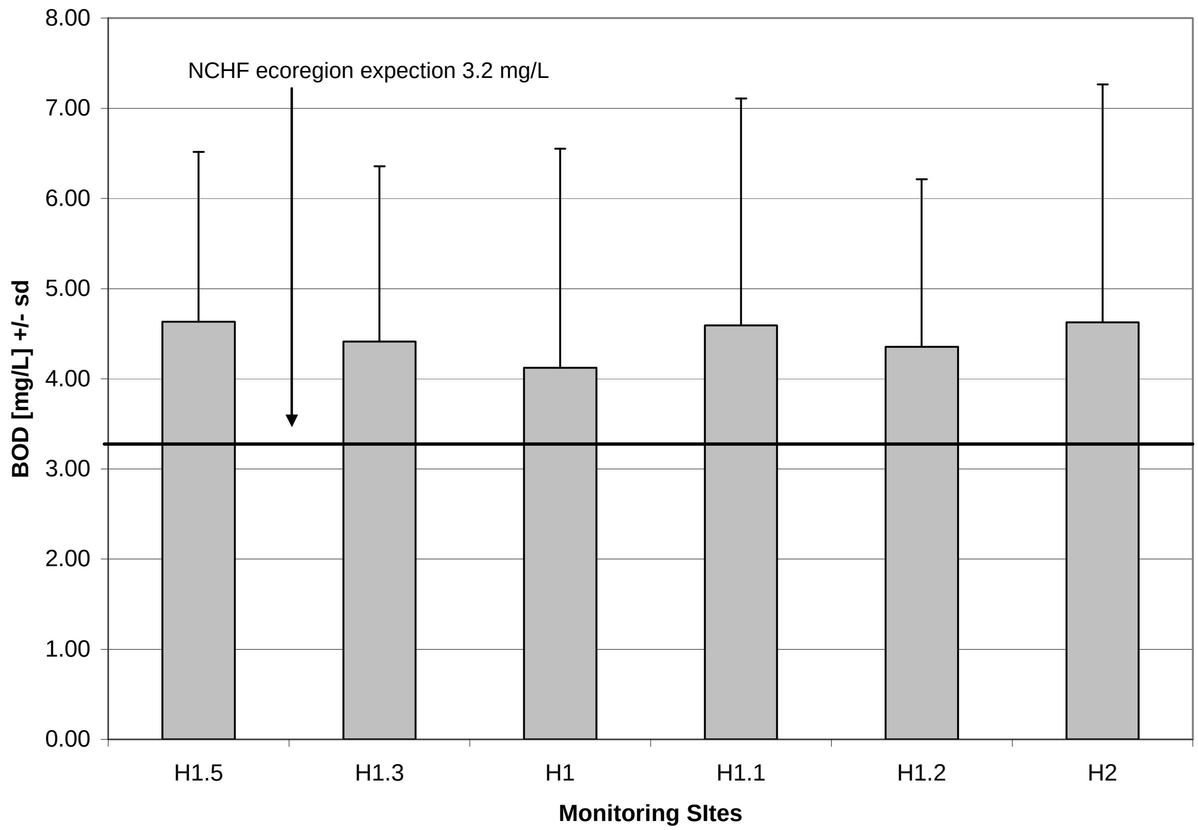


Figure 12. Annual Average Biological Oxygen Demand Concentrations

Heavy Metals, Pesticides, and Herbicides

On May 23, 2005, water samples were collected along Hardwood Creek and analyzed for heavy metals, pesticides, and herbicides. Data was collected during the spring as this is the time period that most farmers apply these types of chemicals. All samples were below both the MPCA water quality standards and detection limits, indicating that these toxins are not probable stressors in Hardwood Creek. Therefore this candidate cause was not evaluated further. Results are located in Section 6D: Lab Reports.

BIOLOGICAL DATA

Biological assessments and criteria address the cumulative impacts of all stressors, especially habitat degradation and chemical contamination, which result in a loss of biological diversity. To assess the current status of the biological community in Hardwood Creek, both fisheries data and macroinvertebrate data were collected and analyzed.

Fisheries

A fish survey was conducted on August 25, 2004 to obtain current data on species occurrence and relative abundance. The survey was conducted in the same reach that was sampled in 1999 by MN DNR Fisheries. The station was sampled using a stream shocker. Fish collected during the surveys were identified, tallied, and released.

The results of the survey were 380 fish representing ten species in seven families. Black bullhead, central mudminnow, and bluegill were the most abundant species and consisted of 49.7, 21.1, and 20.5 percent of the total catch, respectively. An Index of Biotic Integrity (IBI) was calculated to be 51. The Index of Biotic Integrity (IBI) created by the MPCA uses fish sampling data to indicate the overall health and integrity of a stream. The IBI assesses the health of fish communities using twelve different metrics. These twelve metrics fall into three categories: species composition, trophic composition, and fish abundance and condition. Data are obtained for each of these metrics at a given site, and a number rating is assigned to each metric. The sum of the twelve ratings yields an overall site score, with scores ranging from 0 for exceptionally poor quality to 100 for sites of exceptionally high quality. The IBI integrates information from individual, population, community, and ecosystem levels into a single ecologically based index of water resource quality. In comparison, in 1999, 30 fish representing 5 species in 5 families were surveyed. Central mudminnow and Johnny darter were the most abundant species and comprised 40.0 and 36.7 percent of the total catch, respectively. The result of the IBI was 38. The main difference between these two fish surveys may be the length sampled. In 2004, a 1000-ft stretch was sampled. The only difference this may have resulted in is a higher IBI score. The score of 51 is higher than 38 but is still indicative of a stressed system.

Macroinvertebrates

Macroinvertebrates were collected at monitoring sites H2 and H1.2 on May 2004 and October 7, 2004. Samples were collected using the EPA's RBP Protocol for Multiple Habitats. Twenty jabs were taken based on the percentage of available in-stream habitat. Macroinvertebrates collected were identified to the lowest practical taxonomic level. Results were submitted to MPCA.

Due to historic ditching, the lower portion of Hardwood Creek has considerably greater habitat heterogeneity than the upper reach. Environmental conditions in the upper reach make it extremely hard to sample fish. To gain a better understanding of the biological community in this section of the creek and how it compares to the section downstream of Highway 61, the University Of Minnesota Department of Entomology was contracted to evaluate Chironomidae in Hardwood Creek. In addition, the University of Minnesota also collected macroinvertebrates along Hardwood Creek using a dip net. The method uses dip-nets (DN) employed in a consistent manner and is described in Section E: Chironomidae of Hardwood Creek in Relation to Recent and Past Ditching Practices. While the methods of collecting both data sets prohibit these data from being used in IBI calculations, the continuous nature of the data set provides insight to the TMDL study.

Chironomidae and Macroinvertebrates

Chironomidae where evaluated in greater detail in Hardwood Creek because they consist of a majority of the benthic organisms found in the creek, and macroinvertebrates were evaluated in greater detail because macroinvertebrates are commonly collected by federal, state and local agencies. Several metrics were calculated from the data including species richness, biotic index based on tolerances of organic enrichment, and Brillouin's index (for a description of various metrics, see Section E). In addition, functional feeding groups and habitat preferences were evaluated to better understand the food web in Hardwood Creek.

The biotic index values calculated along Hardwood Creek indicated that most sites have fair water quality with significant organic enrichment. It is uncertain if these are common conditions in Hardwood Creek or if they are representative of the minor maintenance that occurred in the winter of 2004. Because the minor maintenance increased both coarse and fine organic material in the stream, it was hypothesized that there would be an increase in the presence of collector gatherers (organisms that consume coarse organic matter) and collector filterers (organisms that consume fine organic matter). These feeding groups will vary along different sections of the stream, as well as with certain influencing external factors, such as that of pollution. Typically, there are five functional feeding groups that macroinvertebrates belong to; Figure 13 shows the common percent contribution of each feeding group in relationship to stream size.

1) Collector-gatherers gather fine particulate organic matter (detritus) and/or small organisms as food sources
2) Collector-filterers use a filter to collect fine particulate organic matter (detritus) and/or small organisms as food sources
3) Shredders shred and chew coarse particulate organic matter (e.g., leaves, bark, etc.) as a food source
4) Scrapers scrape and graze biofilm, including diatoms and Cyanobacteria off of exposed surfaces as a food source
5) Predators eat other insects and macroinvertebrates as a main food source

Percent EPT in Hardwood Creek was low at all monitoring sites. However, monitoring site H1.1 had the highest percentage of EPT with a moderate ranking. Percent Chironomidae was ranked low at all monitoring sites except for monitoring site H1.5, which had a high ranking. It is believed that this ranking is a result of the maintenance that took place in this stretch. As a result of this disturbance, Hirudeana and Gastropoda have dominated the benthic community allowing little colonization of other invertebrates. Percent dominance of the top three taxa also ranked low at all sites as all sites were greater than 50%. Overall, the Chironomidae and macroinvertebrates showed a distinct difference between the stretch of Hardwood Creek upstream and downstream of Highway 61. Downstream of Highway 61, metrics calculated were consistent with the both the fisheries data collected at monitoring site H.2 and the macroinvertebrates collected using MPCA protocol at H.2 and H1.2.

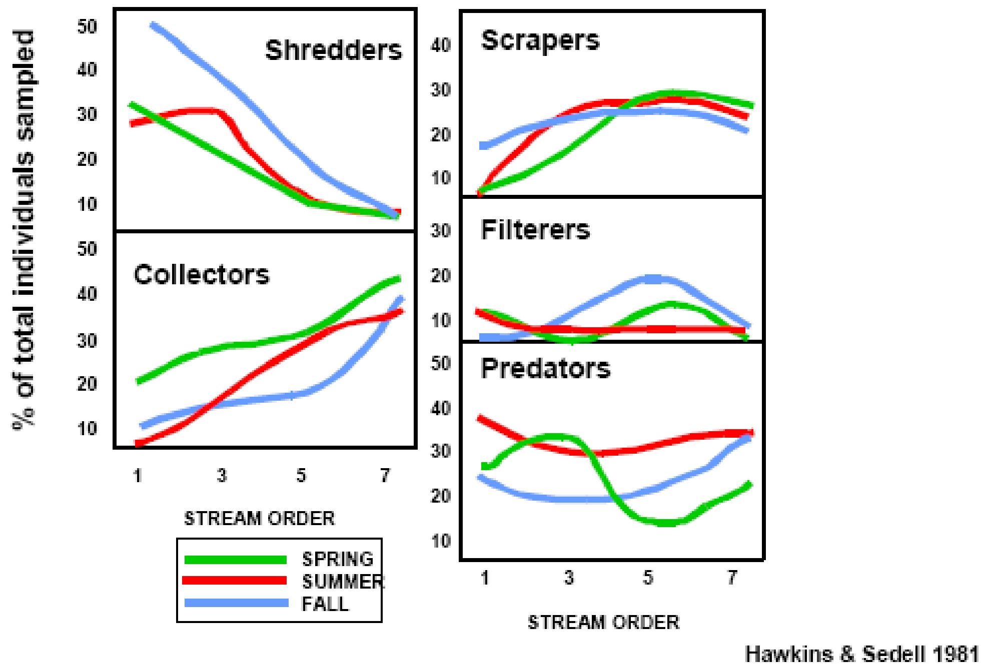


Figure 13. Longitudinal and Seasonal Trends in Functional Feeding Groups

4. Characterize Causes

While the three candidate causes evaluated for the strength of evidence are listed separately, these three causes interact and have a cumulative impact on the biota of the creek. Table 2 lists the three candidate causes analyzed in the strength of evidence evaluation and includes the parameters that were examined for each candidate cause. Water quality parameters included in the table are means from 2002-2004 unless otherwise noted, with the exception of monitoring site H2, which are based on data from 1999-2004. For each water quality parameter, the goal is also included. Due to the unconsolidated bottom in upper reach, no in-stream habitat data was collected for sites H1.5 through H1. Table 3 summarizes the evidence weighed in the analysis of likely stressors in Hardwood Creek.

Table 2. Parameters and Potential Effects at Monitoring Sites along Hardwood Creek

Candidate Cause	Parameter	Site H1.5 (std)	Site H1.3 (std)	Site H1 (std)	Site H1.1 (std)	Site H1.2 (std)	Site H2 (std)	Goal
Sediment	TSS (mg/L)	8.4	14.7	31.5	21.9	40.4	26.6	16
	D50 (mm)				0.15	0.41	0.23	NA
	% Sand and Silt				95%	66%	70%	NA
	% Course substrates				5%	34%	30%	NA
	Bed Shear stress (lbs/ft2)				4.25	0.5	0.1	NA
	Gradient (%)				0.325	0.21	0.2	NA
	Width:Depth				5.7	6.7	14.9	NA
	Entrenchment				8.1	1.8	3.3	NA
	Bank Erosion				Yes	Yes	Yes	NA
	Collapsed Banks				Yes	Yes	Yes	NA
	% EPT			18.6	32	14	23	NA
	% Chironomidae			52	47	68	57	NA
Low dissolved oxygen	TP (mg/L)	0.14	0.18	0.23	0.21	0.27	0.25	0.15
	SRP (mg/L)	0.07	0.09	0.1	0.1	0.12	0.14	NA
	TKN (mg/L)	1.36	1.42	1.87	1.43	1.62	1.58	NA
	NO_2^-+NO_3^-	0.12	0.12	0.16	0.23	0.24	0.3	0.26
	BOD (mg/L)	4.6	4.4	4.1	4.6	4.4	4.6	3.2
	% Cover	0%	10%	10%	50%	75%	60%	NA
	Biotic Index			6.4	6	6.2	6.2	NA
Excess nutrients	BOD (mg/L)	4.6	4.4	4.1	4.6	4.4	4.6	3.2
	SRP (mg/L)	0.07	0.09	0.1	0.1	0.12	0.14	NA
	NO_2^-+NO_3^-	0.12	0.12	0.16	0.23	0.24	0.3	0.26
	TSS (mg/L)	8.4	14.7	31.5	21.9	40.4	26.6	16
	Turbidity (NTU)	17	13	15		21	19	25
	Biotic Index			6.4	6	6.2	6.2	NA

Table 3. Strength of Evidence Table for Three Candidate Causes of Biological Impairment in Hardwood Creek

	Consideration	Sediment		Low Dissolved Oxygen (due to organic matter)		Low Dissolved Oxygen (due to nutrient enrichment)		Nutrient Enrichment (altering food resources)	
		Results	Score	Results	Score	Results	Score	Results	Score
Case – Specific Evidence	Spatial Co-occurrence	Non-attainment observed in areas with high percent fines, high width to depth ratios, low D50s and low habitat scores. Monitoring sites H1.5, H1.3, and H1 have unconsolidated bottoms and altered habitat due to channelization. Downstream monitoring sites H1.1, H1.2, and H2 have inconsistent Rosgen values and low habitat scores indicating sediment and altered hydrology are likely stressors.	++	Non-attainment observed in areas with low dissolved oxygen. No evidence of recovery of BOD in system. Dissolved oxygen concentration on average are higher in Reach 2 than in Reach 1 due to higher stream gradient and more natural stream conditions.	++	Uncertain: Phosphorus and nitrogen increases as you move downstream with all sites, with the exception of H1.5, elevated above recommended levels. Non-attainment in these areas.	++	No data was collected at monitoring site H2. Observational data does not indicate excessive algae blooms throughout the system. A few blooms were observed in stagnant areas around the culverts of monitoring sites H1.5 and H1.3	NE
	Temporality	No observations made prior to historical creation of Judicial Ditch 2	NE	No observations made prior to historical creation of Judicial Ditch 2	NE	No observations made prior to historical creation of Judicial Ditch 2	NE	No observations made prior to historical creation of Judicial Ditch 2	NE
	Consistency of Association	At monitoring site H2, a 2004 fish survey resulted in an IBI that would suggest attainment. However, a longer reach of stream was sampled which may have resulted in the slightly higher IBI score. 2004 macroinvertebrate data collected at monitoring sites H2 and H1.2 indicate non-attainment for the M-IBI. Additional Chironomidae and macroinvertebrate data also show low EPT values, high % Chironomidae values.	+	At monitoring site H2, a 2004 fish survey resulted in an IBI that would suggest attainment. 2004 macroinvertebrate data collected at monitoring sites H2 and H1.2 indicate non-attainment for the M-IBI	+	At monitoring site H2, a 2004 fish survey resulted in an IBI that would suggest attainment. 2004 macroinvertebrate data collected at monitoring sites H2 and H1.2 indicate non-attainment for the M-IBI. Supplemental Chironomidae data and macroinvertebrate data show high biotic index values.	+	Nutrient enrichment increases as you move downstream. Fish and invertebrate communities are more diverse in Reach 2.	-
	Biological Gradient	No evidence from fish data as only site H2 was sampled but macroinvertebrate data indicate a difference from Reach 1 and 2. Reach 1 has considerably less microhabitat heterogeneity than Reach 2. EPT was low for all sites. However, dissolved oxygen and nutrient enrichment may have some interference.	++	No evidence from fish data but macroinvertebrate data indicates a difference from Reach 1 and 2. In addition, the Biotic Index indicates that all sites along Hardwood Creek are experiencing some organic enrichment. However, most of the organic enrichment comes from the disturbance of upstream peatlands. BOD data collected in 2004 indicate elevated levels at all monitoring sites. It is uncertain if levels are elevated due to 2004 winter maintenance or if they normal. Small diel shifts in dissolved oxygen levels indicate that for 2004, organic matter is most likely cause of dissolved oxygen.	++	Habitat alteration interferes with this consideration. However, no observational data on excessive algal mats or blooms. Looking at macroinvertebrate functional feeding groups, scrapers were not dominant and made up less than 5% of the biological community. It is uncertain what role the 2004 winter maintenance had on the biological community. Anoka County Volunteer Stream Monitoring saw a shift in the dominant family go from a filter feeder to a shredder indicating that the macroinvertebrate community did respond to the maintenance. Small diel shifts in dissolved oxygen levels indicate that for 2004, nutrient enrichment is not the prominent cause of dissolved oxygen.	-	Not applicable: Low dissolved oxygen and habitat alteration interfere with this consideration	NA
	Complete exposure pathway	Evidence for all steps. In-stream habitat degradation due to high sediment well documented.	+++	Evidence for all steps. Low dissolved oxygen well documented. In Reach 1, low dissolved oxygen is naturally occurring. In Reach 2, dissolved oxygen is low during summer critical flow conditions.	++	Uncertain: Nutrient concentrations are elevated and would be available for algal growth. Concentrations of algae or chlorophyll a were not measured	+	Uncertain: Nutrient concentrations are elevated and would be available for algal growth. Concentrations of algae or chlorophyll a were not measured	0
	Experiment	No evidence	NE	No evidence	NE	No evidence	NE	No evidence	NE

Table 3. Strength of Evidence Table for Three Candidate Causes of Biological Impairment in Hardwood Creek, cont.

	Consideration	Sediment		Low Dissolved Oxygen (due to organic matter)		Low Dissolved Oxygen (due to nutrient enrichment)		Nutrient Enrichment (altering food resources)	
		Results	Score	Results	Score	Results	Score	Results	Score
Based on other situations of biological knowledge	Plausibility: Mechanism	Loss of species: Lack of habitat heterogeneity and embedded substrate limit forage, reproductive, and cover habitats for fish and invertebrates.	+	Loss of species: Low dissolved oxygen is not tolerated by many species of fish and macroinvertebrates (Allen, 1995).	+	Loss of species: Low dissolved oxygen is not tolerated by many species of fish and macroinvertebrates (Allen, 1995).	+	Loss of species: Increases in autochthonous energy could alter individuals and communities of fish and macroinvertebrates.	+
	Plausibility: Stressor Response	Loss of species: Fish species can migrate out of areas with low dissolved oxygen. Macroinvertebrates don't have this ability.	+	Loss of species: Fish species can migrate out of areas with low dissolved oxygen. Macroinvertebrates don't have such ability. It is well documented that dissolved oxygen in aquatic systems can cause mortality, reduced growth rates, reproductive failure, and decreases in food availability.	+	Loss of species: Fish species can migrate out of areas with low dissolved oxygen. Macroinvertebrates don't have such ability. It is well documented that dissolved oxygen in aquatic systems can cause mortality, reduced growth rates, reproductive failure, and decreases in food availability.	+	Loss of species: In systems with altered food resources, omnivores are dominant.	+
	Consistency of Association	Loss of species: In agricultural areas with or adjacent to channelization, showed similar decreases in IBI and M-IBI metrics (Sovell, etc).	++	Loss of species: Fish kills occur in Minnesota streams and lakes that have low dissolved oxygen levels. In areas of Minnesota where dissolved oxygen levels are marginal, IBI and M-IBI scores are generally low.	+	Loss of species: Fish kills occur in Minnesota streams and lakes that have low dissolved oxygen levels. In areas of Minnesota where dissolved oxygen levels are marginal, IBI and M-IBI scores are generally low.	+	Loss of species: At many sites in Minnesota, IBI and M-IBI scores were above attainment criteria at these levels of phosphorus and nitrogen (MPCA, 2003).	-
	Specificity of Cause	Loss of species: Several	0	Loss of species: Several	0	Loss of species: Several	0	Loss of species:	0
	Analogy	Not applicable	NA	Not applicable	NA	Not applicable	NA	Not applicable	NA
	Experiment	Loss of species: Studies using artificial substrate and created pool and riffles, improved fish in the Mississippi River	+++	No evidence	NE	No evidence	NE	No evidence	NE
	Predictive Performance	No evidence	NE	No evidence		NE	No evidence	NE	No evidence

	Consideration	Sediment		Low Dissolved Oxygen (due to organic matter)		Low Dissolved Oxygen (due to nutrient enrichment)		Nutrient Enrichment (altering food resources)	
		Results	Score	Results	Score	Results	Score	Results	Score
Multiple Lines of Evidence	Consistency of Evidence	Loss of species: All consistent	+++	Loss of species: All consistent	++	Loss of species: Magnitude of change inconsistent with magnitude of effect. However, situation masked by changes in topographic and geomorphic conditions	+	Inconsistent: Magnitude of change inconsistent with magnitude of effect	--
	Coherence of Evidence	Loss of species: None	0	Loss of species: None	0	Loss of species: None	0	Loss of species: None	0

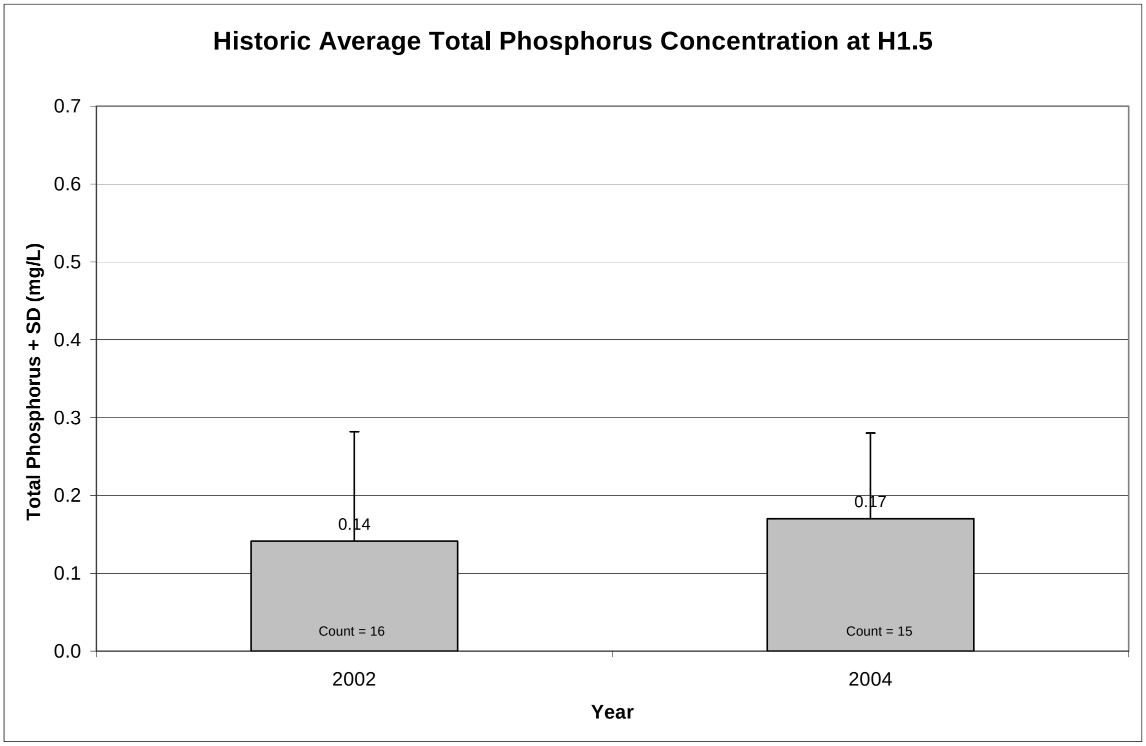
5. Sufficiency of Evidence

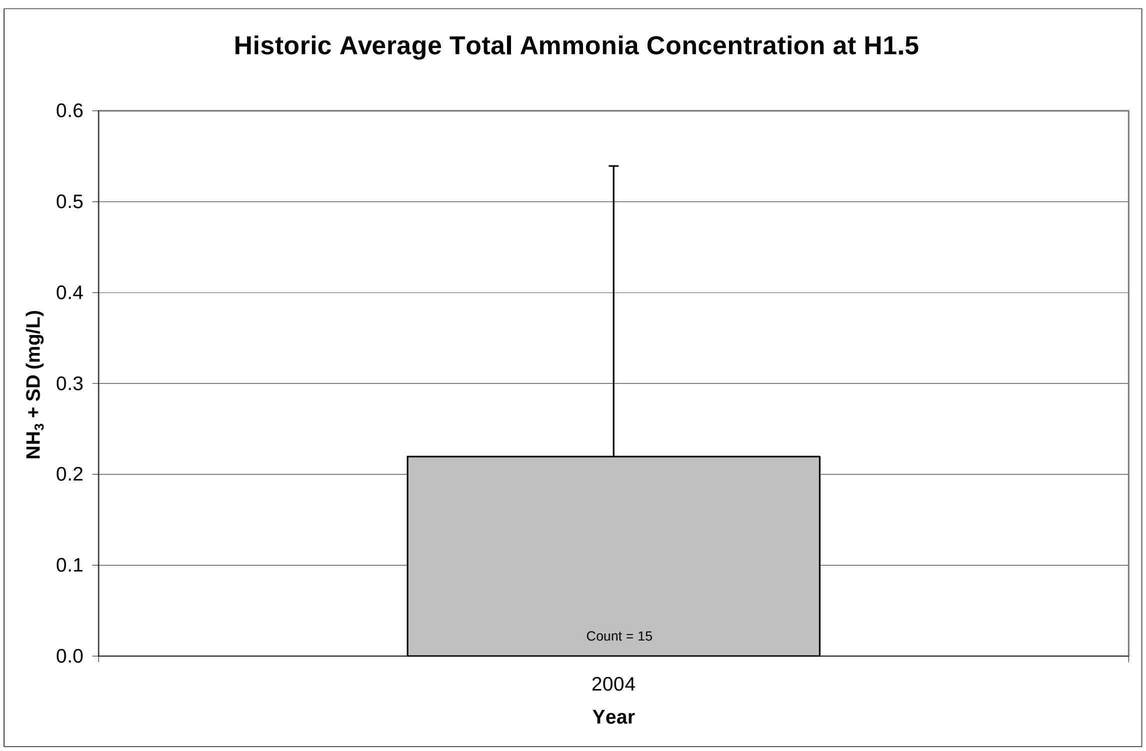
At monitoring site H2 there is a decline in the IBI that is characterized by a decreased number of fish species. Candidate cause #4 (heavy metals, pesticides, and herbicides) was eliminated. Candidate causes #1 (sedimentation), #2 (low dissolved oxygen), and #3 (nutrient enrichment) were evaluated in the strength of evidence analysis. The strength of evidence strongly supports a causal relationship between low IBI scores and high sediment and low dissolved oxygen. Nutrient enrichment is likely to have some influence on the low IBI score but the strength of evidence analysis did not strongly support a causal relationship. Phosphorus enrichment is being addressed in the Peltier Lake eutrophication TMDL (lake ID 02-0004-00), the water body that Hardwood Creek outlets into. WLAs and LAs for phosphorus are being established as part of the Peltier Lake TMDL, which covers the Hardwood Creek watershed.

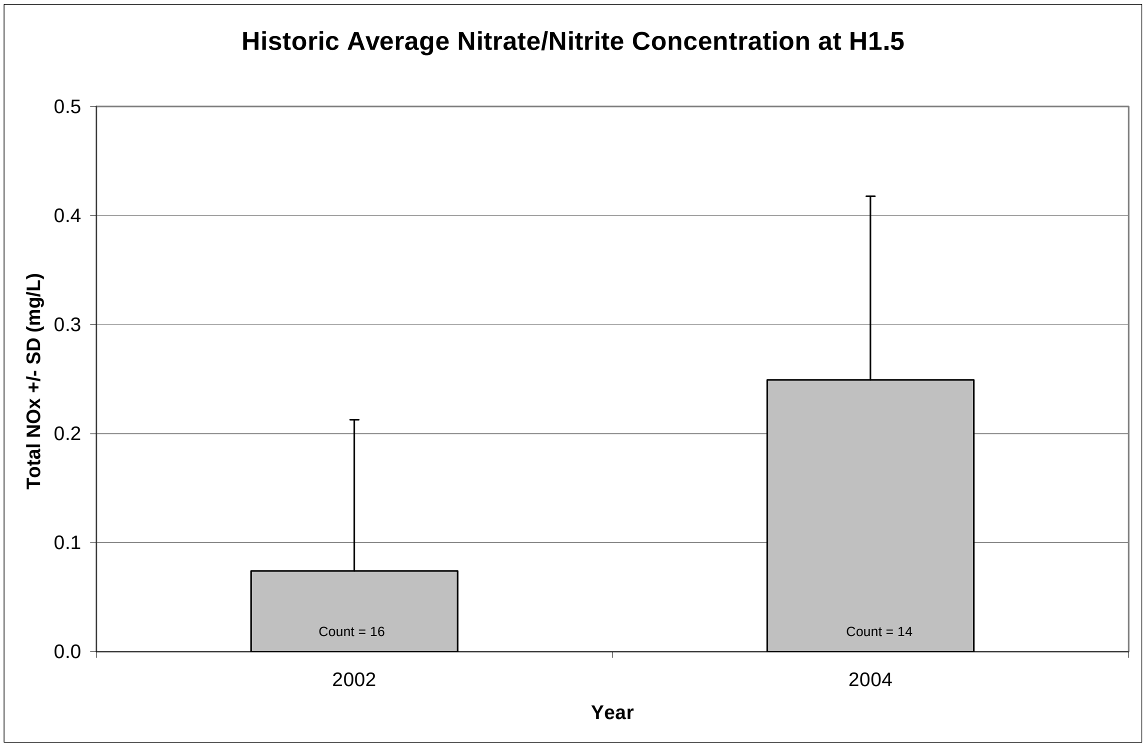
6. Supporting Data

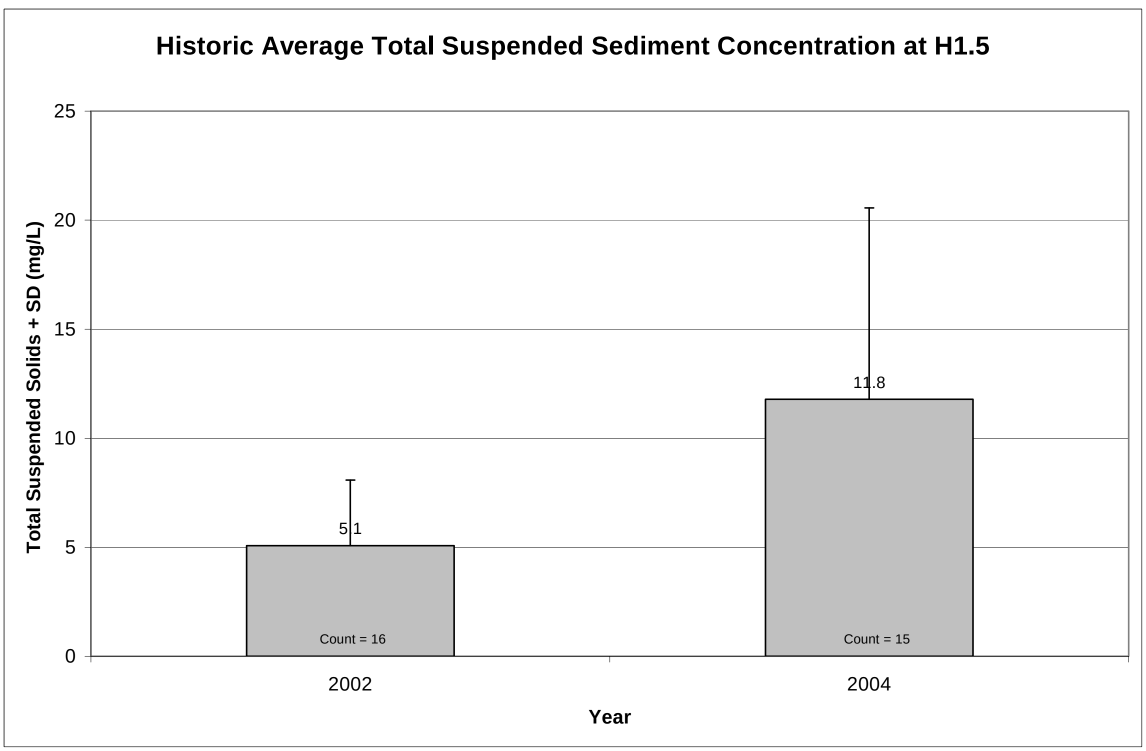
A. Historical Monitoring Data

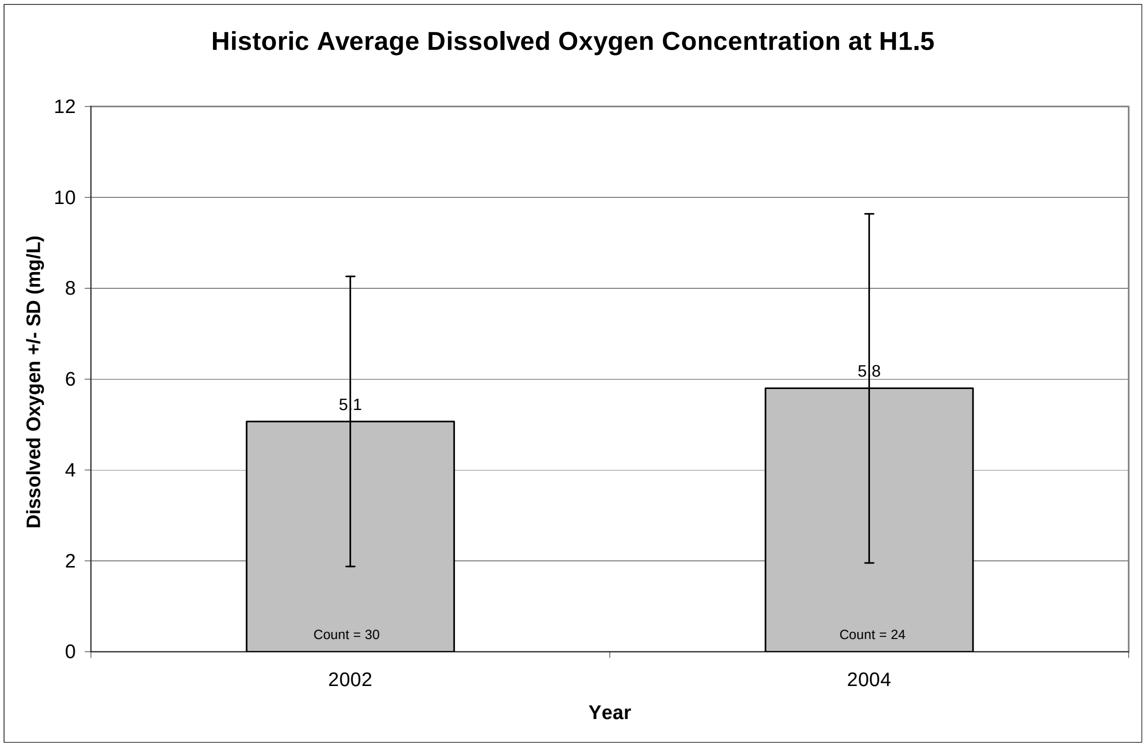
Site H1.5

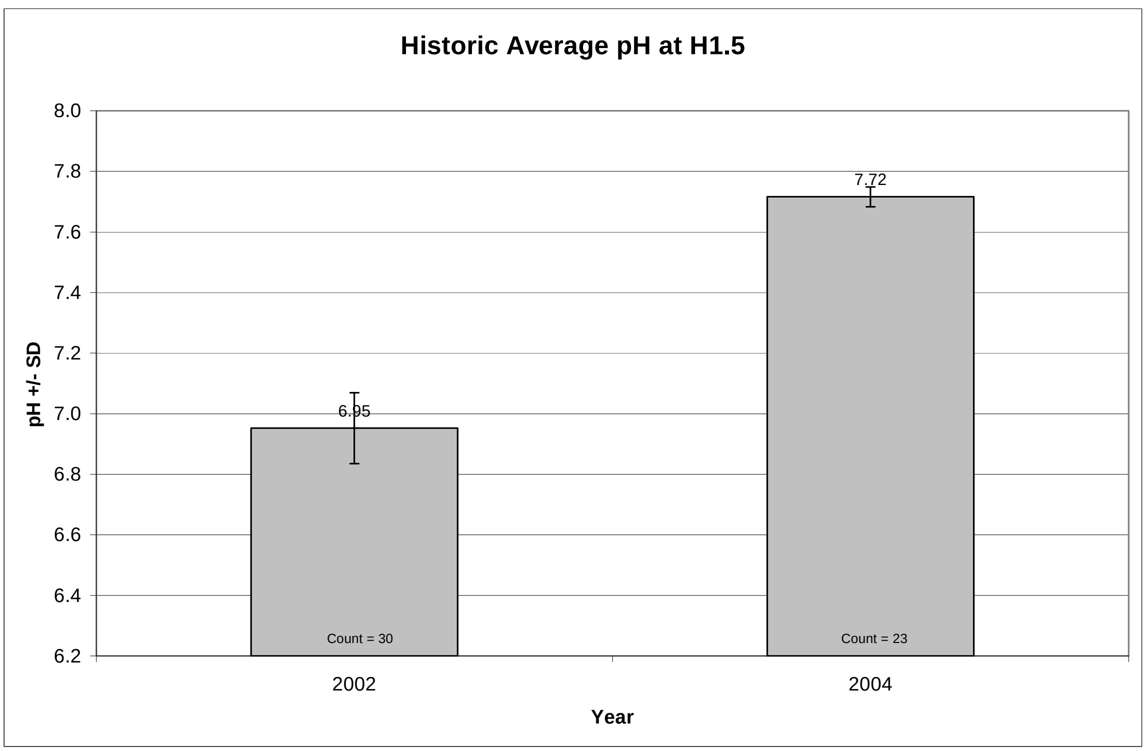


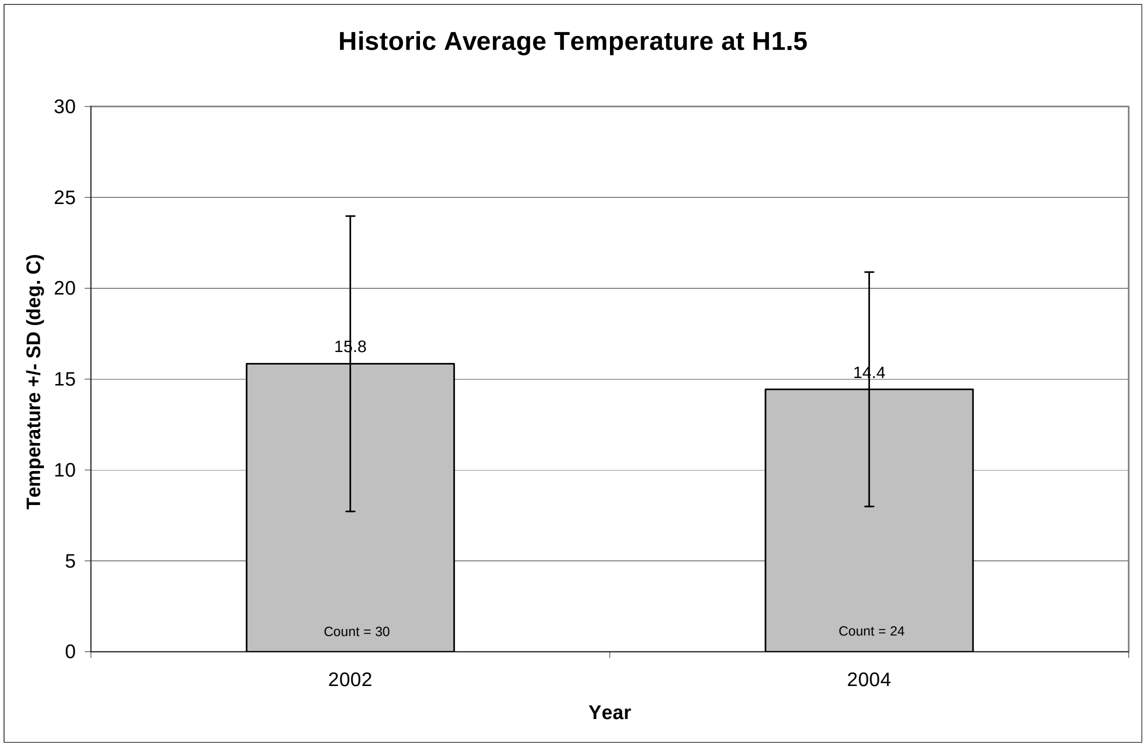



Historic Average Nitrate/Nitrite Concentration at H1.5
Total NOx +/- SD (mg/L)
0.5
0.4
0.3
0.2
0.1
0.0
Count = 16
Count = 14
2002
2004
Year


Historic Average Total Suspended Sediment Concentration at H1.5
Total Suspended Solids + SD (mg/L)
25
20
15
10
5
0
5.1
11.8
Count = 16
Count = 15
2002
2004
Year

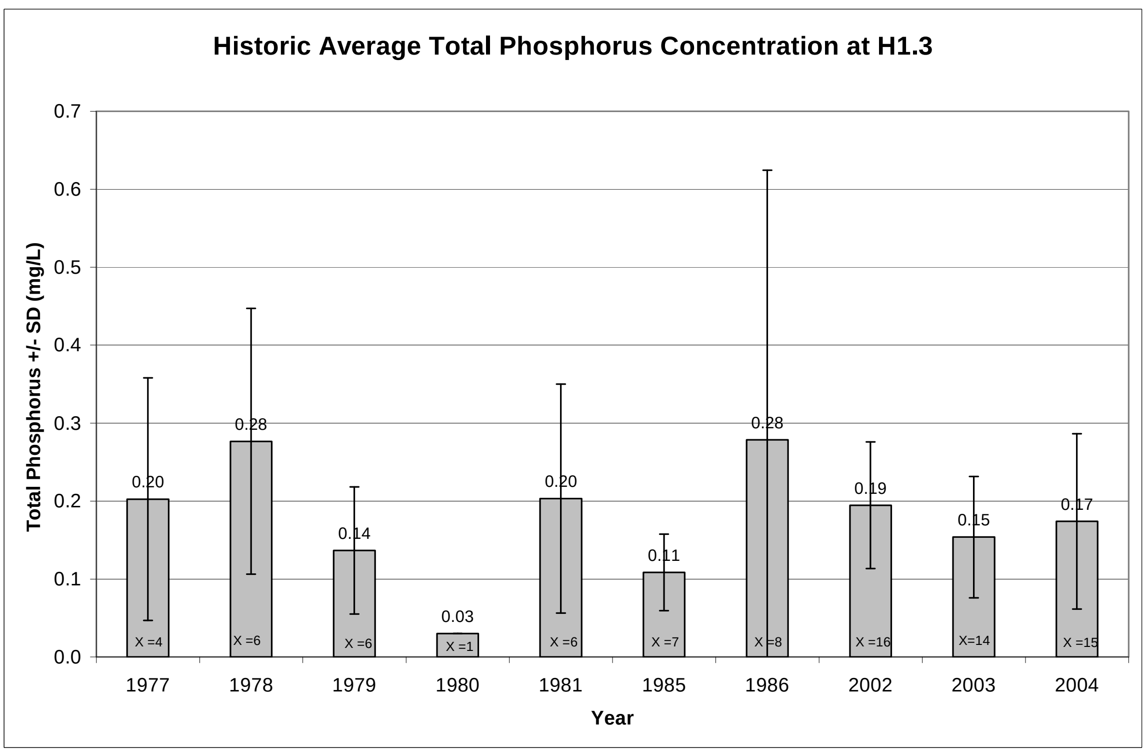

Historic Average Dissolved Oxygen Concentration at H1.5
Dissolved Oxygen +/- SD (mg/L)
12
10
8
6
4
2
0
5.1
5.8
Count = 30
Count = 24
2002
2004
Year


Historic Average pH at H1.5
pH +/- SD
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.95
7.72
Count = 30
Count = 23
2002
2004
Year

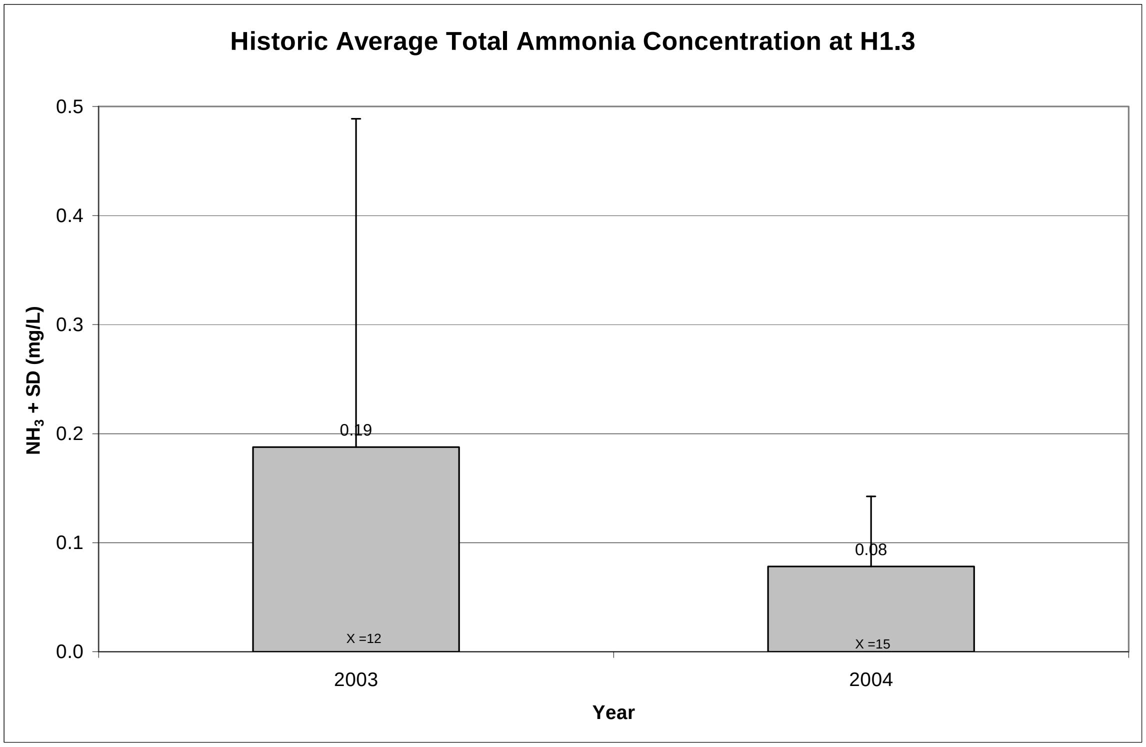


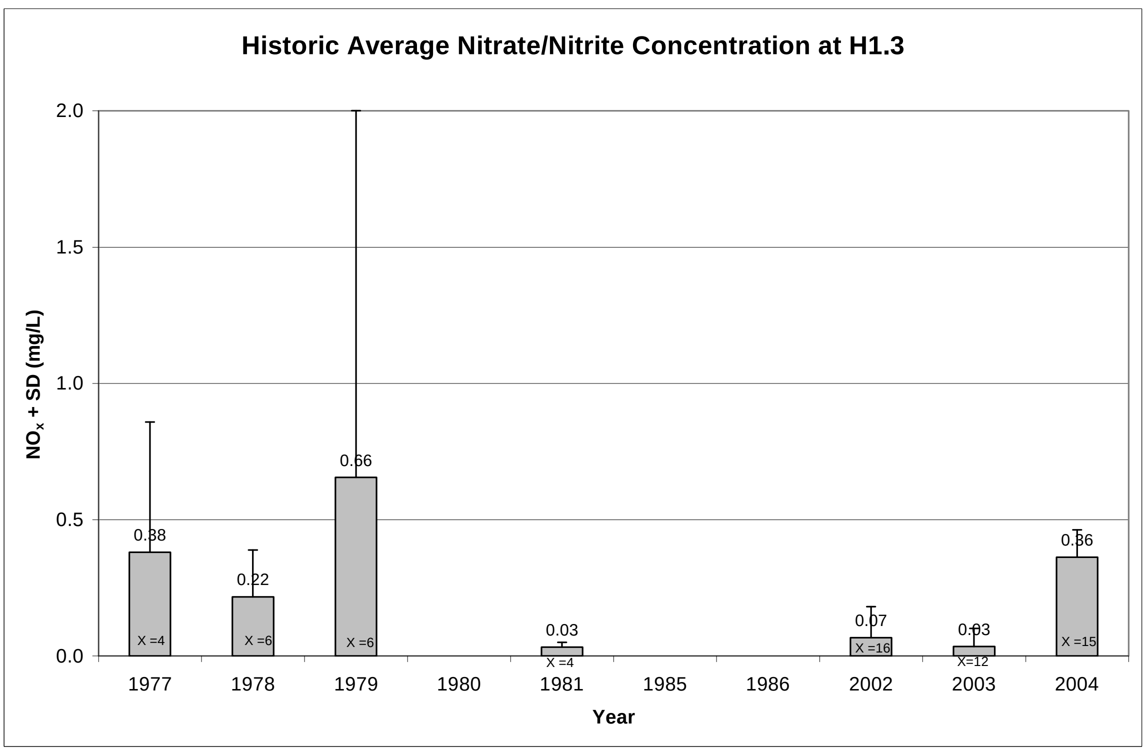
Historic Average Temperature at H1.5
Temperature +/- SD (deg. C)
30
25
20
15
10
5
0
15.8
14.4
Count = 30
Count = 24
2002
2004
Year

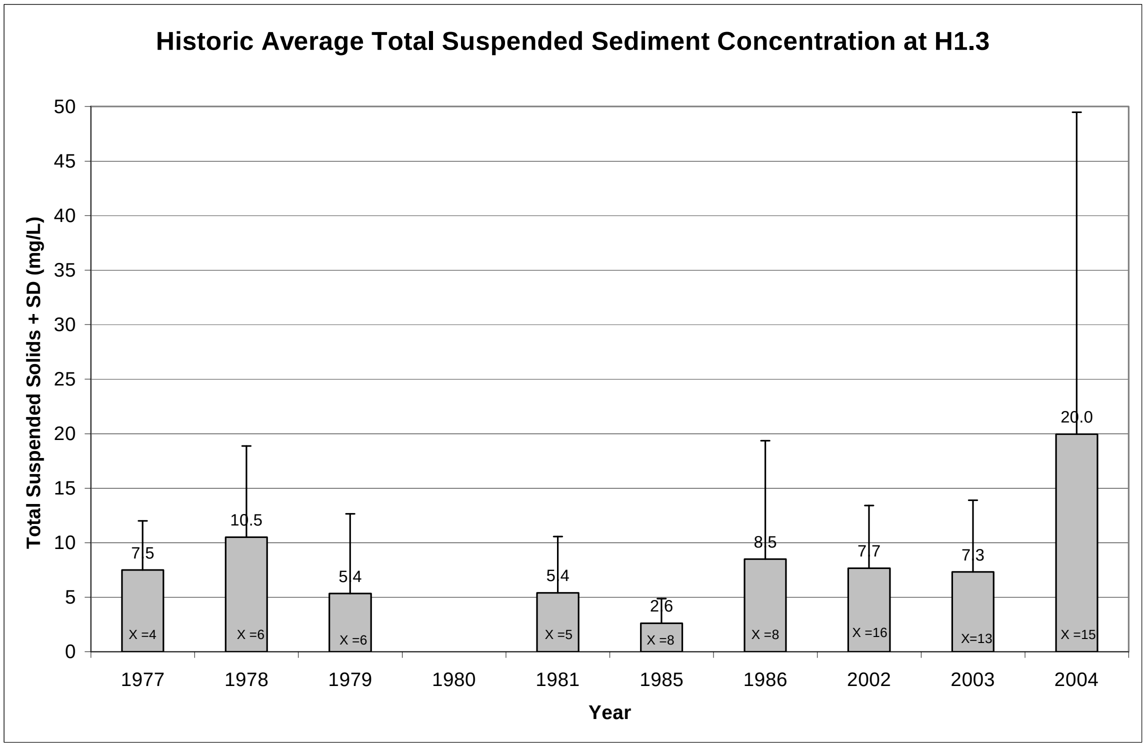
Site H1.3

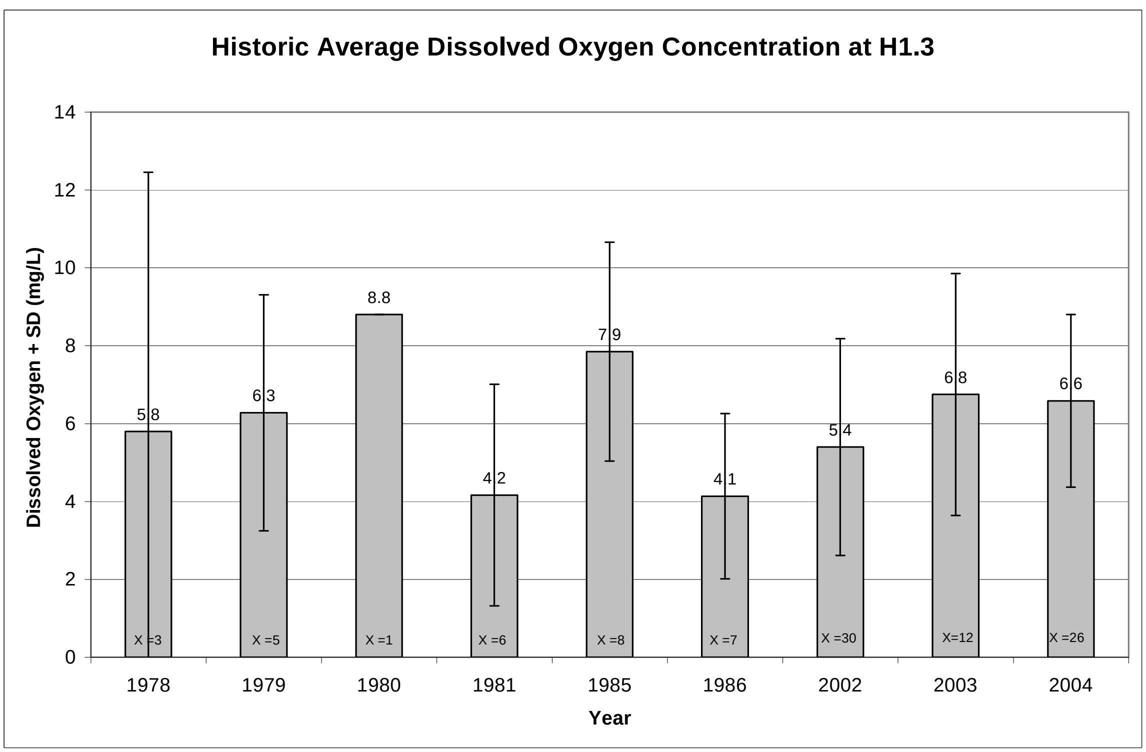


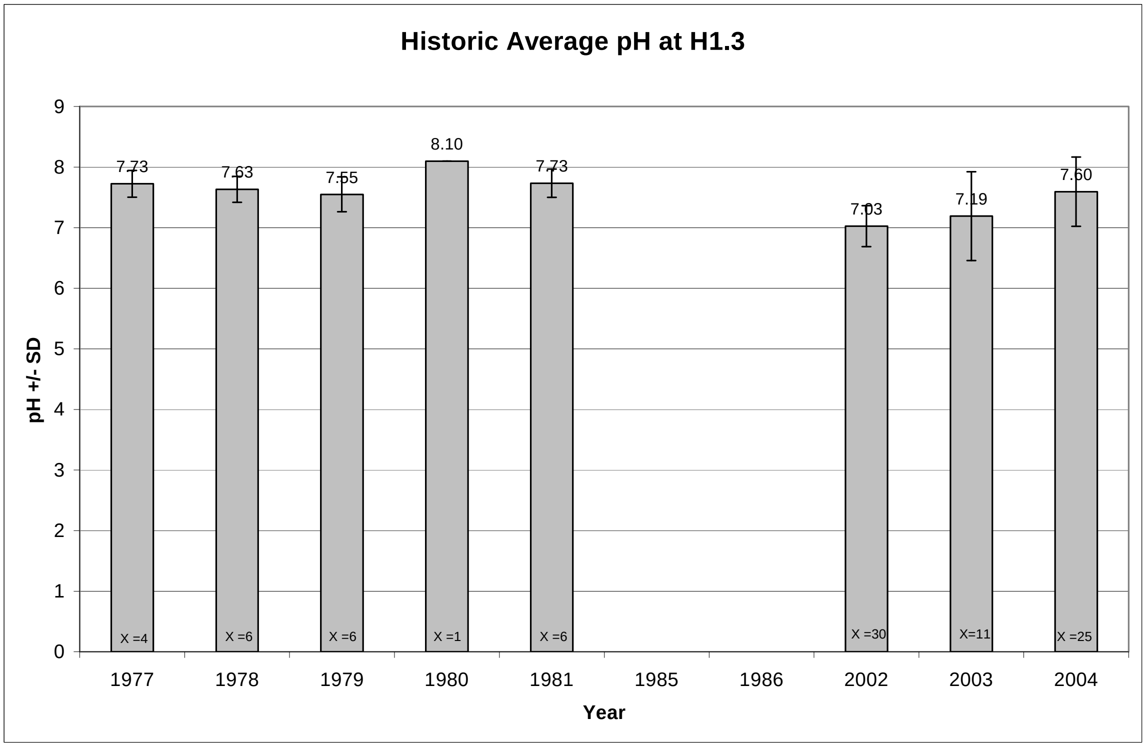
Historic Average Total Phosphorus Concentration at H1.3
Total Phosphorus +/- SD (mg/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.20
0.28
0.14
0.03
0.20
0.11
0.28
0.19
0.15
0.17
X =4
X =6
X =6
X =1
X =6
X =7
X =8
X =16
X=14
X =15
1977
1978
1979
1980
1981
1985
1986
2002
2003
2004
Year

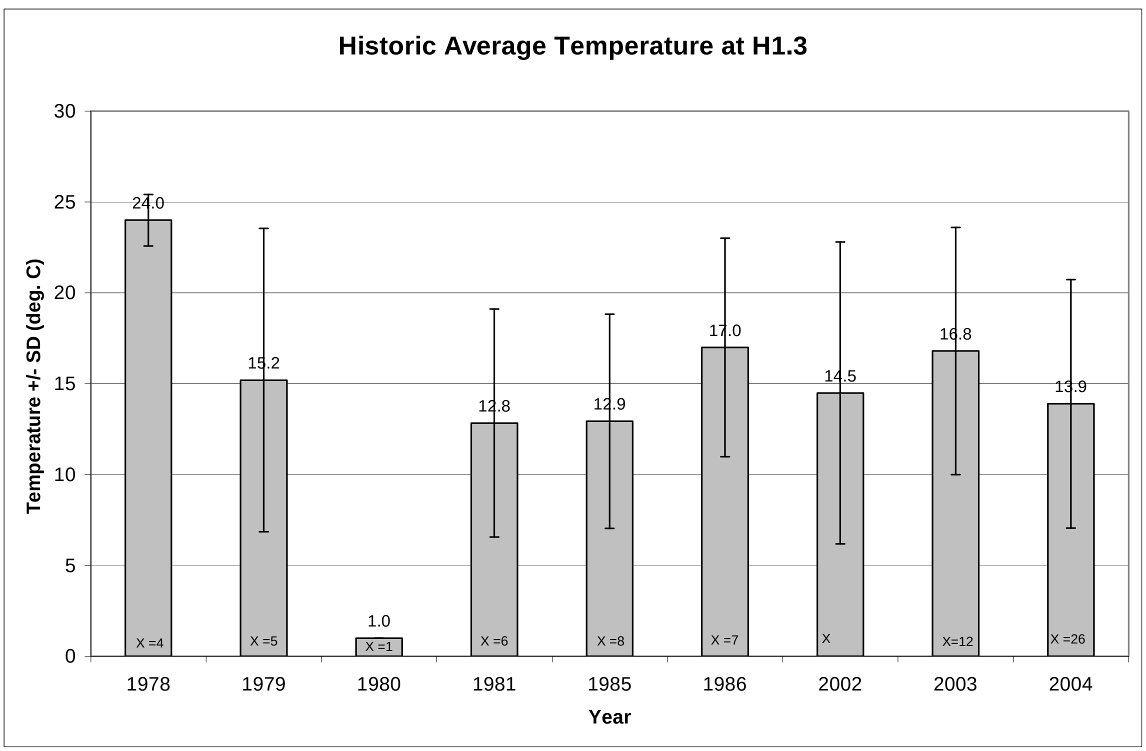

Historic Average Total Ammonia Concentration at H1.3
0.5
0.4
0.3
0.2
0.1
0.0
NH3 + SD (mg/L)
0.19
0.08
X =12
X =15
2003
2004
Year


Historic Average Nitrate/Nitrite Concentration at H1.3
2.0
1.5
1.0
0.5
0.0
NOx + SD (mg/L)
0.38
0.22
0.66
0.03
0.07
0.03
0.36
X =4
X =6
X =6
X =4
X =16
X=12
X =15
1977
1978
1979
1980
1981
1985
1986
2002
2003
2004
Year

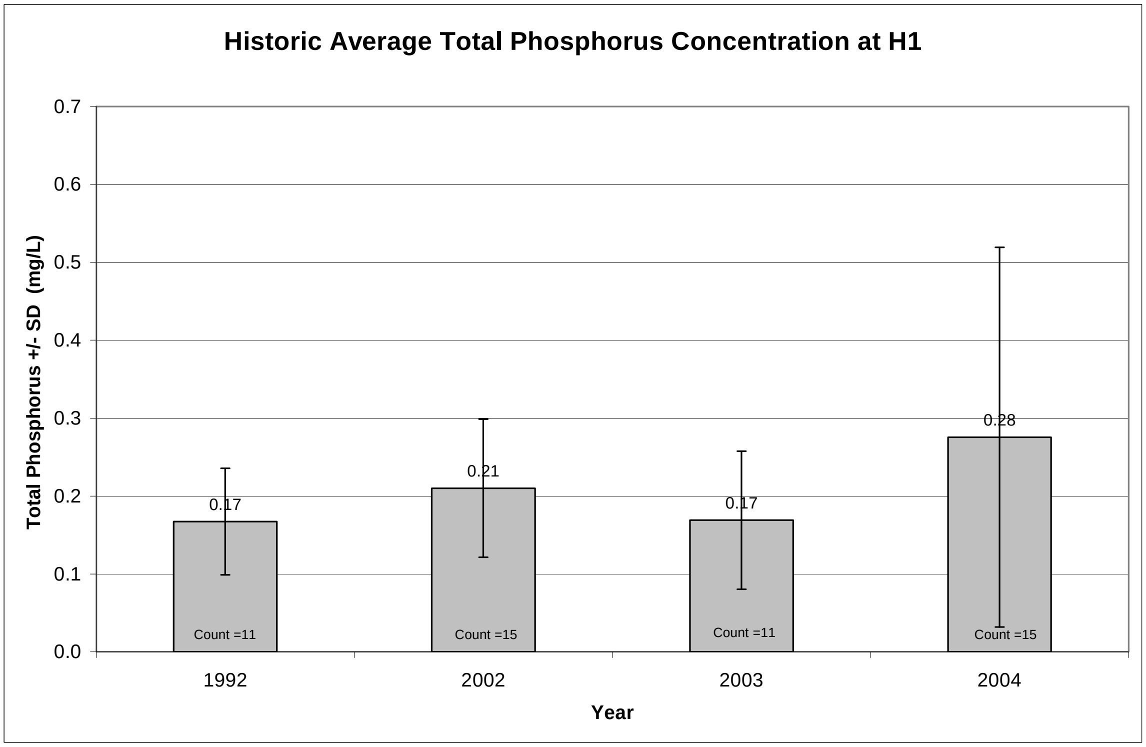

Historic Average Total Suspended Sediment Concentration at H1.3
Total Suspended Solids + SD (mg/L)
Year
50
45
40
35
30
25
20
15
10
5
0
1977
1978
1979
1980
1981
1985
1986
2002
2003
2004
7.5
10.5
5.4
5.4
2.6
8.5
7.7
7.3
20.0
X =4
X =6
X =6
X =5
X =8
X =8
X =16
X=13
X =15

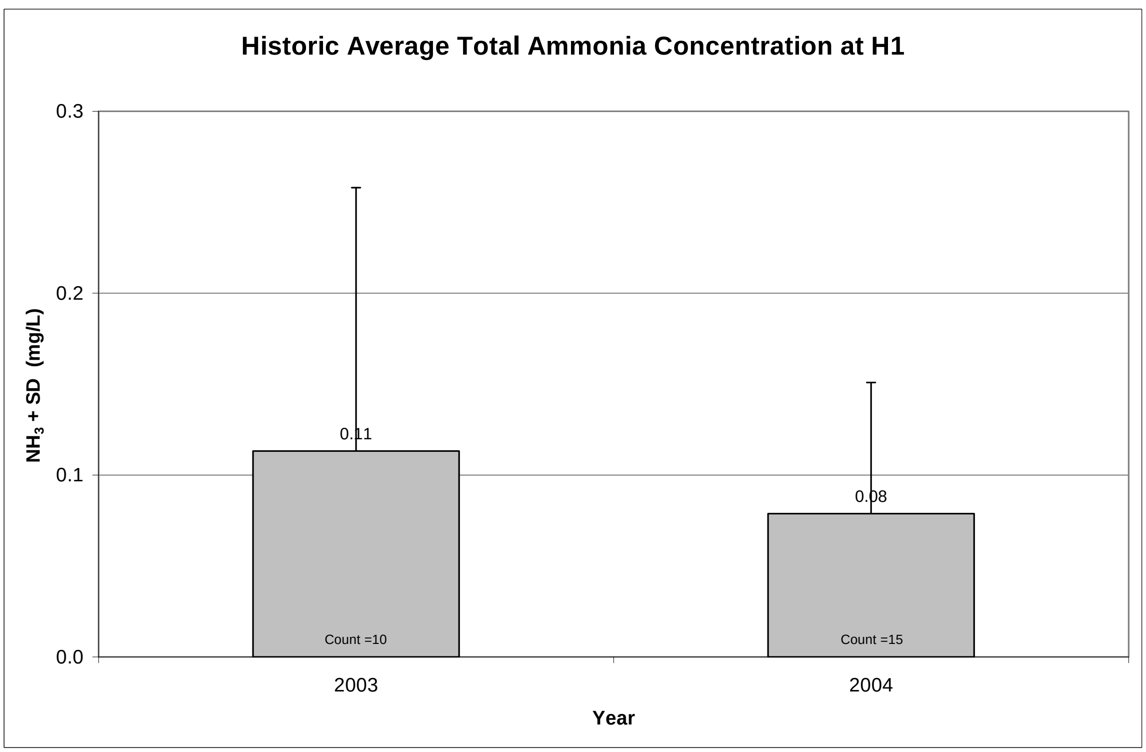

Historic Average Dissolved Oxygen Concentration at H1.3
Dissolved Oxygen + SD (mg/L)
Year
14
12
10
8
6
4
2
0
1978
1979
1980
1981
1985
1986
2002
2003
2004
5.8
6.3
8.8
4.2
7.9
4.1
5.4
6.8
6.6
X =3
X =5
X =1
X =6
X =8
X =7
X =30
X=12
X =26

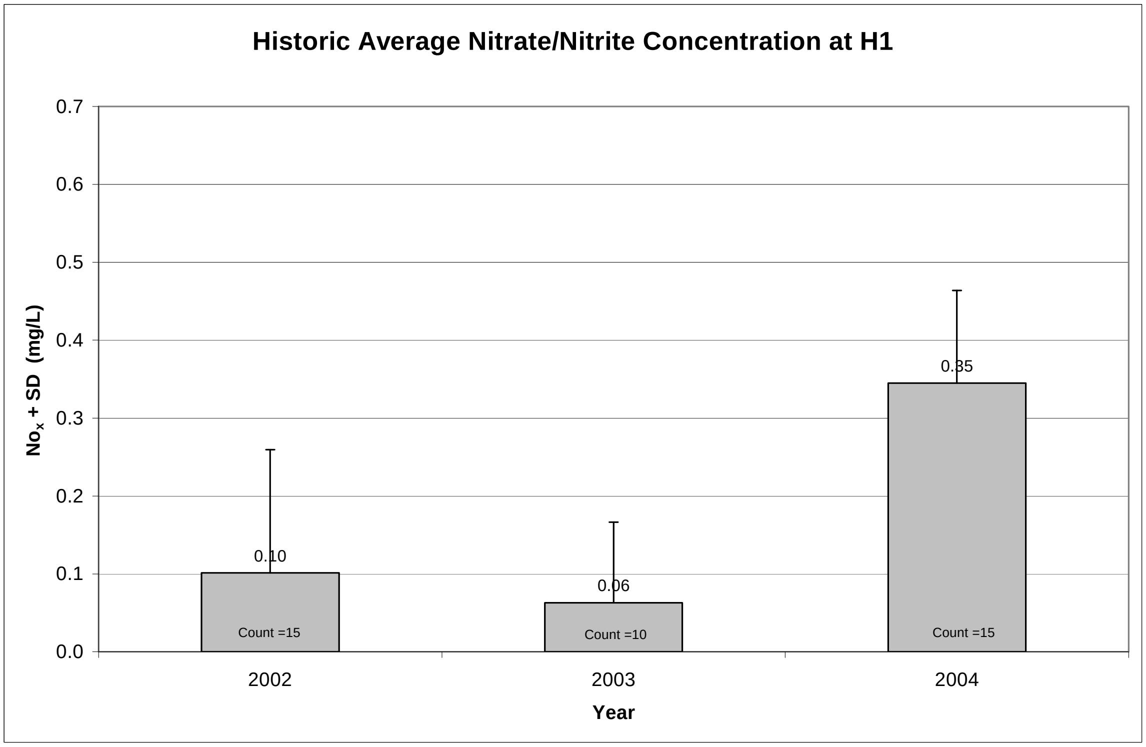

Historic Average pH at H1.3
pH +/- SD
Year
7.73
7.63
7.55
8.10
7.73
7.03
7.19
7.60
X =4
X =6
X =6
X =1
X =6
X =30
X=11
X =25
1977
1978
1979
1980
1981
1985
1986
2002
2003
2004

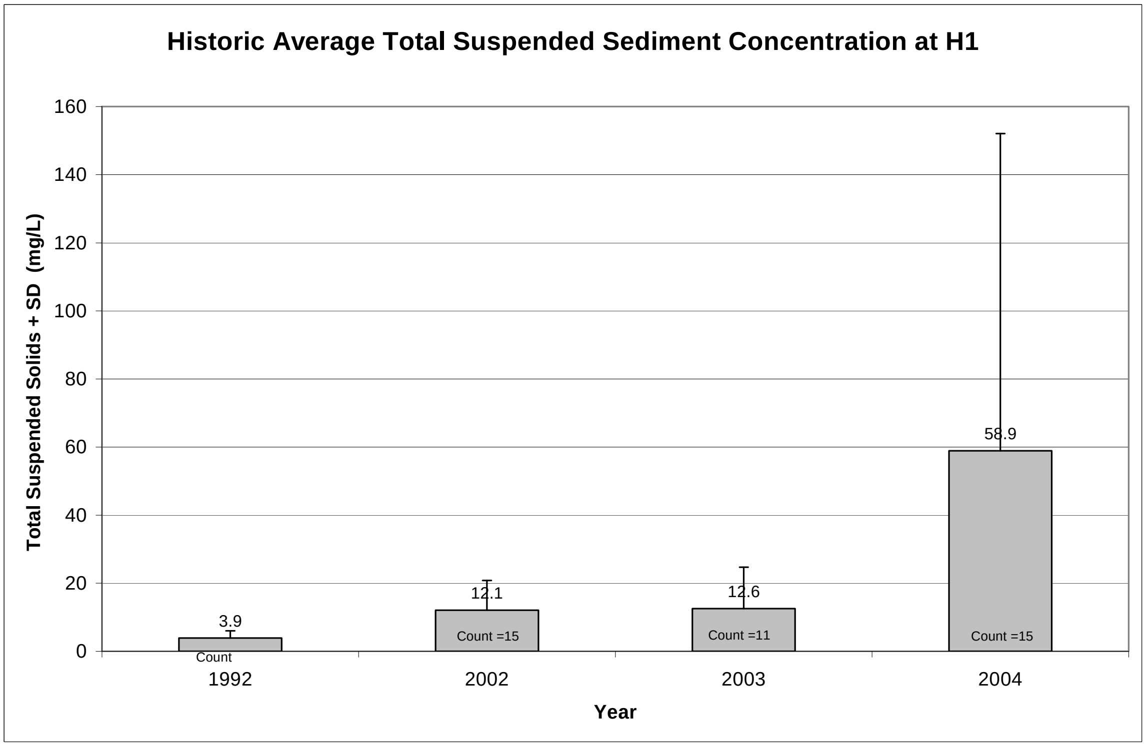

Historic Average Temperature at H1.3
Temperature +/- SD (deg. C)
Year
24.0
15.2
1.0
12.8
12.9
17.0
14.5
16.8
13.9
X =4
X =5
X =1
X =6
X =8
X =7
X
X=12
X =26
1978
1979
1980
1981
1985
1986
2002
2003
2004

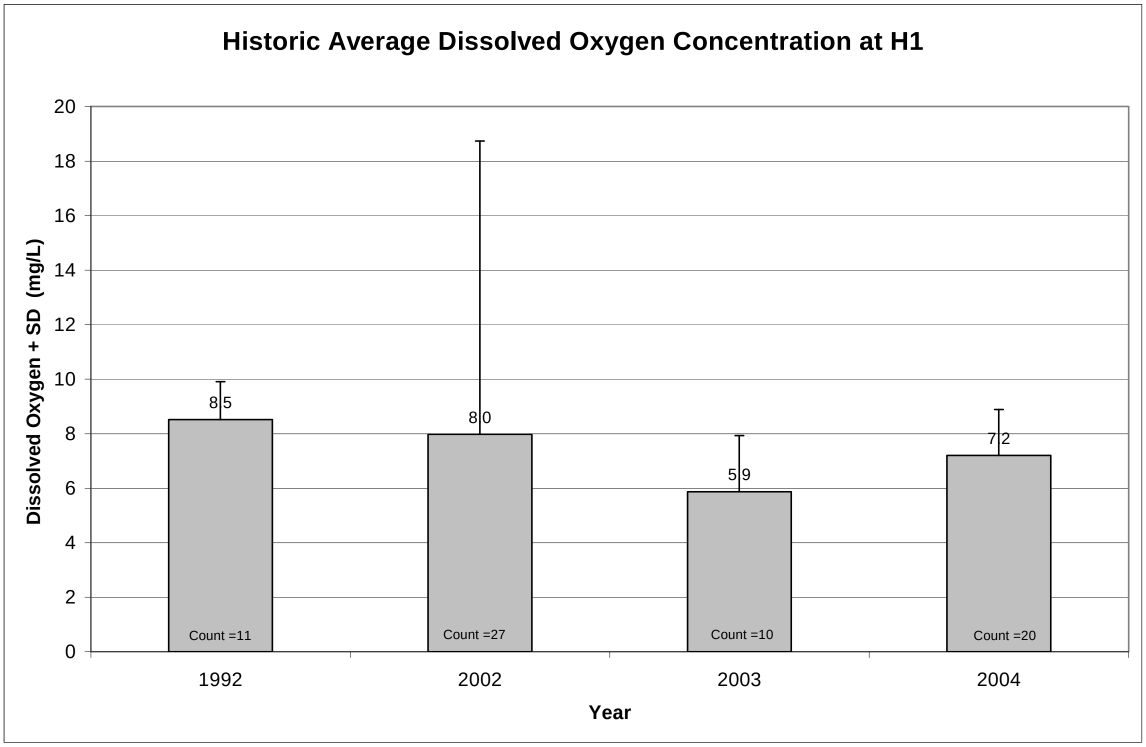
Site H1

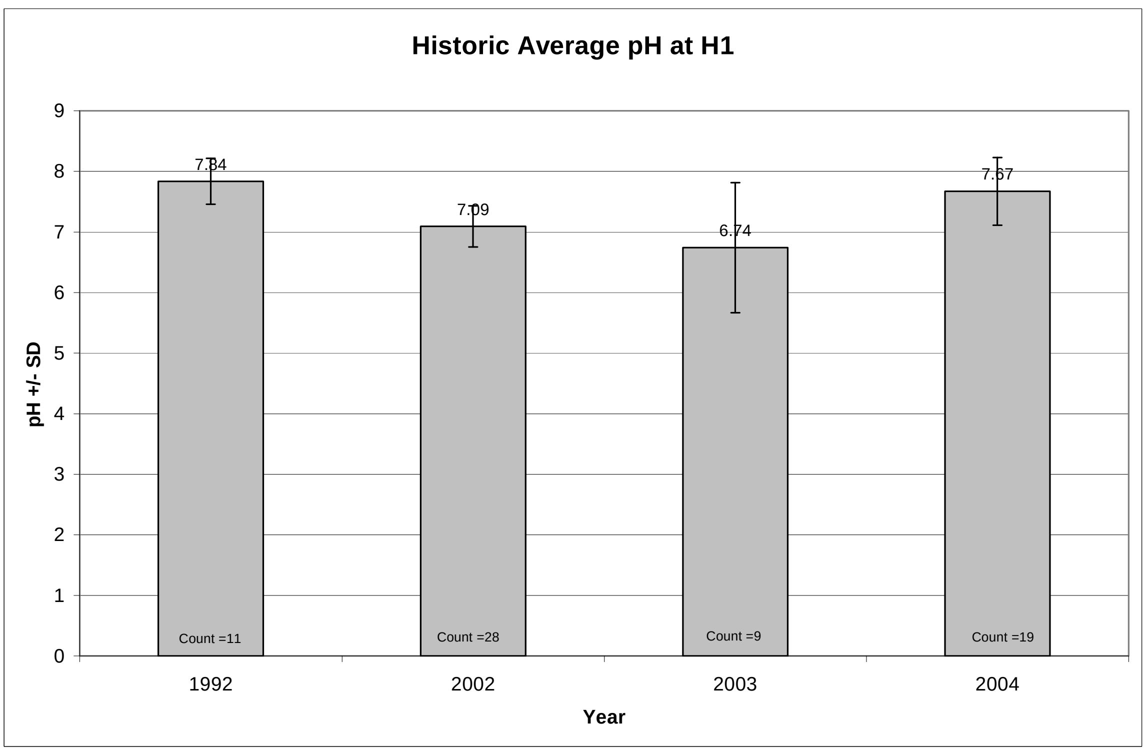

Historic Average Total Phosphorus Concentration at H1
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Total Phosphorus +/- SD (mg/L)
0.17
0.21
0.17
0.28
Count =11
Count =15
Count =11
Count =15
1992
2002
2003
2004
Year

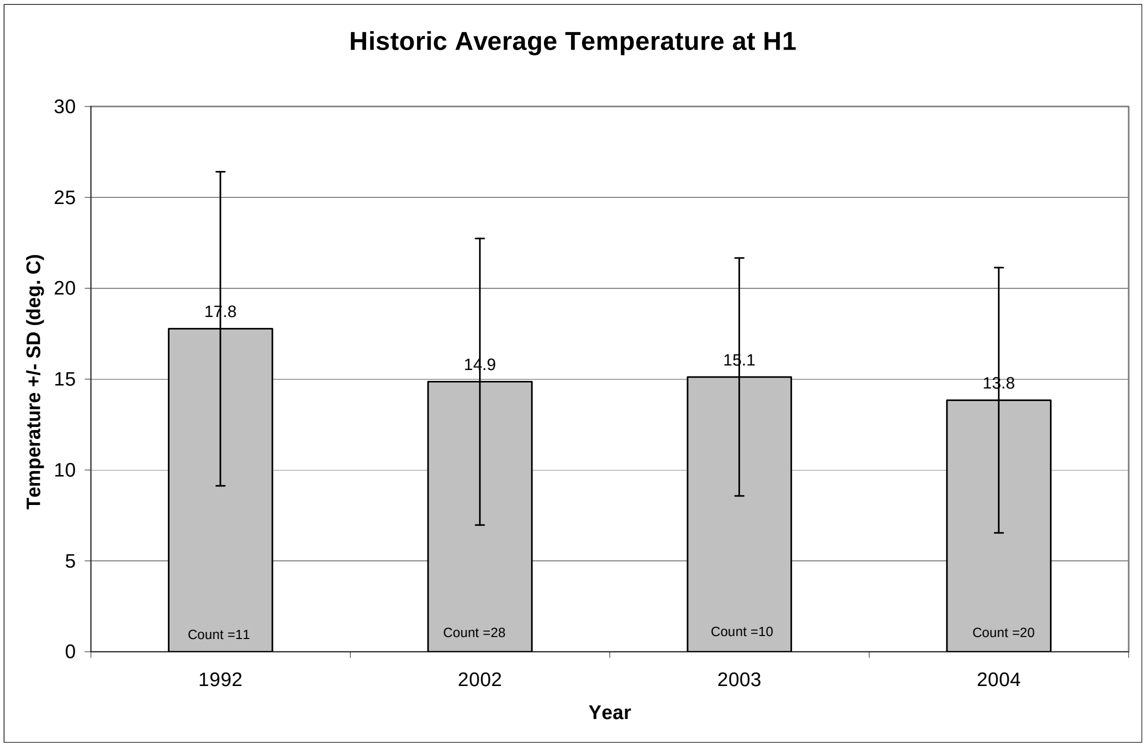

Historic Average Total Ammonia Concentration at H1
0.3
0.2
0.1
0.0
NH_3 + SD (mg/L)
0.11
0.08
Count =10
Count =15
2003
2004
Year


Historic Average Nitrate/Nitrite Concentration at H1
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Nox + SD (mg/L)
0.10
0.06
0.35
Count =15
Count =10
Count =15
2002
2003
2004
Year


Historic Average Total Suspended Sediment Concentration at H1
160
140
120
100
80
60
40
20
0
Total Suspended Solids + SD (mg/L)
3.9
12.1
12.6
58.9
Count
Count =15
Count =11
Count =15
1992
2002
2003
2004
Year

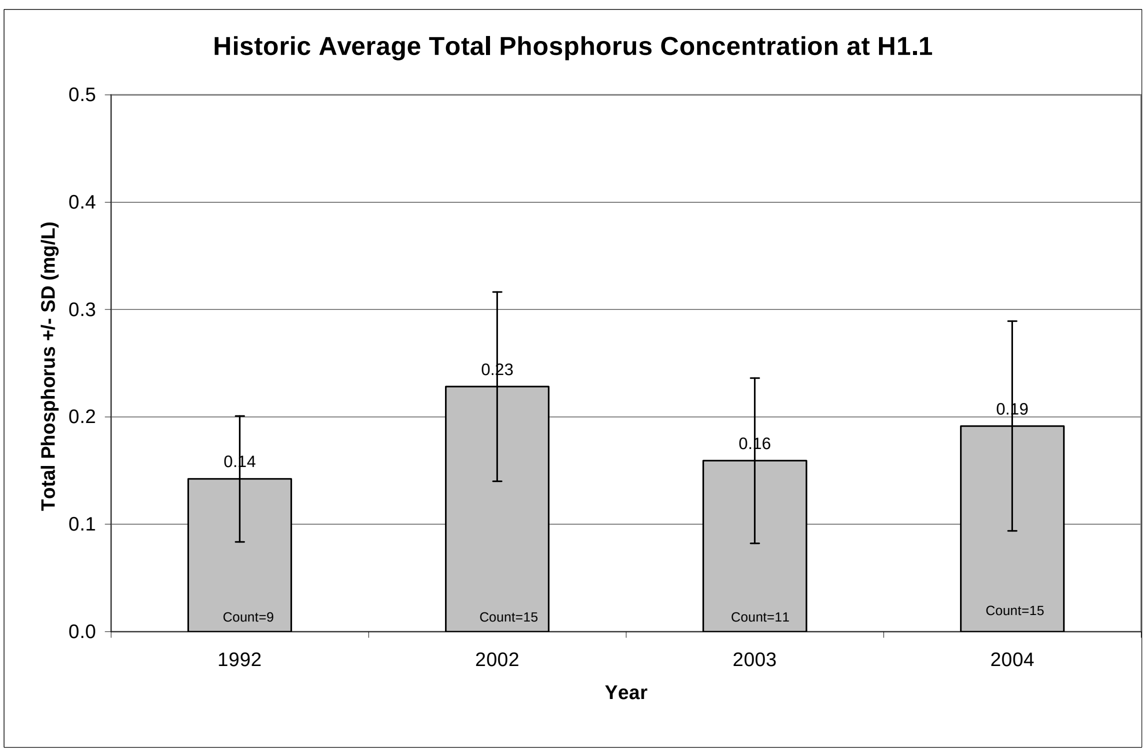

Historic Average Dissolved Oxygen Concentration at H1
Dissolved Oxygen + SD (mg/L)
20
18
16
14
12
10
8
6
4
2
0
8.5
8.0
5.9
7.2
Count =11
Count =27
Count =10
Count =20
1992
2002
2003
2004
Year


Historic Average pH at H1
pH +/- SD
9
8
7
6
5
4
3
2
1
0
7.84
7.09
6.74
7.67
Count =11
Count =28
Count =9
Count =19
1992
2002
2003
2004
Year

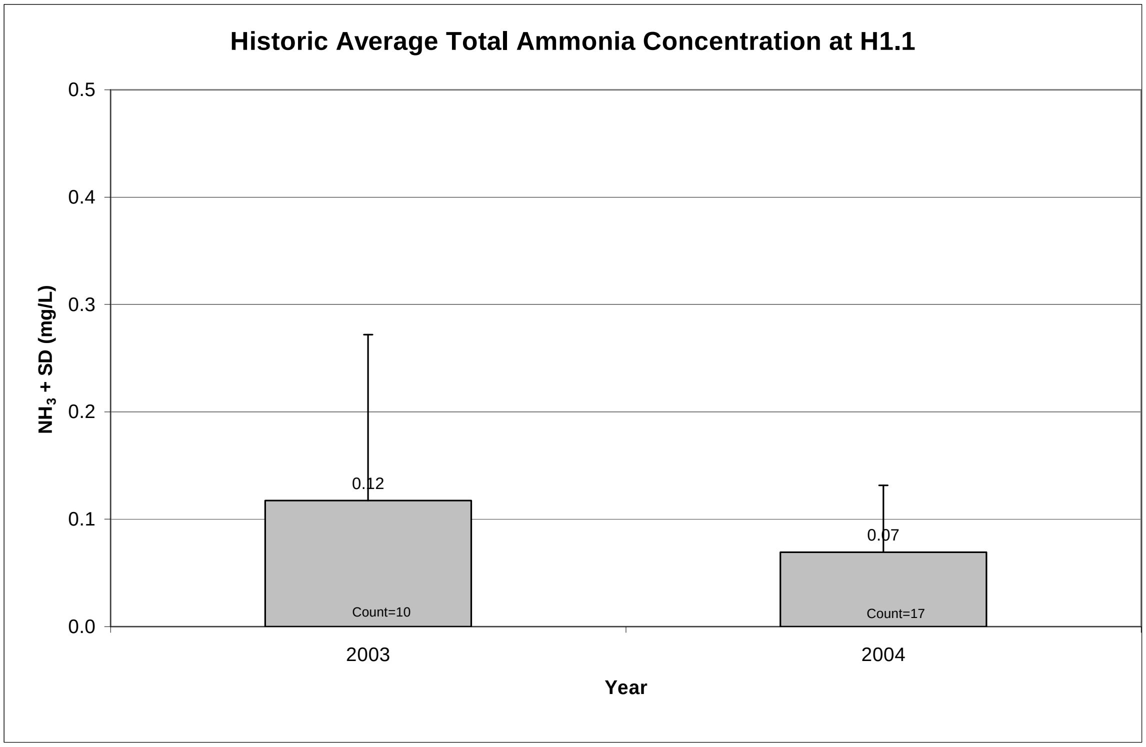


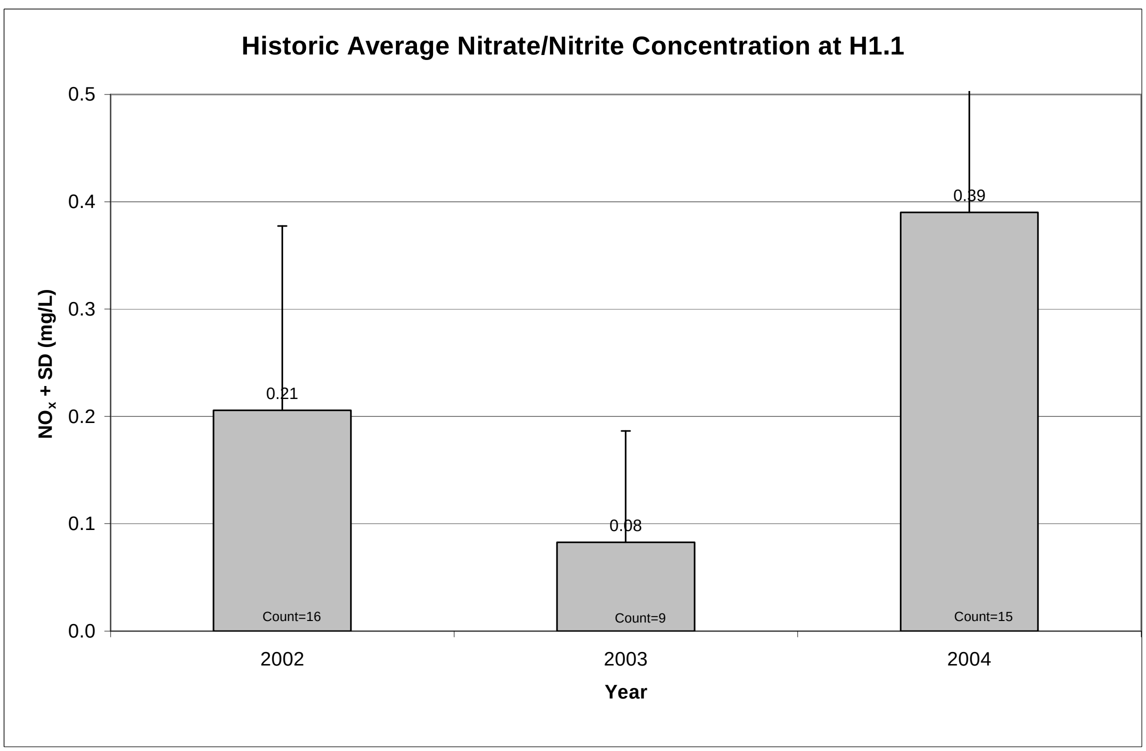
Historic Average Temperature at H1
Temperature +/- SD (deg. C)
30
25
20
15
10
5
0
17.8
14.9
15.1
13.8
Count =11
Count =28
Count =10
Count =20
1992
2002
2003
2004
Year

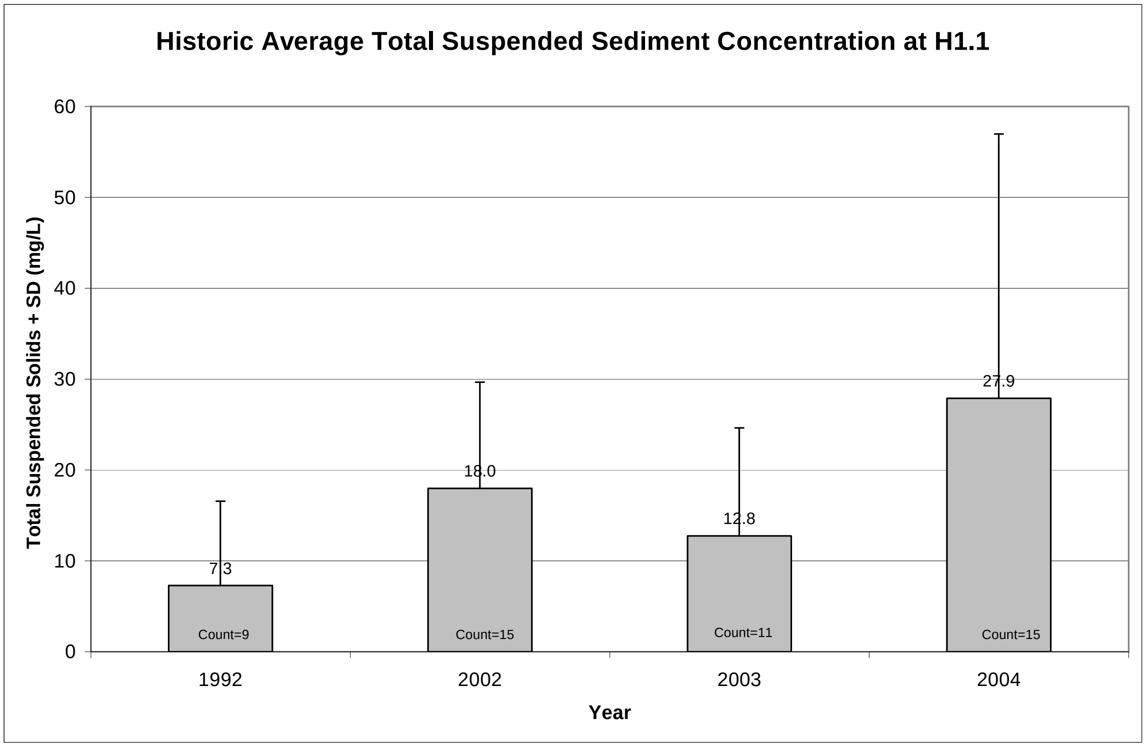
Site H1.1

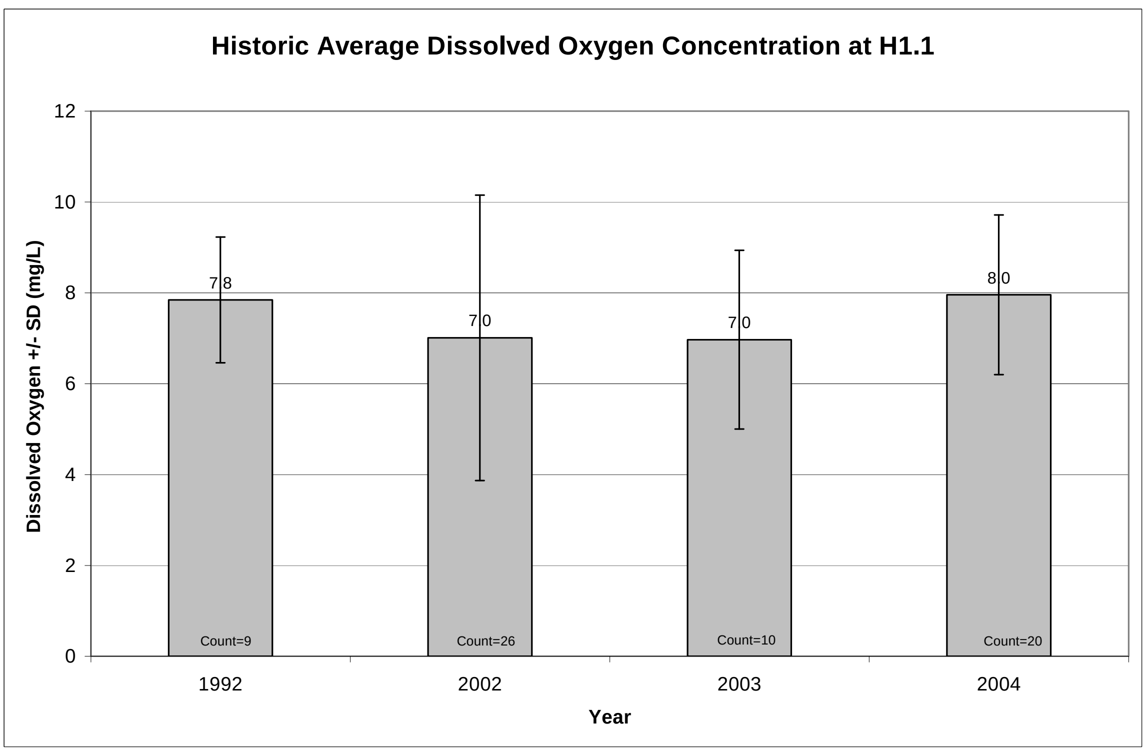


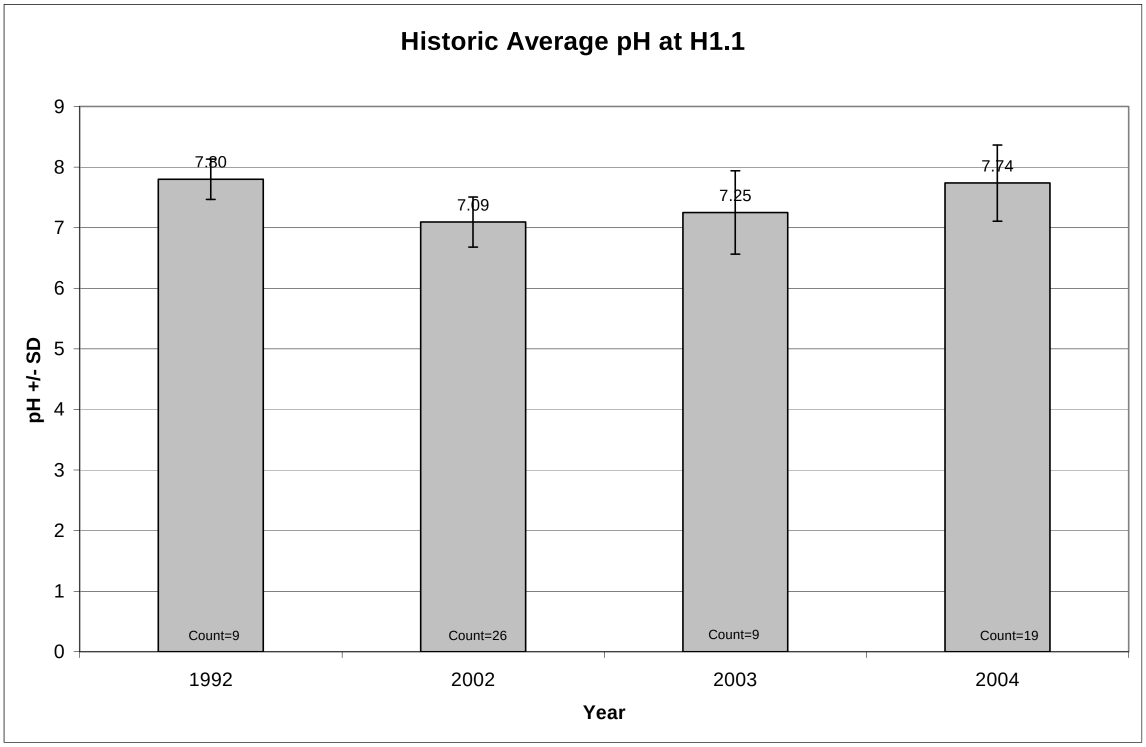
Historic Average Total Phosphorus Concentration at H1.1
Total Phosphorus +/- SD (mg/L)
0.5
0.4
0.3
0.2
0.1
0.0
0.14
0.23
0.16
0.19
Count=9
Count=15
Count=11
Count=15
1992
2002
2003
2004
Year

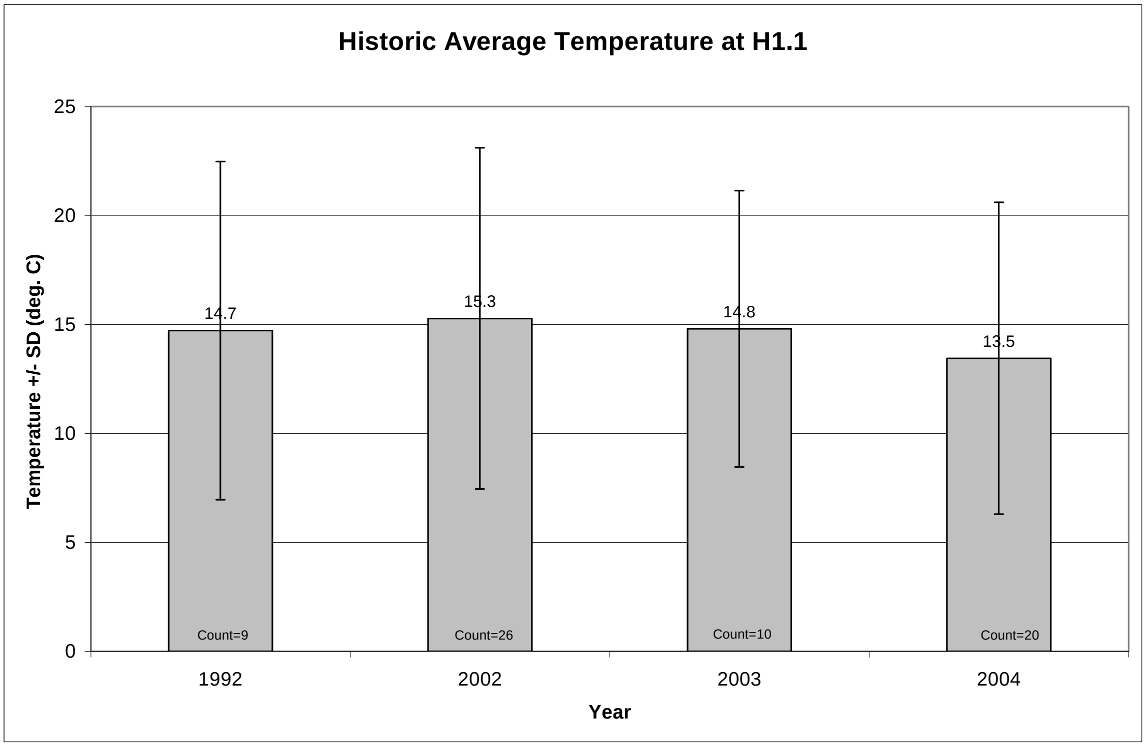

Historic Average Total Ammonia Concentration at H1.1
0.5
0.4
0.3
0.2
0.1
0.0
NH_3 + SD (mg/L)
0.12
0.07
Count=10
Count=17
2003
2004
Year


Historic Average Nitrate/Nitrite Concentration at H1.1
0.5
0.4
0.3
0.2
0.1
0.0
NO_x + SD (mg/L)
0.21
0.08
0.39
Count=16
Count=9
Count=15
2002
2003
2004
Year

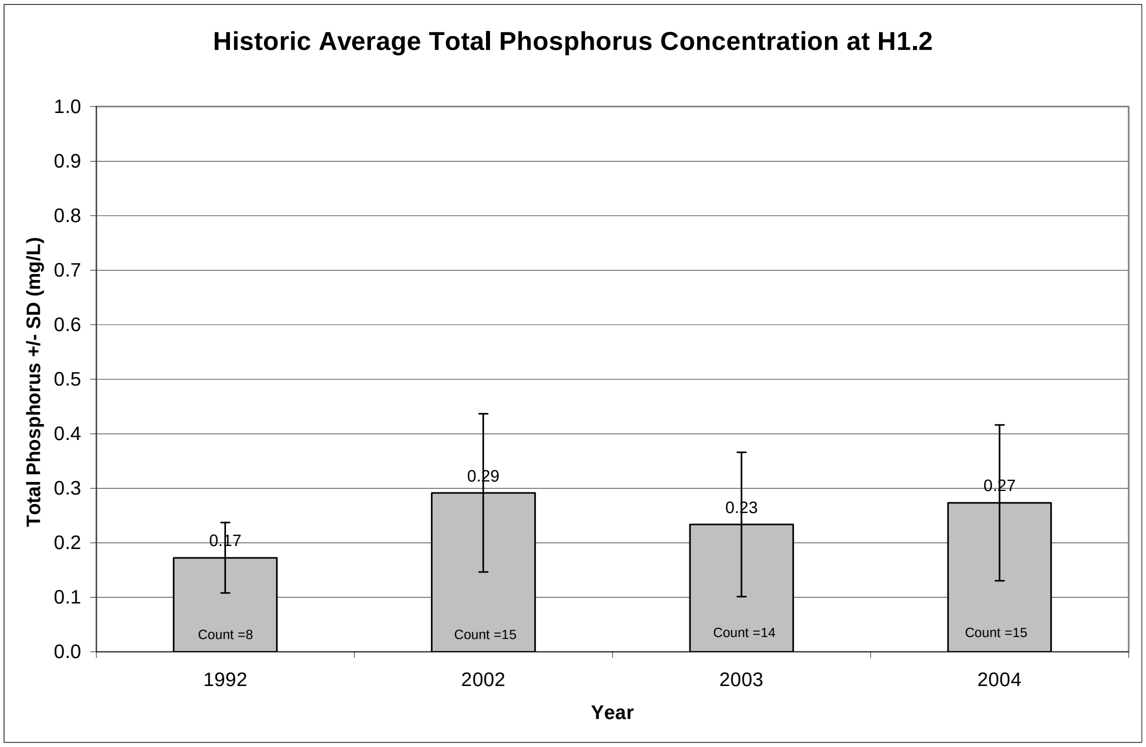

Historic Average Total Suspended Sediment Concentration at H1.1
Total Suspended Solids + SD (mg/L)
60
50
40
30
20
10
0
7.3
18.0
12.8
27.9
Count=9
Count=15
Count=11
Count=15
1992
2002
2003
2004
Year


Historic Average Dissolved Oxygen Concentration at H1.1
Dissolved Oxygen +/- SD (mg/L)
12
10
8
6
4
2
0
7.8
7.0
7.0
8.0
Count=9
Count=26
Count=10
Count=20
1992
2002
2003
2004
Year

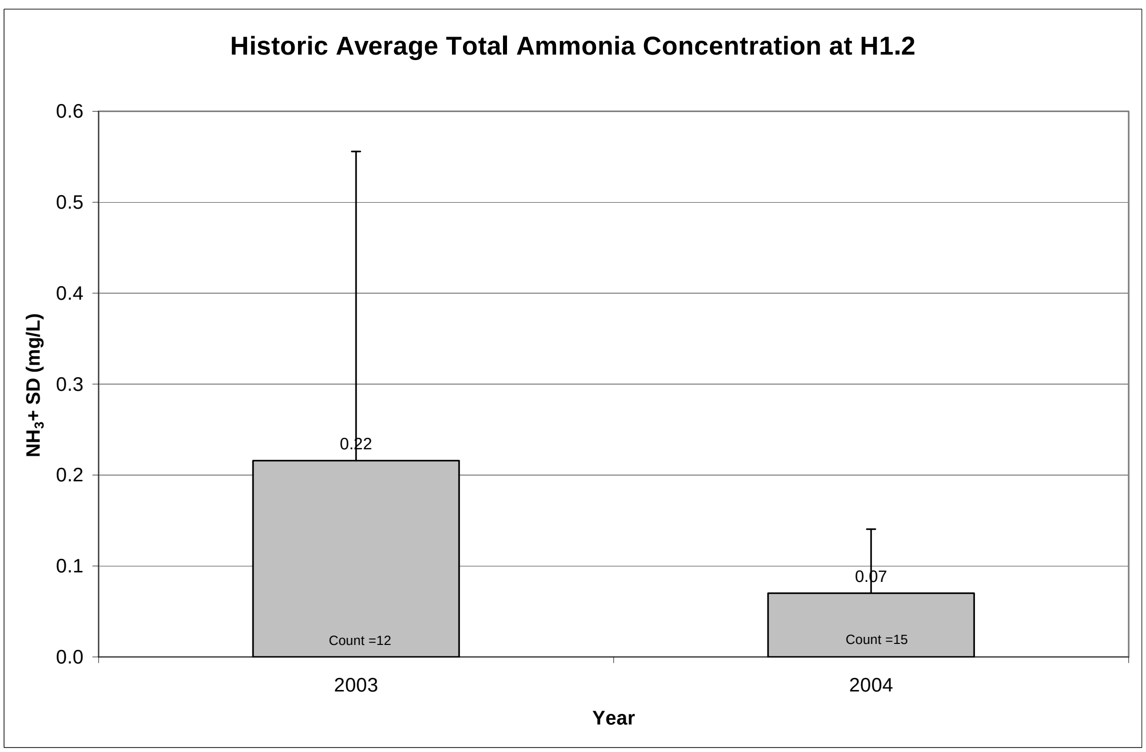

Historic Average pH at H1.1
pH +/- SD
Year
9
8
7
6
5
4
3
2
1
0
7.80
7.09
7.25
7.74
Count=9
Count=26
Count=9
Count=19
1992
2002
2003
2004


Historic Average Temperature at H1.1
Temperature +/- SD (deg. C)
Year
25
20
15
10
5
0
14.7
15.3
14.8
13.5
Count=9
Count=26
Count=10
Count=20
1992
2002
2003
2004

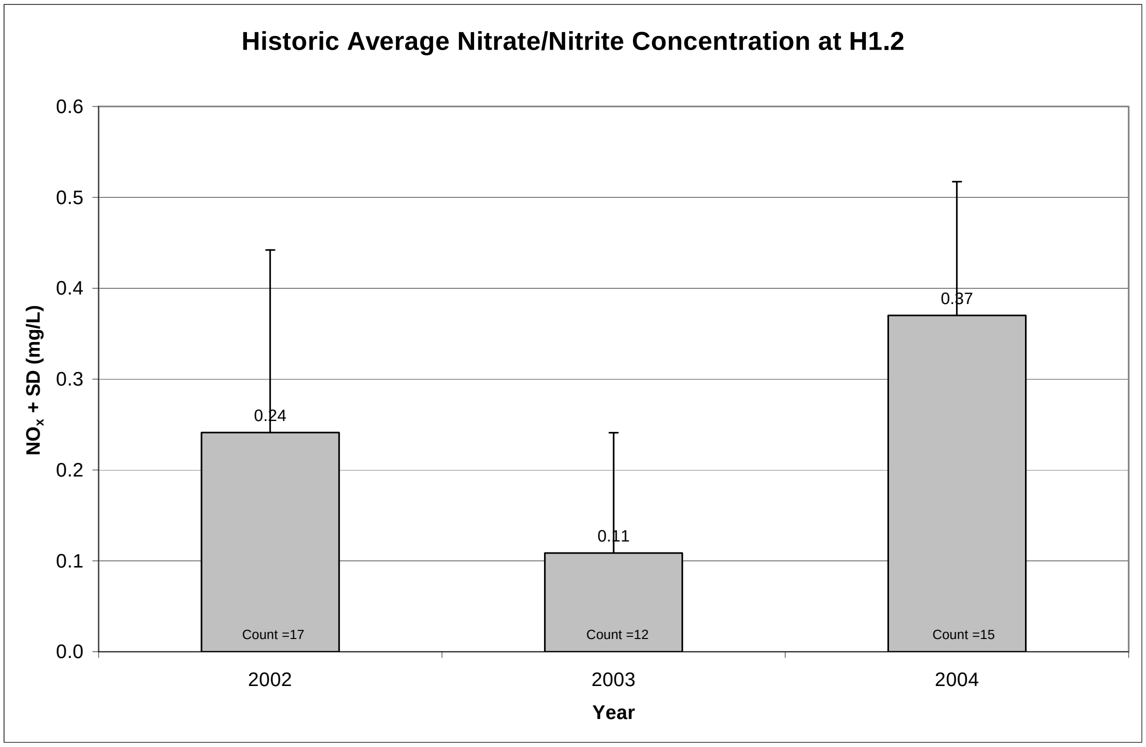
Site H1.2

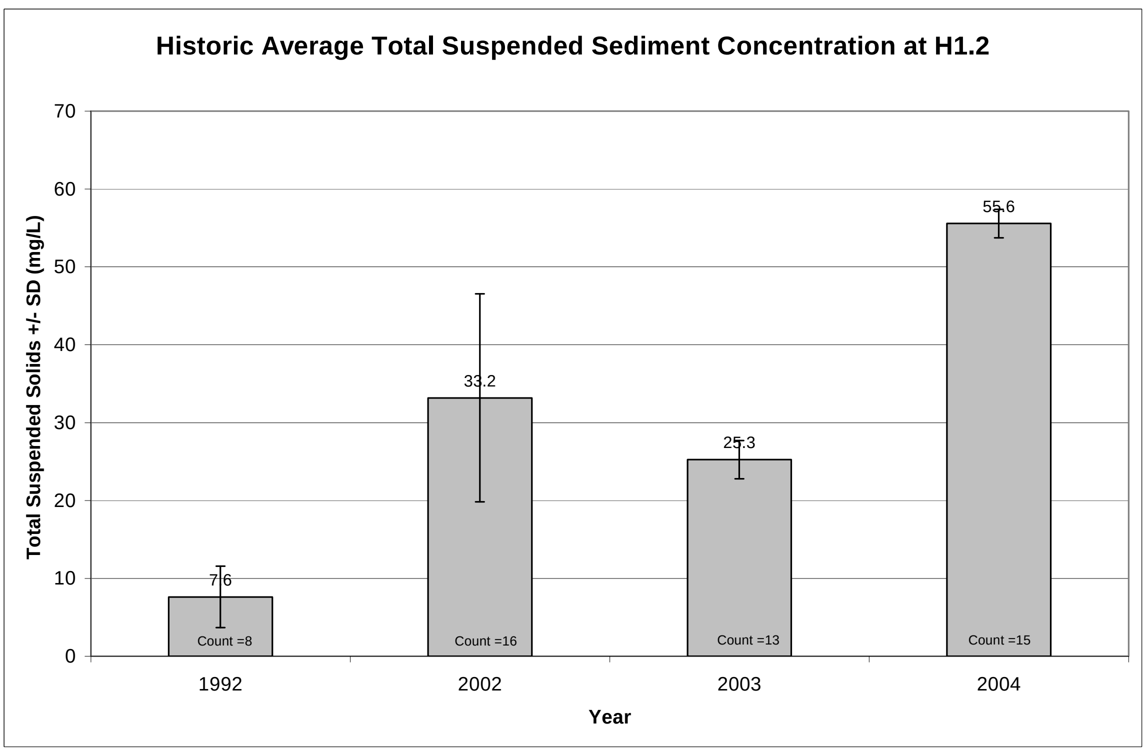


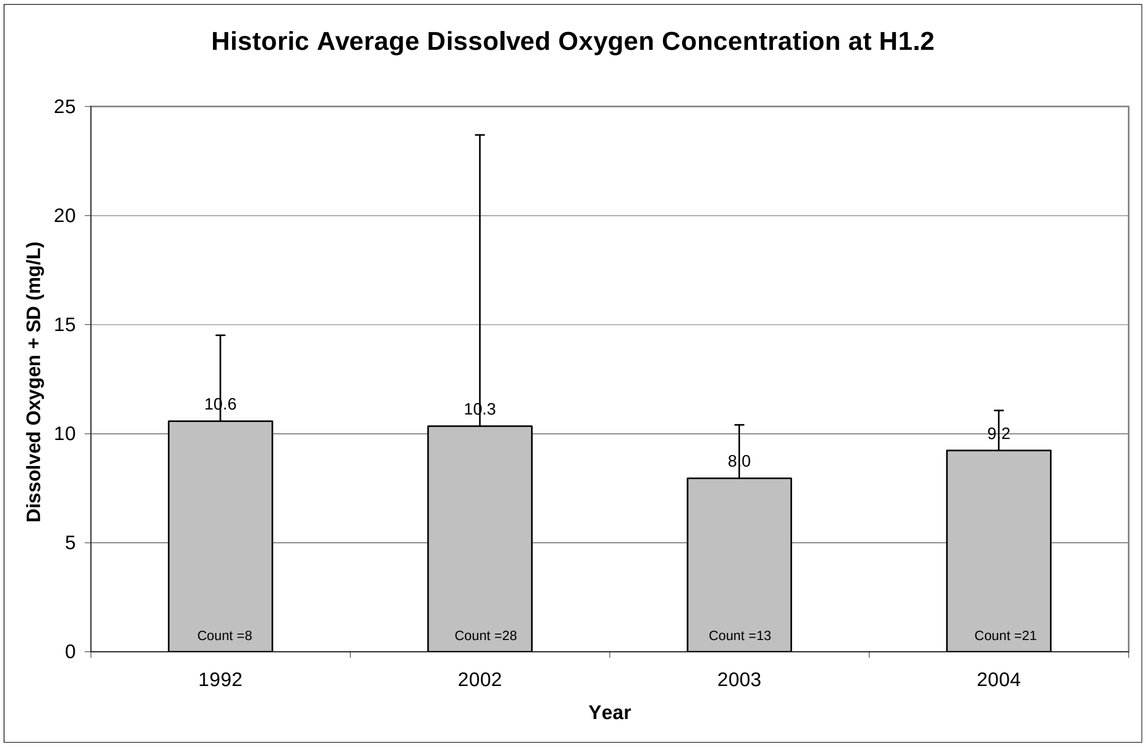
Historic Average Total Phosphorus Concentration at H1.2
Total Phosphorus +/- SD (mg/L)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.17
0.29
0.23
0.27
Count =8
Count =15
Count =14
Count =15
1992
2002
2003
2004
Year

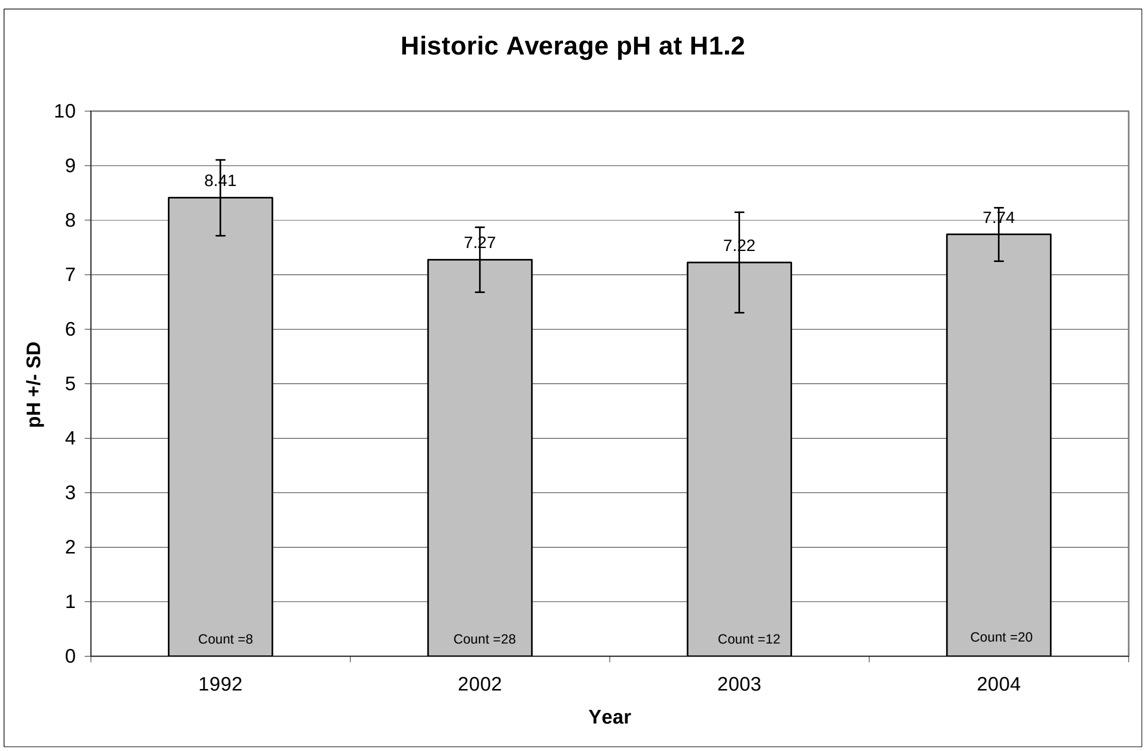


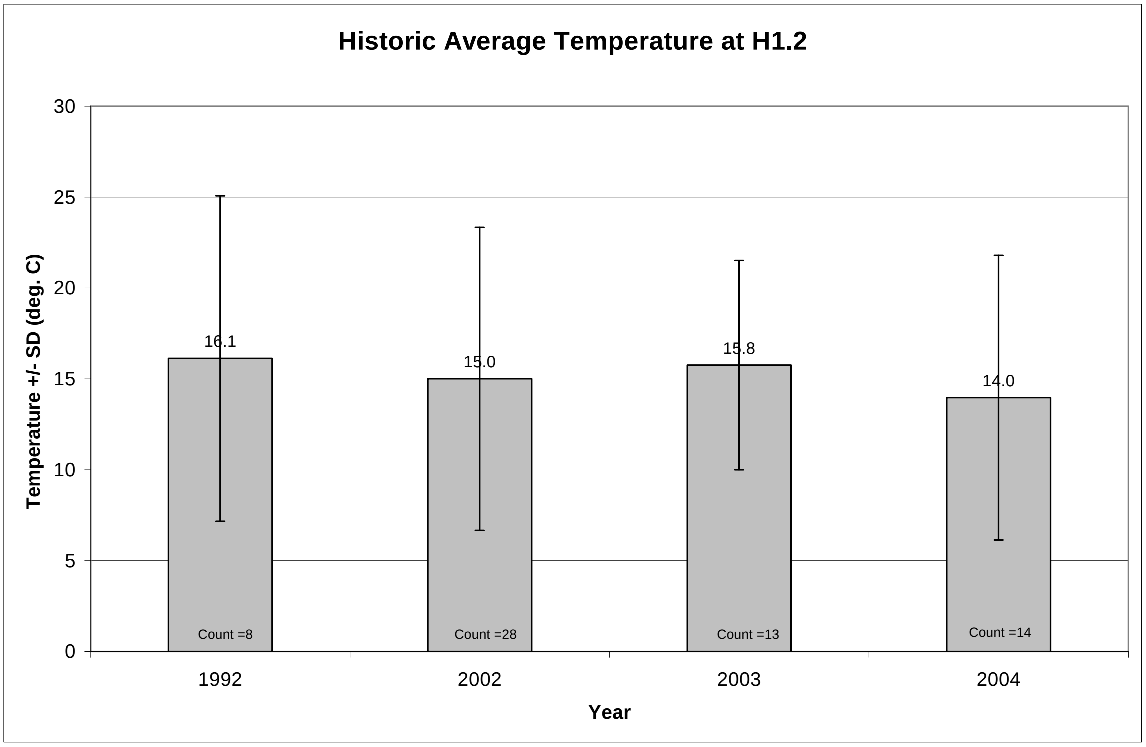
Historic Average Total Ammonia Concentration at H1.2
NH3+ SD (mg/L)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.22
0.07
Count =12
Count =15
2003
2004
Year


Historic Average Nitrate/Nitrite Concentration at H1.2
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NO_x + SD (mg/L)
0.24
0.11
0.37
Count =17
Count =12
Count =15
2002
2003
2004
Year


Historic Average Total Suspended Sediment Concentration at H1.2
70
60
50
40
30
20
10
0
Total Suspended Solids +/- SD (mg/L)
7.6
33.2
25.3
55.6
Count =8
Count =16
Count =13
Count =15
1992
2002
2003
2004
Year

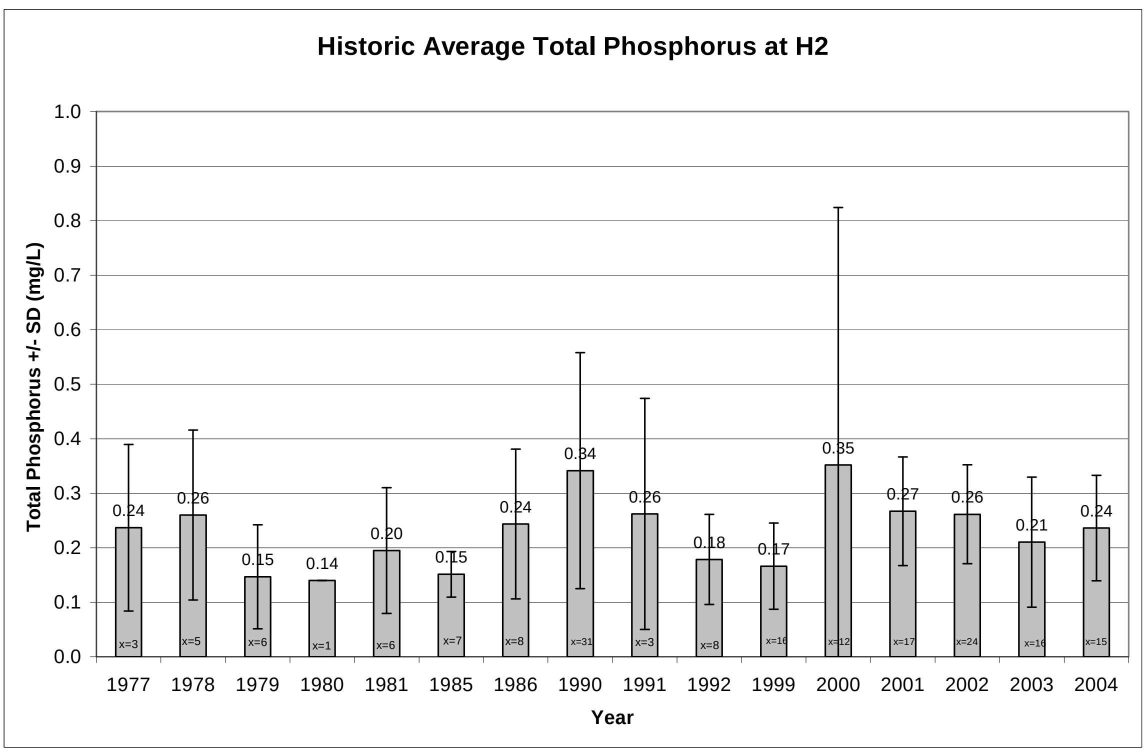

Historic Average Dissolved Oxygen Concentration at H1.2
Dissolved Oxygen + SD (mg/L)
25
20
15
10
5
0
10.6
10.3
8.0
9.2
Count =8
Count =28
Count =13
Count =21
1992
2002
2003
2004
Year


Historic Average pH at H1.2
pH +/- SD
10
9
8
7
6
5
4
3
2
1
0
8.41
7.27
7.22
7.74
Count =8
Count =28
Count =12
Count =20
1992
2002
2003
2004
Year

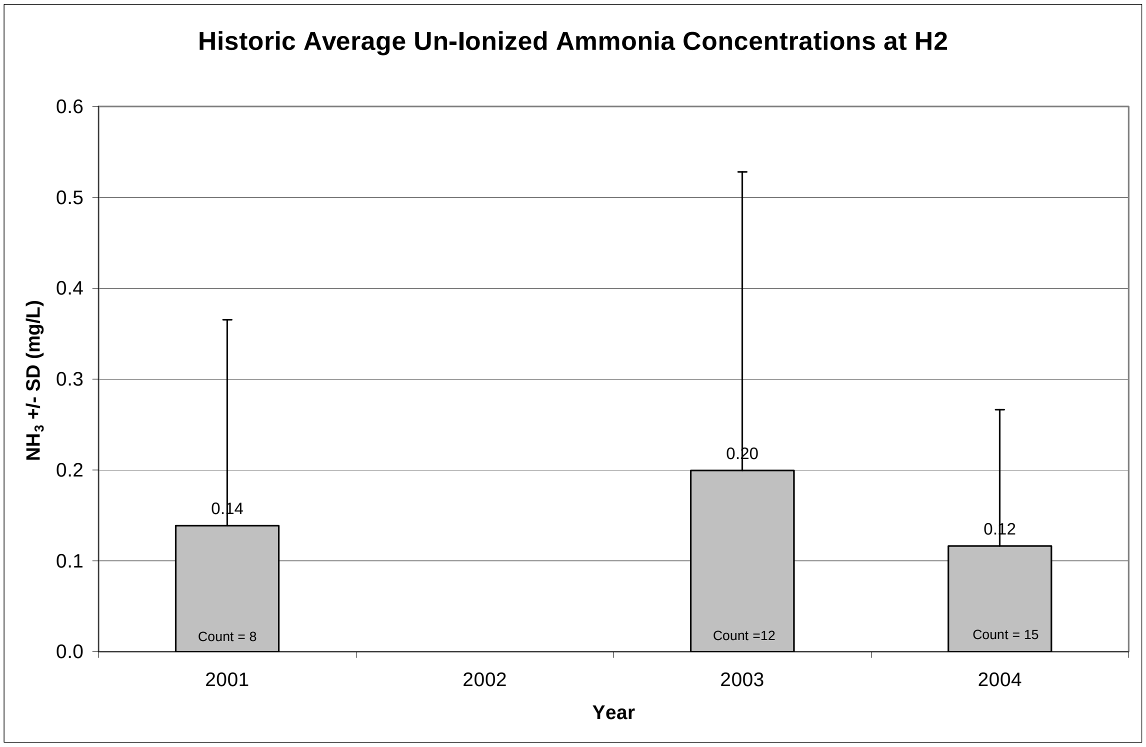


Historic Average Temperature at H1.2
Temperature +/- SD (deg. C)
30
25
20
15
10
5
0
16.1
15.0
15.8
14.0
Count =8
Count =28
Count =13
Count =14
1992
2002
2003
2004
Year

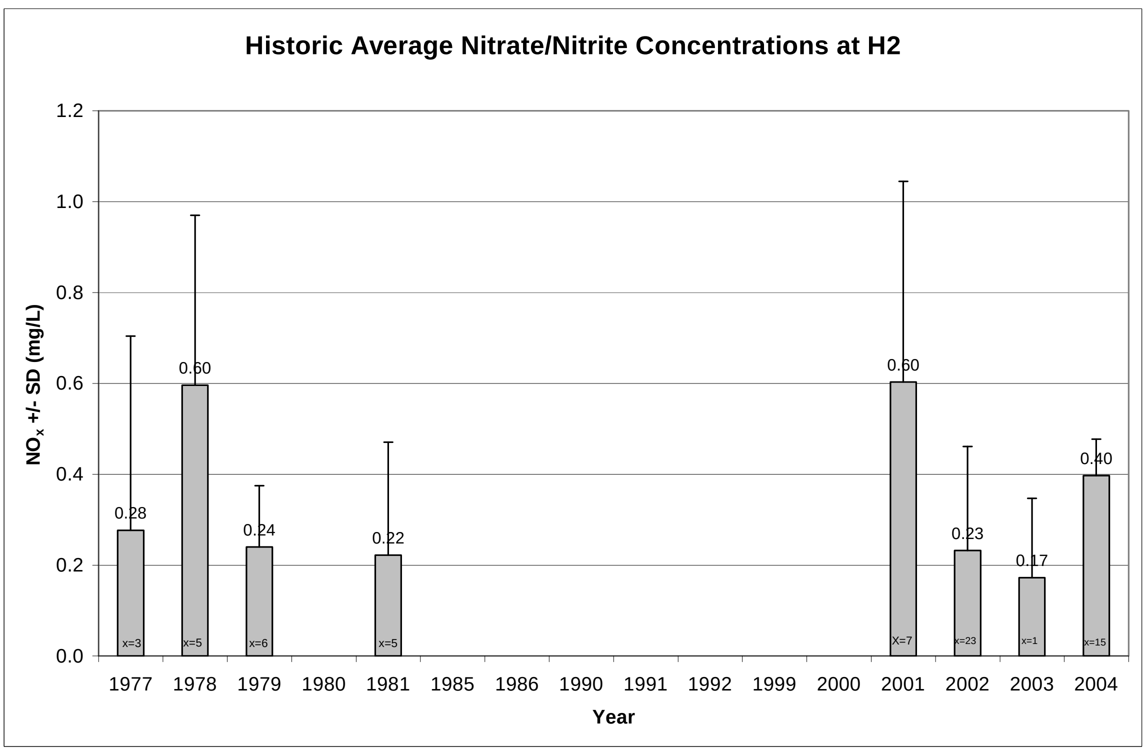
Site H2



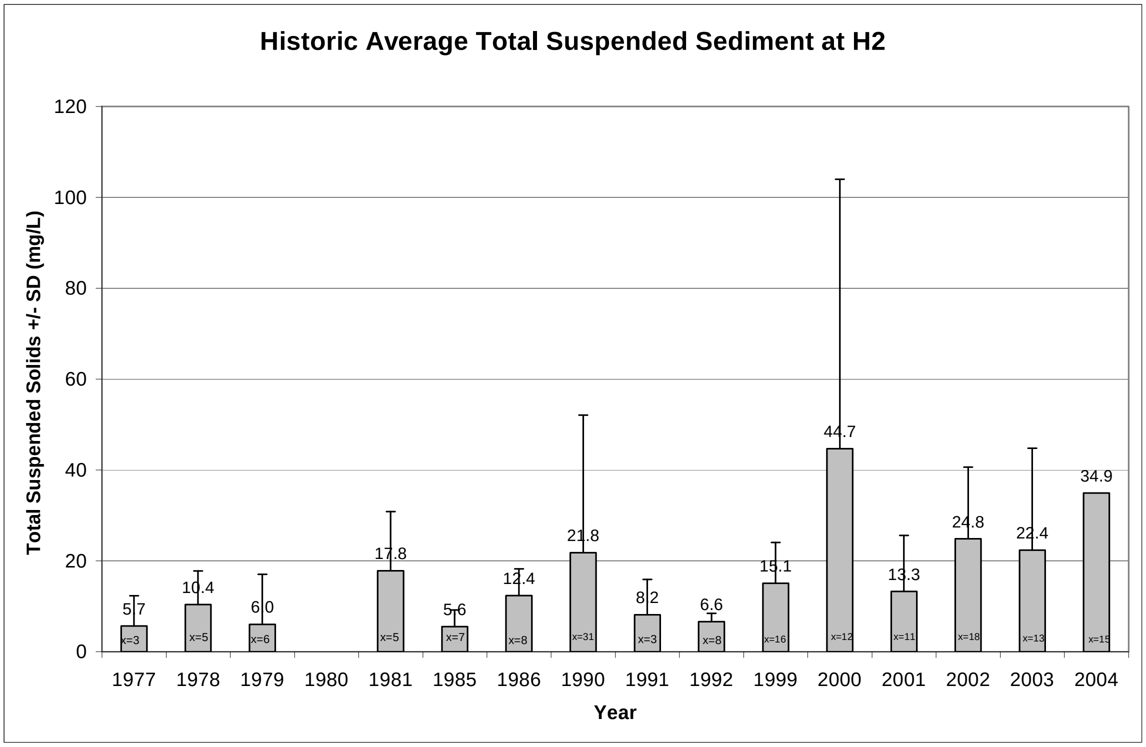
Historic Average Total Phosphorus at H2
Total Phosphorus +/- SD (mg/L)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.24
0.26
0.15
0.14
0.20
0.15
0.24
0.34
0.26
0.18
0.17
0.35
0.27
0.26
0.21
0.24
1977
1978
1979
1980
1981
1985
1986
1990
1991
1992
1999
2000
2001
2002
2003
2004
Year

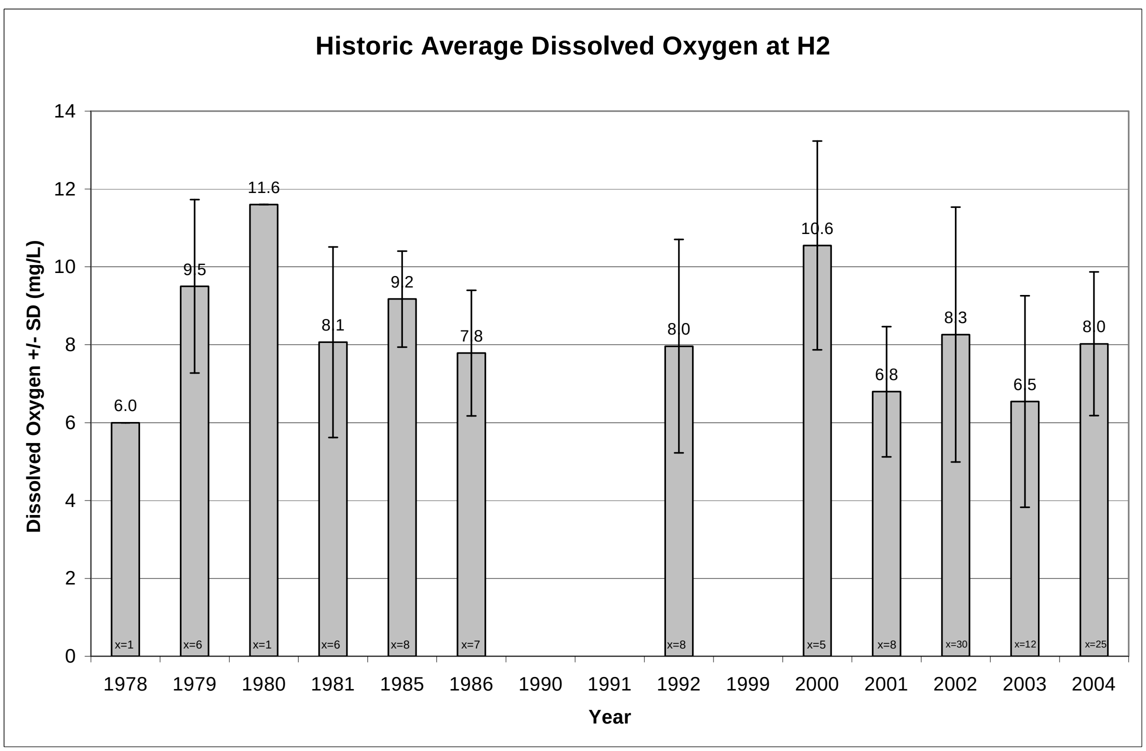


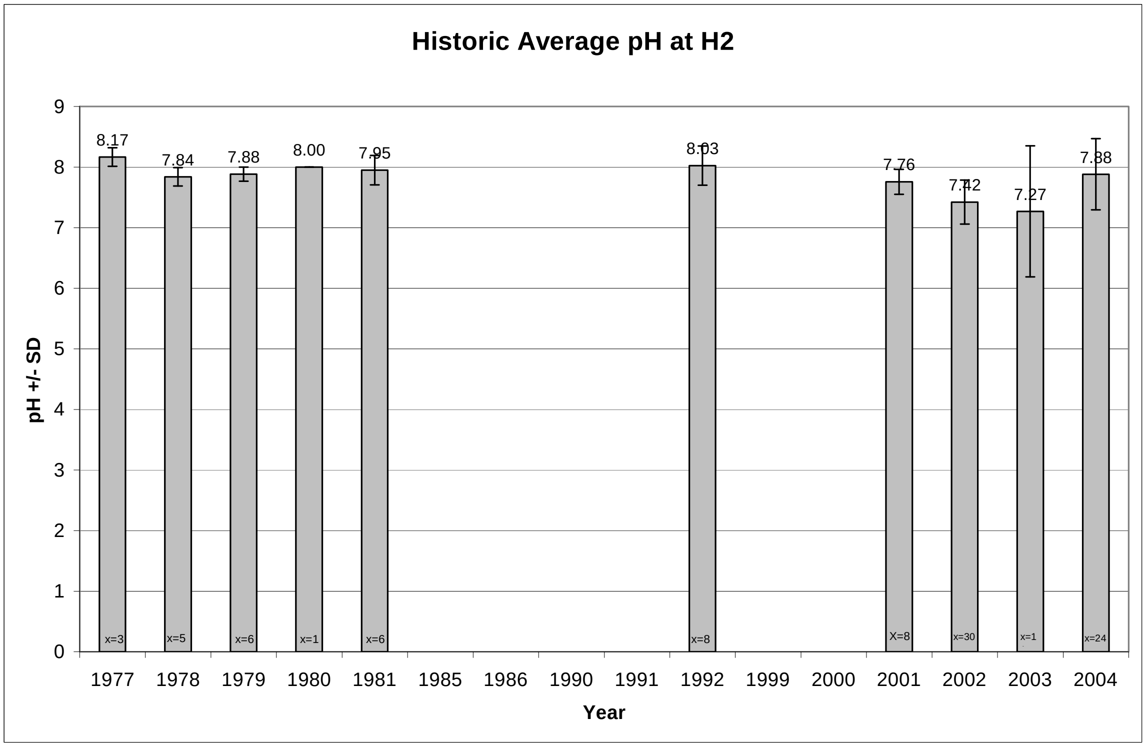
Historic Average Un-Ionized Ammonia Concentrations at H2
NH3 +/- SD (mg/L)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.14
0.20
0.12
Count = 8
Count =12
Count = 15
2001
2002
2003
2004
Year

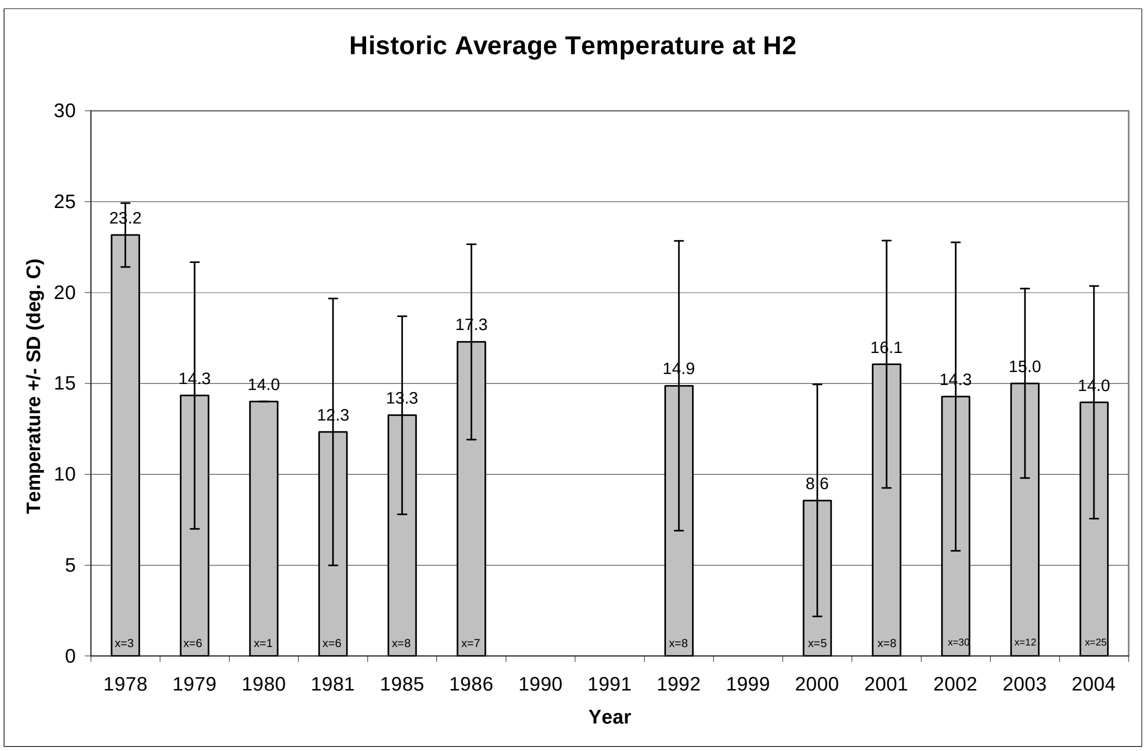


Historic Average Nitrate/Nitrite Concentrations at H2
NOx +/- SD (mg/L)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.28
0.60
0.24
0.22
0.60
0.23
0.17
0.40
x=3
x=5
x=6
x=5
X=7
x=23
x=1
x=15
1977
1978
1979
1980
1981
1985
1986
1990
1991
1992
1999
2000
2001
2002
2003
2004
Year

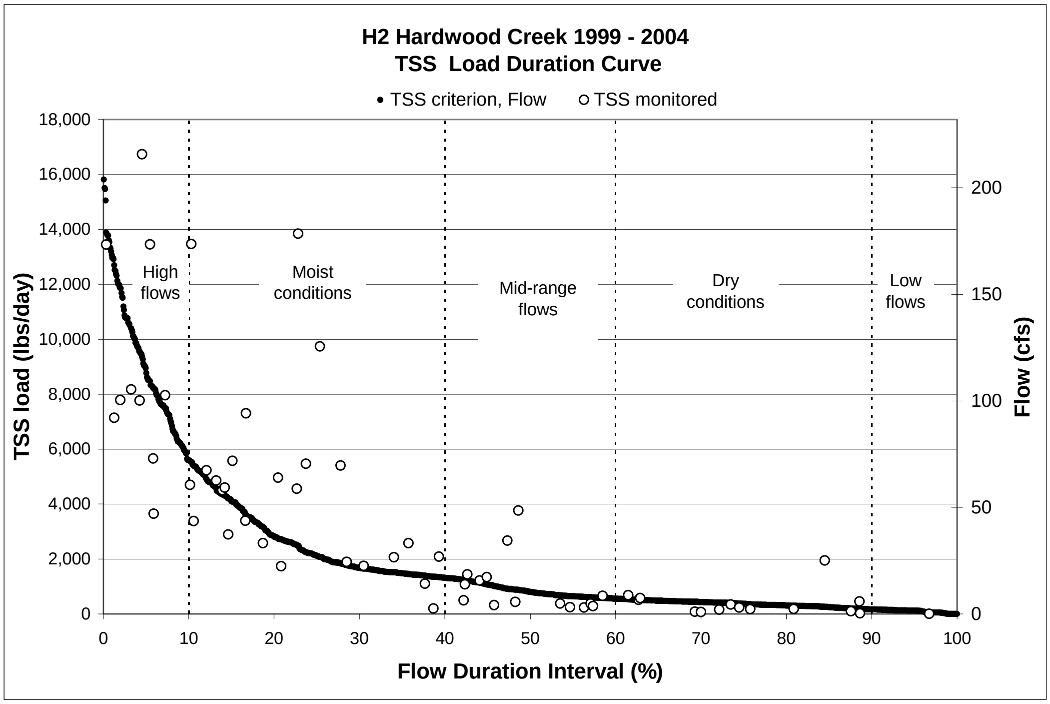

Historic Average Total Suspended Sediment at H2
Total Suspended Solids +/- SD (mg/L)
Year
0
20
40
60
80
100
120
1977
1978
1979
1980
1981
1985
1986
1990
1991
1992
1999
2000
2001
2002
2003
2004
5.7
10.4
6.0
17.8
5.6
12.4
21.8
8.2
6.6
15.1
44.7
13.3
24.8
22.4
34.9

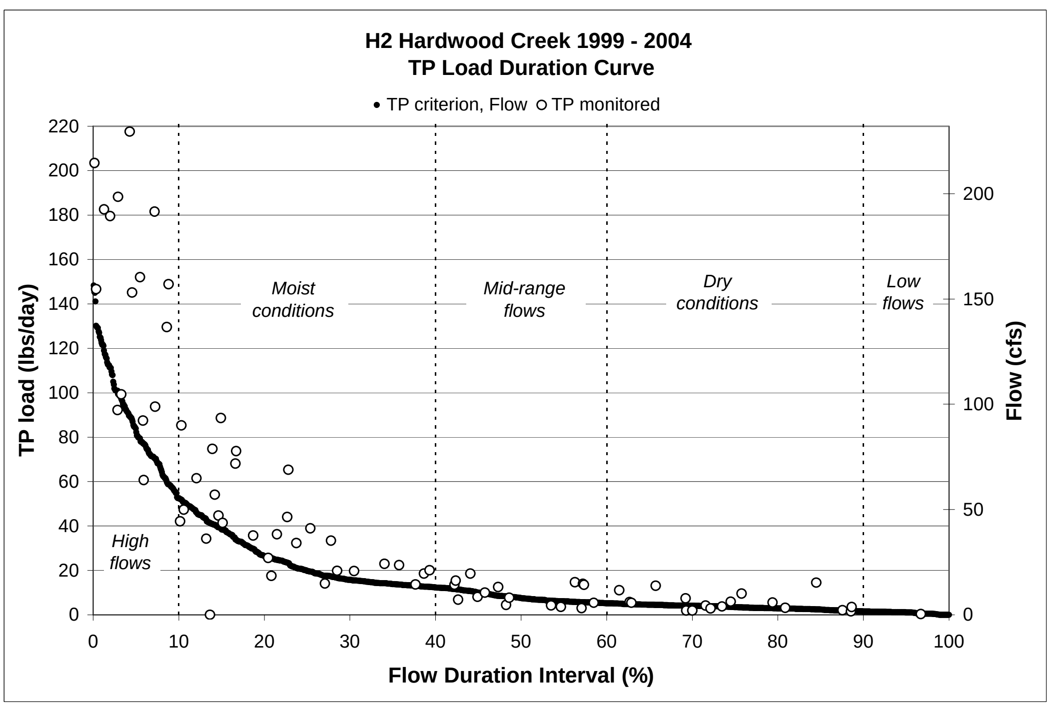

Historic Average Dissolved Oxygen at H2
Dissolved Oxygen +/- SD (mg/L)
Year
0
2
4
6
8
10
12
14
1978
1979
1980
1981
1985
1986
1990
1991
1992
1999
2000
2001
2002
2003
2004
6.0
9.5
11.6
8.1
9.2
7.8
8.0
10.6
6.8
8.3
6.5
8.0

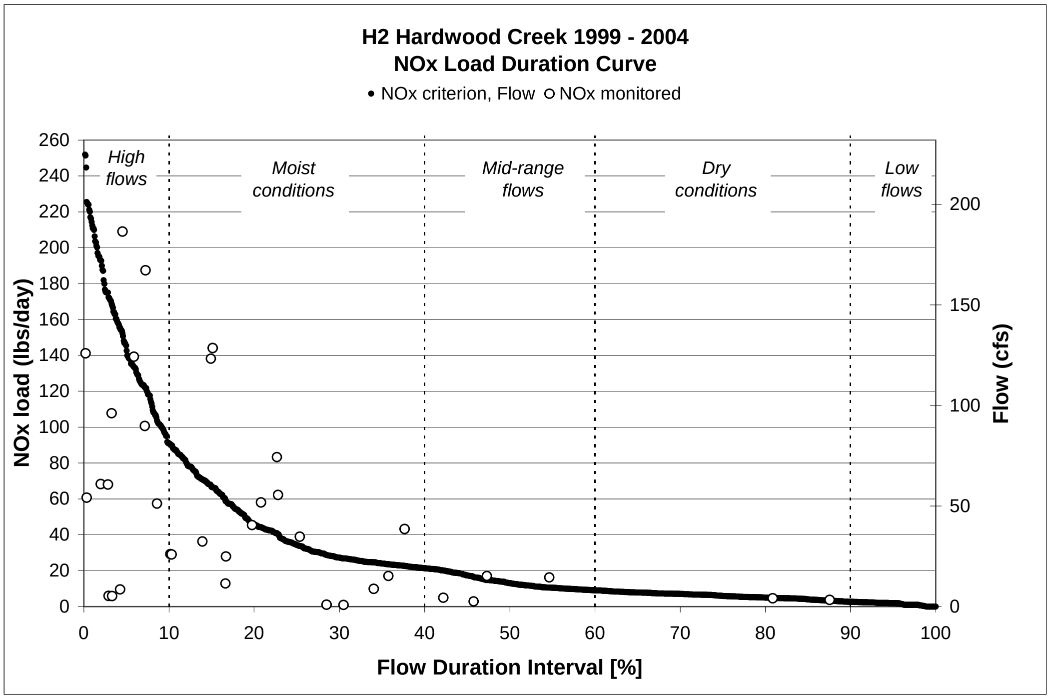

Historic Average pH at H2
pH +/- SD
Year
8.17
7.84
7.88
8.00
7.95
8.03
7.76
7.42
7.27
7.88
1977
1978
1979
1980
1981
1985
1986
1990
1991
1992
1999
2000
2001
2002
2003
2004


Historic Average Temperature at H2
Temperature +/- SD (deg. C)
Year
23.2
14.3
14.0
12.3
13.3
17.3
14.9
8.6
16.1
14.3
15.0
14.0
1978
1979
1980
1981
1985
1986
1990
1991
1992
1999
2000
2001
2002
2003
2004

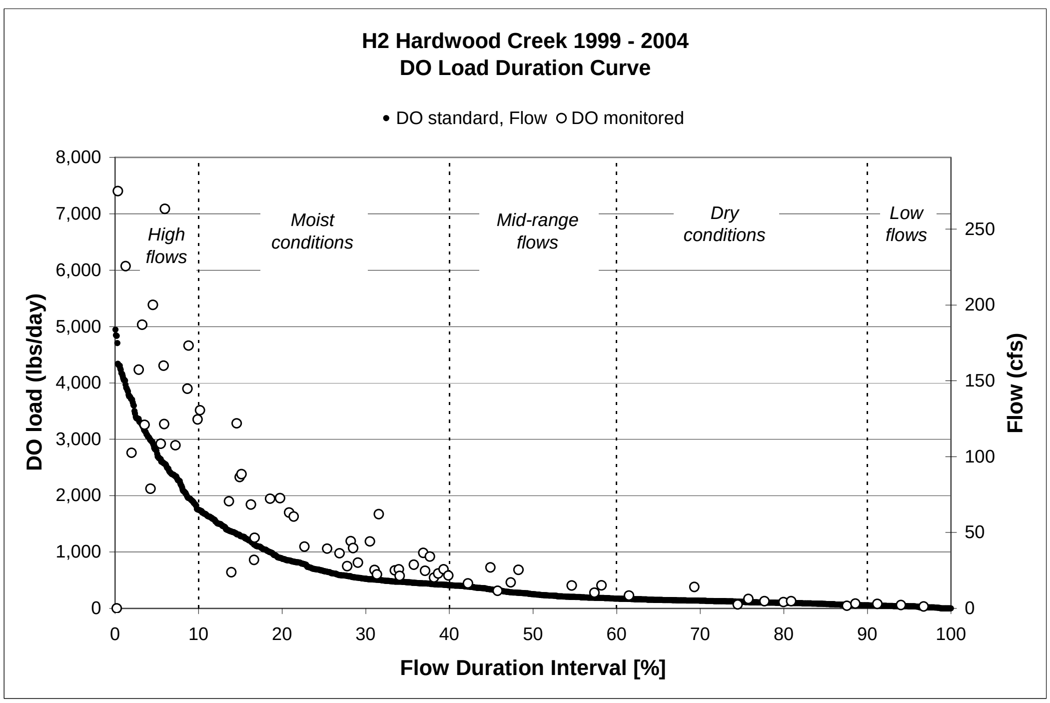
B. FLOW DURATION CURVES



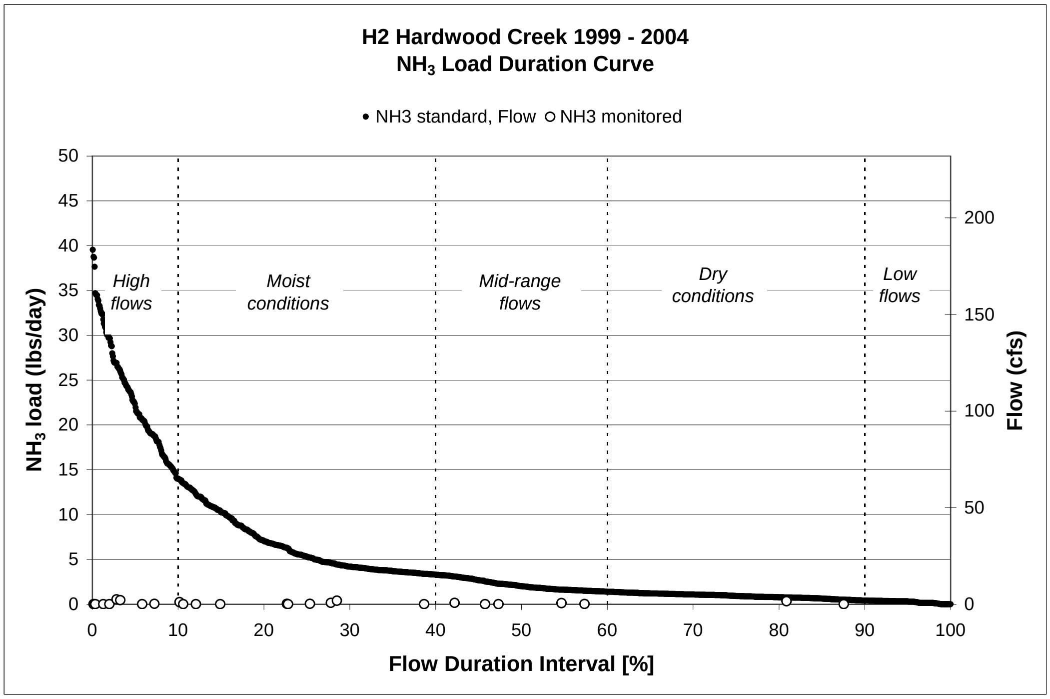




H2 Hardwood Creek 1999 - 2004
NOx Load Duration Curve
• NOx criterion, Flow ○ NOx monitored
High flows
Moist conditions
Mid-range flows
Dry conditions
Low flows
NOx load (lbs/day)
Flow (cfs)
Flow Duration Interval [%]



H2 Hardwood Creek 1999 - 2004
DO Load Duration Curve
• DO standard, Flow ○ DO monitored
High flows
Moist conditions
Mid-range flows
Dry conditions
Low flows
DO load (lbs/day)
Flow (cfs)
Flow Duration Interval [%]


H2 Hardwood Creek 1999 - 2004
NH3 Load Duration Curve
NH3 standard, Flow
NH3 monitored
NH3 load (lbs/day)
Flow (cfs)
Flow Duration Interval [%]
High flows
Moist conditions
Mid-range flows
Dry conditions
Low flows
0
5
10
15
20
25
30
35
40
45
50
0
50
100
150
200
0
10
20
30
40
50
60
70
80
90
100

C. ROSGEN STREAM ASSESSMENT

A Rosgen stream assessment was conducted in the lower half Hardwood Creek along five reaches to better understand the physical characteristics of the creek. In addition to the sub-reach Rosgen assessments that were conducted, each of the five reaches were walked in their entirety to document areas of erosion, deposition and aggradation, debris blockages, and riparian corridor conditions. The upper portion of Hardwood Creek (upstream of Harrow Avenue) has an unconsolidated bottom, making conditions unfavorable to conduct a complete Rosgen assessment in this portion of the system. Despite this, as part of the Washington County Judicial 2 Repair Report, Dr. Sandy Verry was hired to classify several reaches of creek in this section (RCWD 2004).

Assessment Methods

For each reach, approximately 750 feet were surveyed for a Rosgen Level II assessment. In addition, several key parameters of a Rosgen Level III assessment were also collected. A description of each Rosgen assessment is provided below followed by a written summary for each reach. Individual results can be found in the tables and figures at the end of this section.

Level I Rosgen Stream Classification Methods

Level I classification in the Rosgen system describes the geomorphic characteristics that result from integrating basin relief, landform, and valley morphology. The dimension, pattern, and profile of rivers are used to delineate geomorphic types at a coarse scale (Rosgen 1996). This procedure is typically conducted through the evaluation of topographic maps, aerial photographs, and any other broad-scape source. A Level I stream classification serves the following four primary functions:

1) Integrates basin characteristics, valley types, and landforms with respect to the morphology of the stream system
2) Provides a framework for organizing and communicating river information
3) Provides the information for prioritizing the need for detailed assessments or companion inventories
4) Provides information that can be used to correlate similar general level inventories such as fisheries habitat, riparian habitat, etc.

The information derived from a Level I evaluation is the least-specific, but it provides a rapidly-obtainable starting point from which a detailed evaluation can be drawn. Through a Level I characterization, valley types and landforms are evaluated, and the study stream is then categorized as one of the following nine stream types: Aa+, A, B, C, D, DA, E, F, and G (Rosgen 1996). The stream types applicable to Hardwood Creek are briefly described below. The applicability of these stream types was determined through evaluation of topographic data and aerial photographs obtained from Washington County (2002). Most importantly however, these determinations were verified through preliminary field observations of the potential study segments.

The valley that Hardwood Creek lies in is similar in physical characteristics to Valley Type X in the Rosgen system. Rosgen (1996) writes: “Valley Type X is very wide, with very gentle elevation relief and is mostly constructed with alluvial materials, originating from both riverine and lacustrine deposition processes." Landforms commonly observed as Valley Type X are coastal plains, broad lacustrine and/or alluvial flats, which may exhibit peat bogs and expansive wetlands. Stream types C, E and DA are the most commonly observed, although in many instances, where streams have been channelized or the local base level has been changed, G and F stream types are found. In Hardwood Creek, C, E, F, and G stream types were found to occur.

Level II Rosgen Stream Classification Methods

The Level II analysis uses field measurements from specific channel segments to produce a classification level of finer resolution. The ultimate goal of Level II data 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). The Level II criteria are based on the following characteristics, which are measured and calculated from the collected field data:

- Entrenchment ratio
- Width/depth ratio
- Dominant channel materials
- Slope
- Bed features
- Sinuosity
- Meander width ratio

A dichotomous key approach is used to delineate streams from the Level I classifications to the Level II classifications. Level II produces a set of reference reaches or segments for which data may be used to extrapolate to similar segments where data are not available. The use of Level II reference data enables classifications to be completed for other similar areas without requiring the extensive field data collection effort. Rosgen's (1996) use of the term "reference" does not pertain to a non-impacted reference area. The steps used to measure and compute the Level II data are described below. The methods described are those presented by Rosgen (1996) and subsequently used for the Hardwood Creek assessment.

1. Bankfull Elevation – Bankfull elevation is the single most important parameter used in Level II classifications (Rosgen 1996). Bankfull is also used to estimate other important parameters in Level II; therefore its accurate measurement cannot be overstated. Bankfull is often confused with top-of-bank elevation, which in some cases may be coincident with bankfull elevation. The elevation of the top of point bars and the bankfull stage share a common elevation. Several field indicators may be used as a reliable method for determining the bankfull elevation:

- The presence of a floodplain at the elevation of incipient flooding
- The elevation associated with the top of the highest depositional feature
- A break in slope of the banks and/or a change in the particle size distribution
- Evidence of an inundation feature such as small benches
- Staining of rocks
- Exposed root hairs below an intact soil layer indicating exposure to erosive flow
- Lichens and certain riparian plant species

Bankfull is best measured within the narrowest segment of a study area where the channel can freely adjust its lateral boundaries. Areas that possess in-stream deflectors such as rocks, logs, and debris should be avoided. The bankfull elevation is measured on both sides of the channel. The width of the bankfull stage across the channel is also measured and used to compute subsequent parameters such flood prone area (FPA) and entrenchment (see below).

2. Entrenchment – Entrenchment is the vertical containment of a stream and the degree of its incision in the valley floor. An entrenchment ratio is computed in a Level II analysis. This ratio is the width of the flood prone area (FPA) to the width of the bankfull stage. The method used to compute the entrenchment ratio is most easily understood as a series of field measurement steps. To calculate entrenchment, the following measurements are taken with survey equipment:

1) An elevation is determined for a point at the maximum depth of the stream channel.
2) An elevation is determined for the bankfull elevation on both banks.
3) The resulting bankfull elevation is subtracted from the elevation corresponding to the maximum depth of the stream channel (i.e., subtract Step 2 from Step 1).
4) The resulting value is multiplied by 2 then subtracted from Step 1 to obtain the FPA elevation.
5) The rod is moved upslope until the elevation obtained in Step 4 is obtained. This is done for both banks.
6) The distances between the two bankfull elevations and the two FPA elevations are measured to obtain a "bankfull width" and a "FPA width."
7) The FPA width is divided by the bankfull width to compute the "entrenchment ratio."

For stream types that are only slightly entrenched (C, and E), flows that are greater than the bankfull stage overtop their banks and extend onto the surrounding floodplain. For stream types that are deeply entrenched (F and G), the top-of-bank elevations are often much higher than the bankfull elevations. The floodplain is, in essence, contained within the channel.

3. Width/Depth Ratio – The width/depth ratio is the ratio of the bankfull width to the mean depth of the bankfull channel. Determining the width/depth ratio provides a rapid visual assessment of channel stability because of its ability to suggest potential sediment movement. High width/depth ratios (i.e., shallow and wide channels) place stress on the near bank region. As ratios increase even further, the hydraulic stress against the banks also increases and erosion is accelerated. The width/depth ratios were determined by first obtaining a series of channel cross-sections (i.e., elevations) over regularly-spaced intervals along the bankfull width.

4. Sinuosity – Sinuosity is the ratio of stream length to valley length. The length of a stream segment occurring within a length of land will determine how sinuous the stream must be to fit within the length of land. Sinuosity was determined for the stream segments in this study through the interpretation of aerial photographs of the study area, coupled with measurements of the stream length divided by that occurring within the specific valley length.

5. Channel Materials – Channel materials determine the extent of sediment transport and provide the resistance to hydraulic stress. This parameter is measured using a method presented in

Rosgen (1996) referred to as the modified Wolman method. A segment of the stream equating to 20 to 30 bankfull widths is surveyed for the frequency of riffles, pools, glides, runs, etc. Then the bed material sampling locations are adjusted so that the bed features are sampled on a proportional basis along this segment. For example, assuming a stream segment is composed of 30 percent riffles and 70 percent pools. Then a minimum of 30 observations are taken in riffles and a minimum of 70 observations are taken in pools. Proportional sampling is essential for determining channel material size since bed features exhibit specific particle sizes.

Channel materials are typically determined using particle size as a determinant. Numeric indicators are used to classify the particle sizes of the channel materials. These indicators are 1 (bedrock), 2 (boulder), 3 (cobble), 4 (gravel), 5 (sand), and 6 (silt-clay).

6. Slope – The slope of the water surface of a river plays a major role in determining its channel morphology and associated sediment, hydraulic, and biological functions. A longitudinal profile along a stream segment is the preferred method for determining slope. This is accomplished by measuring the difference in water surface elevation per unit stream length, usually a minimum of 20 channel widths in length.

Level III Rosgen Stream Classification Methods

Whereas the Level I and Level II analyses provide the basic morphological template for describing streams, the Level III analysis overlays additional descriptive and predictive variables onto the Level I and II classifications to describe the stream's existing condition relative to its departure from its full potential. Rosgen (1996) defines "full potential" as a self-formed stream that is stable, self-maintained, and whose physical and biological function is at an optimum. This description assumes that a stable stream is able to maintain its dimension, pattern, and profile over time, without significant aggradation or degradation. This stream will also have the ability to effectively transport its flow and detritus throughout its watershed. This is obviously a simplified definition of a stream's steady state, and it is assumed that the concept of dynamic equilibrium is inherent in Rosgen's (1996) morphological definition of a stable stream.

Defining the full potential of a stream will vary with specific management goals, and in the case of Hardwood Creek, one of the immediate goals should be to curtail the advanced rate of erosion. Other management goals such as meeting total maximum daily load (TMDL) objectives for pollutants such as phosphorus can be attempted concurrently, or may be more easily achieved following the immediate task of minimizing erosion.

As important as it is to acknowledge the dynamic equilibrium of a stream, it is equally important to recognize that many streams have been degraded for so long that the stream's existing state may be construed as its baseline condition. The Level III analysis therefore attempts to distinguish these two conditions under the premise that a stream functioning under its full potential will exhibit a set of characteristics that are associated with stability. Subsequently, the absence or departure from these anticipated characteristics imply a departure from stable conditions. The Level III analysis accomplishes this by combining the predictive tools for determining a stream's full potential relative to the stream's natural tendency to evolve to a particular morphological form. There are field-measurable characteristics that a stream will exhibit when departing from its full potential. An example of some common characteristics are a change in the width/depth ratio, a reduction in sinuosity, an increase in channel slope, the establishment of a bi-modal particle distribution (possibly occurring in Hardwood Creek), an increase in bar deposition (possibly occurring in Hardwood Creek), an acceleration in bank erosion (observed in Hardwood Creek), an increase in sediment supply (observed in Hardwood Creek), a decrease in sediment transport capacity, a decrease in meander width ratio (a Rosgen-based measurement), and an increase in channel aggradation.

The recurring theme in Rosgen's (1996) examples of stream evolution, and departure from stability, is an abandonment of the floodplain. As described in the Level II analysis, the floodplain of an F stream type lies within the stream channel as a result of deep entrenchment. A conventional floodplain is present and functioning in E and C stream types. Therefore, the F stream types identified in this study are handling the majority of their flood flows entirely within their channel. This condition results in advanced erosion, sediment transport, and an increase in the width/depth ratio, all warning signs of stream departure.

Finally, since the Level III analysis attempts to predict the most likely state that a stream is evolving towards, it avoids the assumption that a stream should be restored to its original condition. This is because the environmental factors that caused a stream to depart from its original condition, such as an increase in stormwater volume, may preclude the stream from returning to this condition. Furthermore, the current environmental conditions may be pushing a stream towards a certain morphological type, and attempts to return the stream to a previous condition may be virtually impossible.

The following Level III parameters were measured in Hardwood Creek to describe the stream condition: (1) riparian vegetation, (2) streamflow regime, (3) stream size and stream order, (4) organic debris and channel blockage, (5) depositional patterns, (6) streambank erosion potential, and (7) channel stability.

Stream Assessments

Stream Reach 1

Stream Reach 1 is the lower most reach of Hardwood Creek, extending from Highway 35E to Anoka County Road 21. This is the reach fish were surveyed in 1999 and 2004. In addition, both macroinvertebrates and Chironomidae were collected in 2004.

Stream reach 1 is classified as a type C stream that is moderately entrenched with a low to moderate gradient. There are a few sections of the creek in this reach where moderate erosion is occurring. The majority of this reach is dominated by runs with several pools present. With the exception of the first several hundred feet downstream of Highway 35E, this reach is unditched and naturally meandering.

Channel stability in this reach was classified as fair to poor and bank erosion potential was classified as moderate. Riparian conditions are mostly intact but the buffer could be wider. In addition, very little undergrowth occurs along the banks, making them susceptible to high flows. Within 50-100 feet from the buffer, row crop agriculture or residential lawns are common.

Photograph 1. Reach 1 along Hardwood Creek, Minnesota

Stream Reach 2

Stream Reach 2 is located between 35E and 170th Street. This reach is a type E and is one of the most disturbed reaches with severe bank erosion occurring almost the entire length. Most of this reach is low to moderate gradient, meandering, run-glide stream with a low width to depth ratio and high sediment supply.

Channel stability was ranked poor and bank erosion is moderate to high with a lot of vertical streambank degradation. The riparian corridor is dominated by box elder, green ash, and in some places reed canary grass. In some locations, row crop agriculture and residential lawns directly abut the creek. Channel material consists predominantly of sand with some gravel. A majority of the gravel appears to be washed in from 170th Street and is located just downstream of the culvert. Areas where there is gravel are slightly embedded.

Photograph 2. Reach 2 along Hardwood Creek, Minnesota

Stream Reach 3

Stream Reach 3 is located between 170th Street and Elmcrest Avenue. The steam is a type G and is entrenched with most flood flows fully contained within the channel. The reed canary grass provides protection against high flows but in several areas the vertical bank has been undercut and is eroding. Channel stability was ranked fair and bank erosion potential was ranked low to moderate. The channel material is predominately sand with some gravel that is fairly embedded with fines.

Photograph 3. Reach 3 along Hardwood Creek

Photograph 4. Reach 3 along Hardwood Creek

Stream Reach 4

Stream Reach 4 is a type F stream and is located from Elmcrest Avenue to 165th and is moderately entrenched with a low to moderate gradient. There are a few sections of the creek in this reach where severe erosion is occurring. The majority of this reach is dominated by runs with few pools present.

Channel material consists predominately of sand with some gravel with slight embeddedness occurring. Channel stability is this reach was classified as high and bank erosion potential was classified as moderate to high. Riparian conditions are mostly cattle, horse and llama farms with a few residential lawns.

Photograph 5. Reach 4 along Hardwood Creek

Stream Reach 5

Stream Reach 5 extends from Fenway Avenue North to 174th Street North. This reach is no longer considered Hardwood Creek but is technically considered Washington County Judicial Ditch 2. The channel is considered a type C channel and is slightly entrenched. Channel material is comprised 100% of sand. Riparian vegetation is dominated by reed canary grass and agricultural fields. Channel stability and bank erosion potential is moderate in the reach. There are a few areas with significant vertical bank erosion occurring. There are no channel blockages or debris in this reach.

Photograph 6. Reach 5 along Hardwood Creek

Table 4. Channel Material in Hardwood Creek

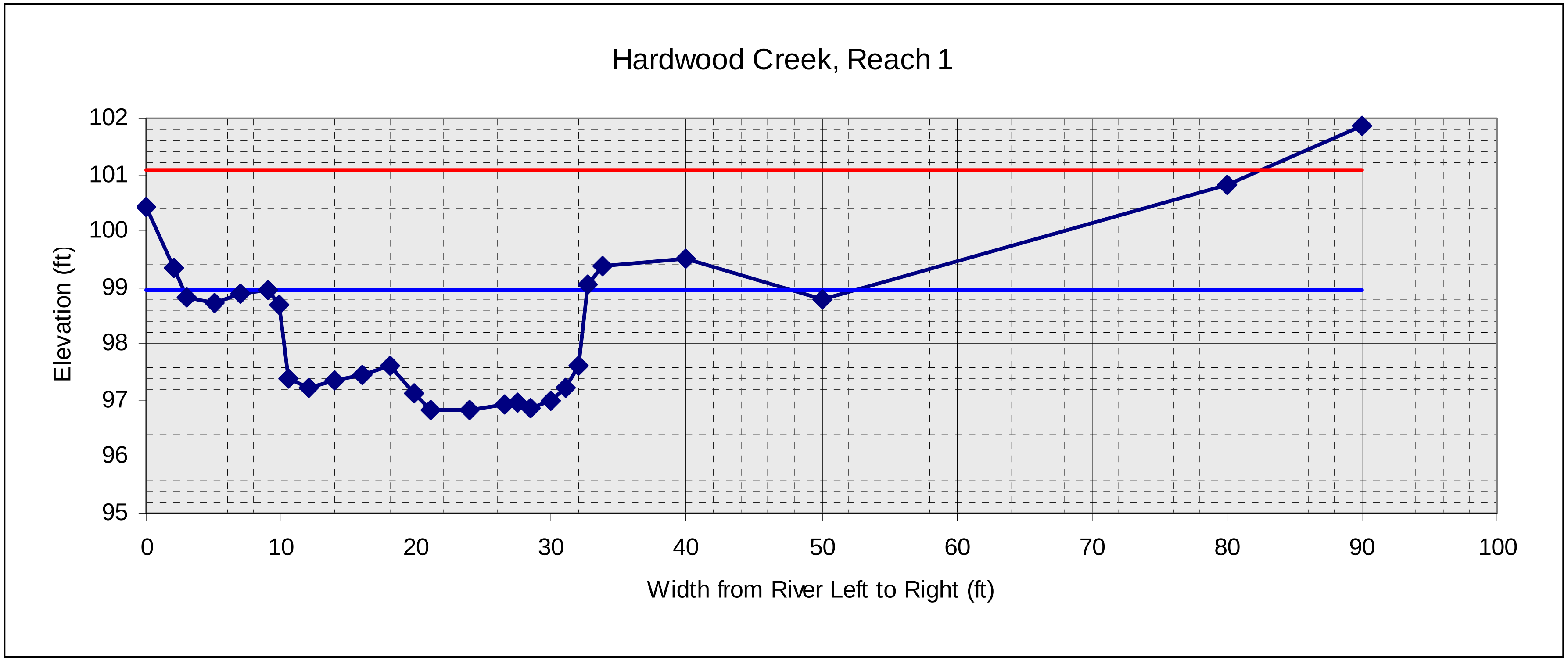
	D16	D35	D50	D84	D95	silt/clay (%)	sand (%)	gravel (%)	cobble (%)	boulder (%)	bedrock (%)
Reach 1	0.10	0.16	0.23	1.50	5.29	69.00	16.00	0.00	0.00	0.00	0.00
Reach 2	0.00	0.12	0.41	27.00	93.92	29.00	41.00	18.00	12.00	0.00	0.00
Reach 3	0.00	0.10	0.15	2.96	9.07	32.00	44.00	25.00	0.00	0.00	0.00
Reach 4	0.10	0.12	0.15	12.28	71.36	23.00	44.00	25.00	9.00	0.00	0.00
Reach 5	0.05	0.11	0.13	0.25	0.33	9.00	91.00	0.00	0.00	0.00	0.00

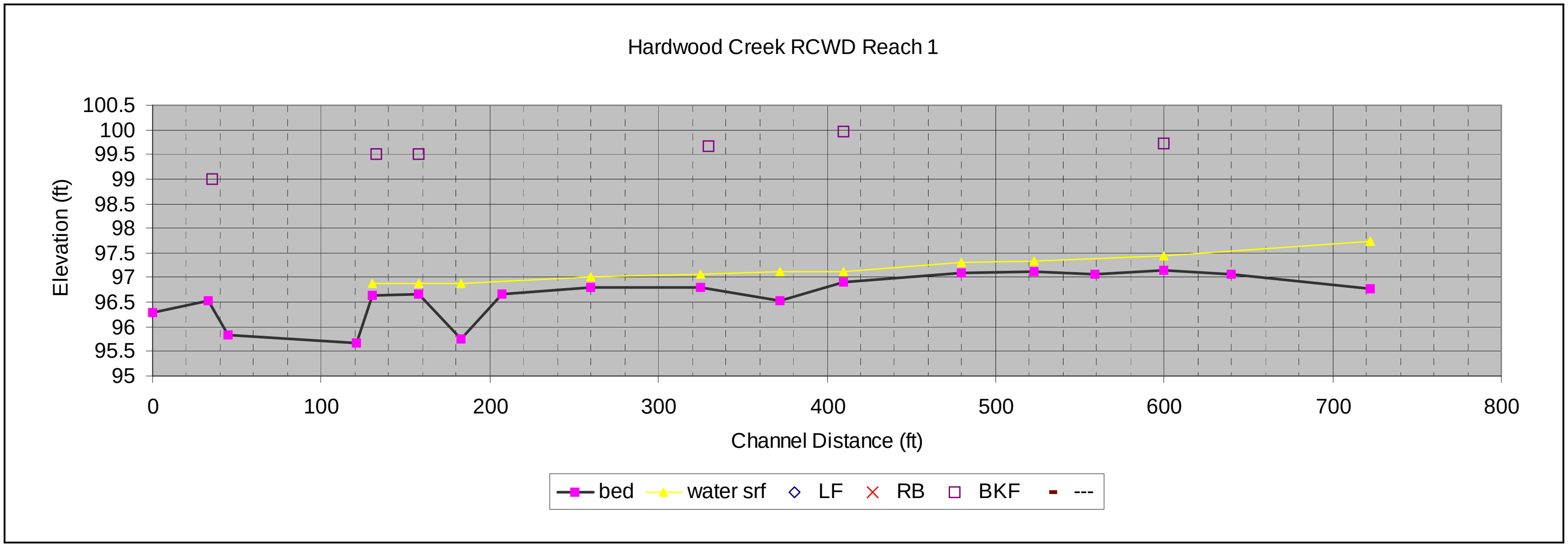
Table 6. Key Rosgen Level III Parameters for Hardwood Creek

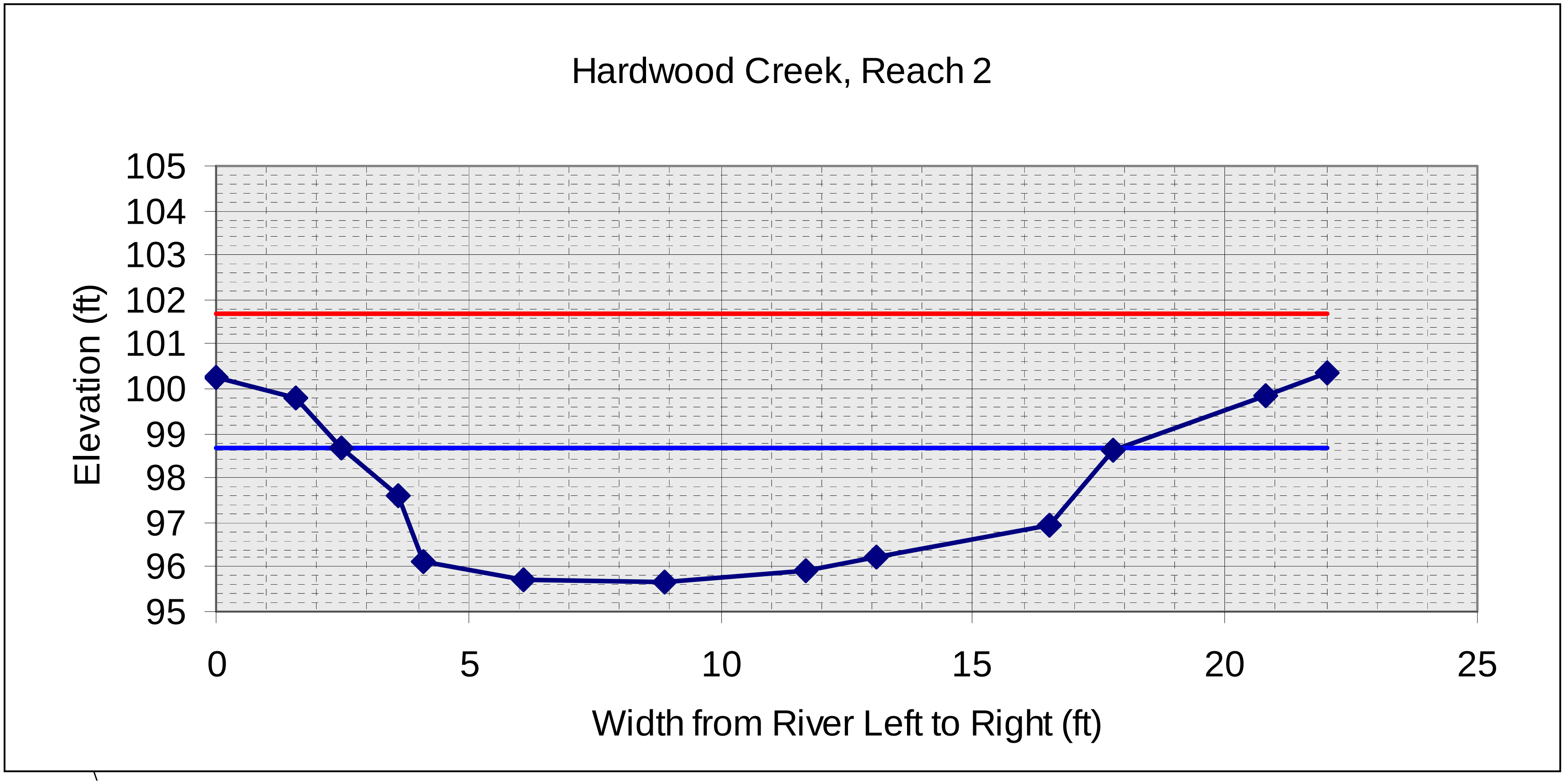
	Sinuosity	Channel Slope	x-section area	Bankfull width (feet)	Max. Depth (feet)	Bank Height (feet)	Width of Floodprone Area	Mean depth (feet)	Wetted Perimeter (feet)	Hydraulic Radius	Width/Depth Ratio	Entrenchment Ratio
Reach 1	1.3	0.06	41.37	24.80	2.13	3.60	82.00	1.67	36.37	1.14	14.87	3.31
Reach 2	1.5	0.05	35.53	15.42	3.02	4.64	30.00	2.30	17.92	1.98	6.69	1.95
Reach 3	1.7	0.05	28.29	12.40	3.56	3.67	100.00	2.28	15.63	1.81	5.43	1.50
Reach 4	2.2	0.04	29.71	35.80	0.83	3.45	36.00	0.83	19.50	1.52	43.13	1.01
Reach 5	1.1	0.01	30.00	13.06	2.99	3.75	40.20	2.30	16.15	1.86	5.69	3.08

Table 5. Key Rosgen Level III Parameters for Hardwood Creek

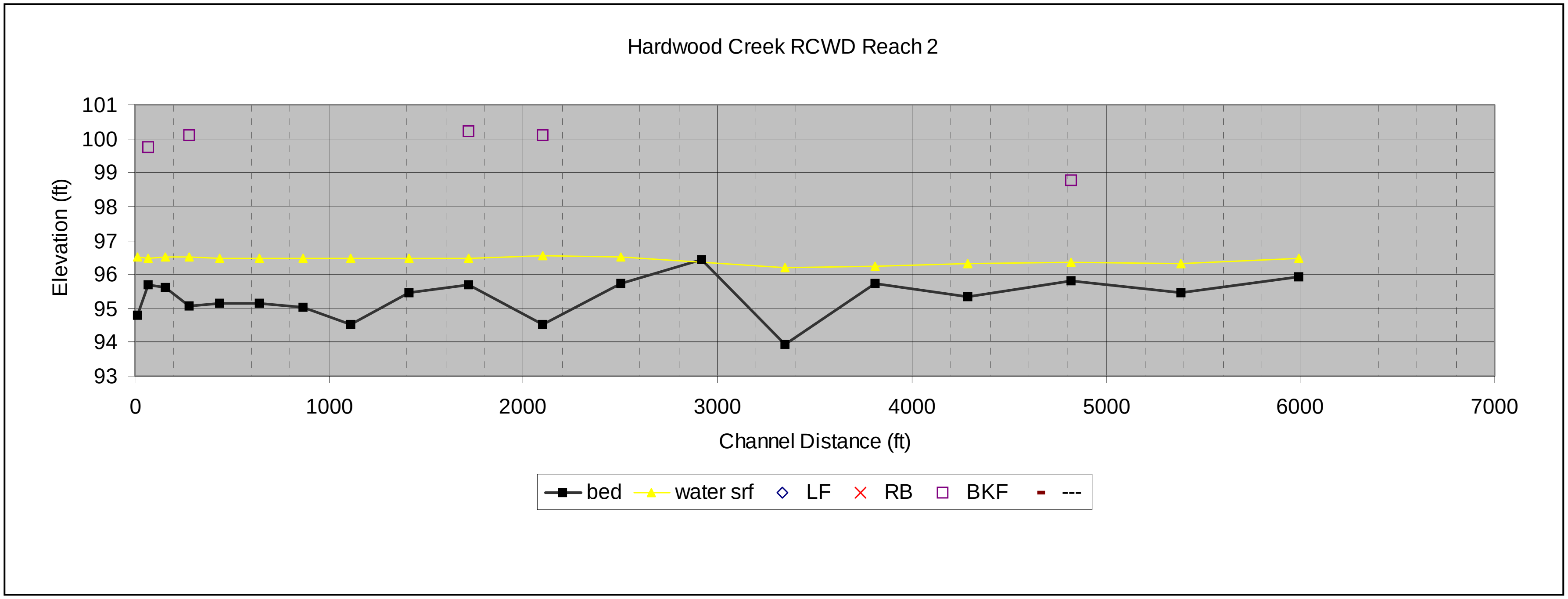
	Pfankuch Rating	Stream Channel Debris/Blockages	Bank Erosion Potential	Depostional Pattern	Stream Size	Flow Regime	Riparian Vegetation
Reach 1	127 (poor)	Numerous	Moderate	B-1	S-5	P-2	4b, 6b,9b
Reach 2	114 (poor)	Numerous	Moderate	B-1	S-4	P-2	4a, 6b,9c
Reach 3	92 (fair)	Moderate	Low	B-1	S-4	P-2	4c
Reach 4	122 (poor)	Infrequent	Moderate/High	B-1	S-5	P-2	4b, 5b
Reach 5	na	na	na	na	S-4	P-2	4c


Hardwood Creek, Reach 1
Elevation (ft)
102
101
100
99
98
97
96
95
0
10
20
30
40
50
60
70
80
90
100
Width from River Left to Right (ft)

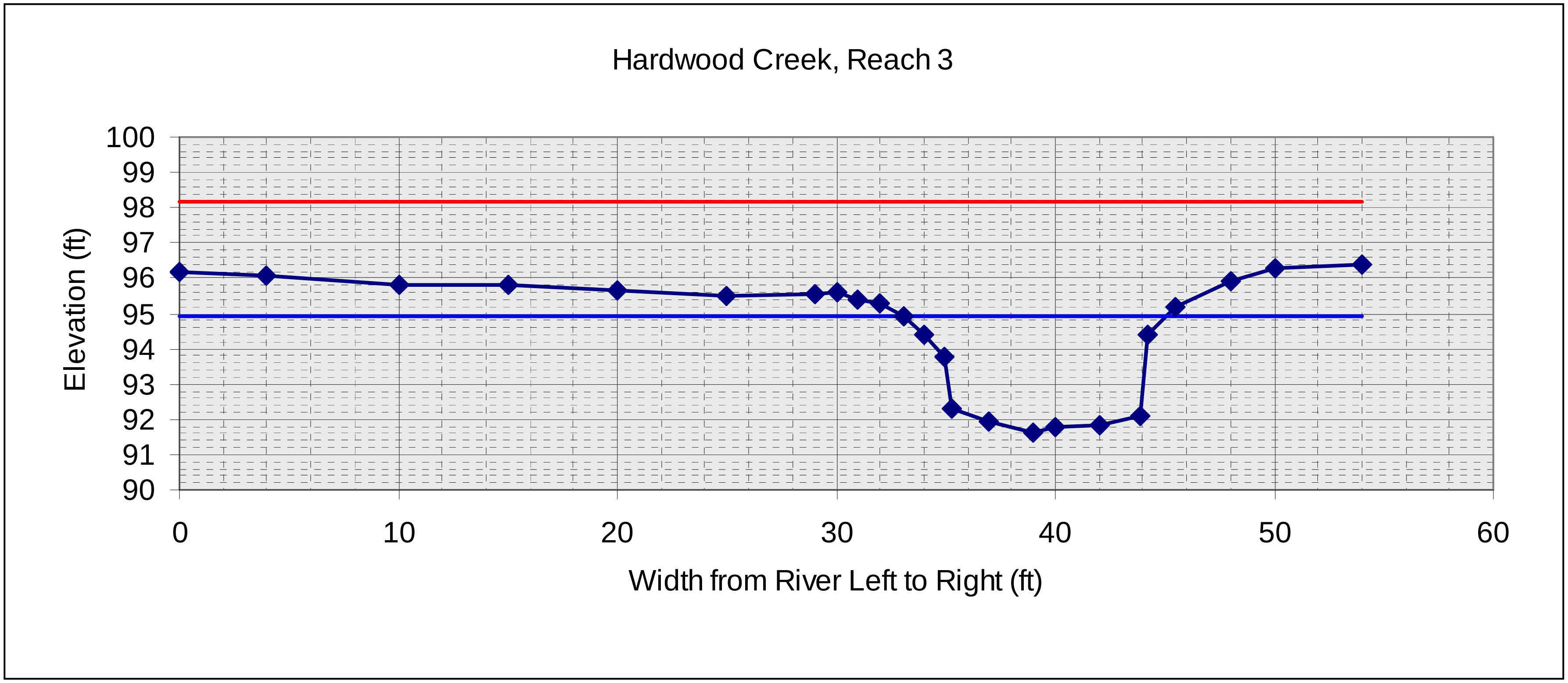

Hardwood Creek RCWD Reach 1
Elevation (ft)
100.5
100
99.5
99
98.5
98
97.5
97
96.5
96
95.5
95
0
100
200
300
400
500
600
700
800
Channel Distance (ft)
bed
water srf
LF
RB
BKF



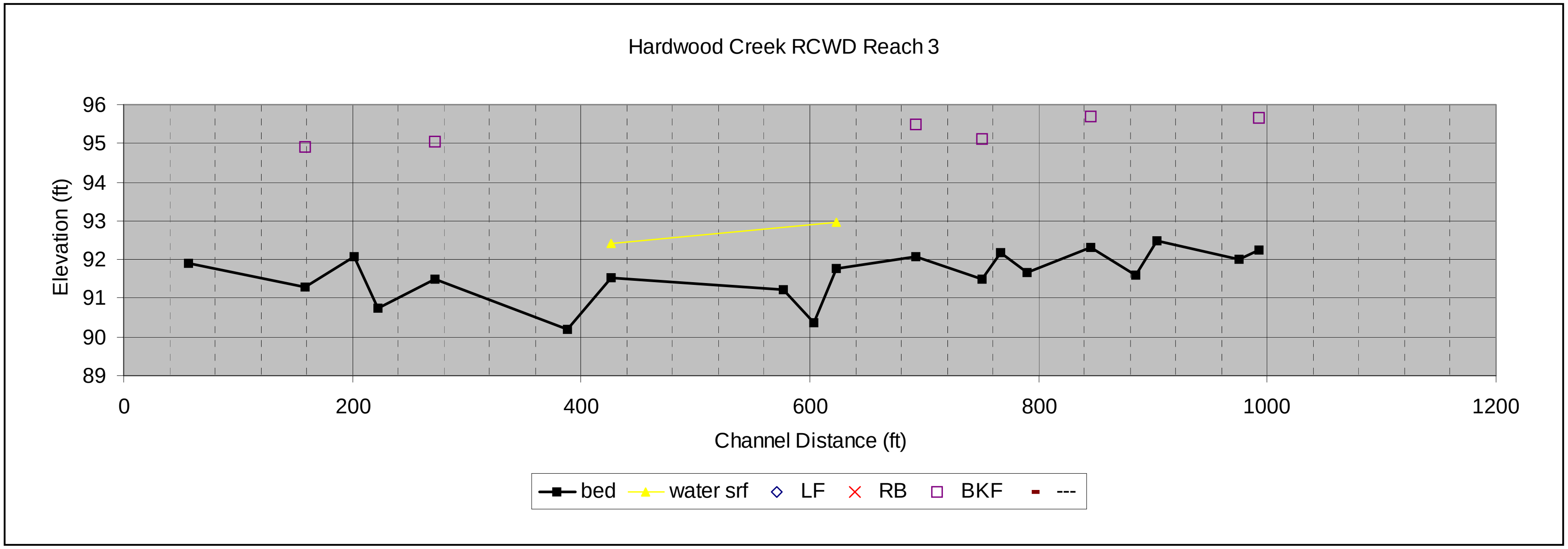
Hardwood Creek, Reach 2
105
104
103
102
101
100
99
98
97
96
95
Elevation (ft)
0
5
10
15
20
25
Width from River Left to Right (ft)



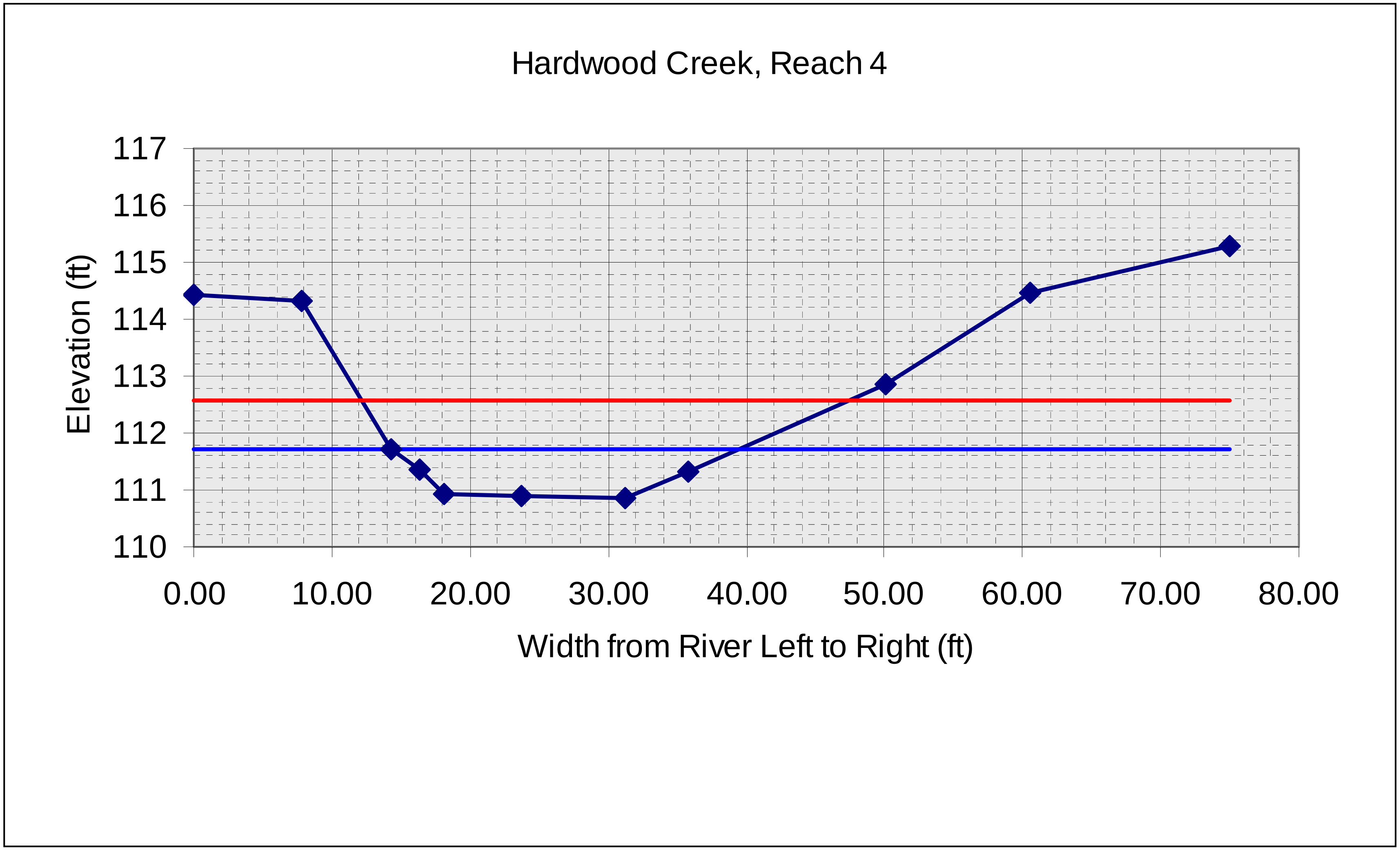
Hardwood Creek RCWD Reach 2
Elevation (ft)
101
100
99
98
97
96
95
94
93
0
1000
2000
3000
4000
5000
6000
7000
Channel Distance (ft)
bed
water srf
LF
RB
BKF

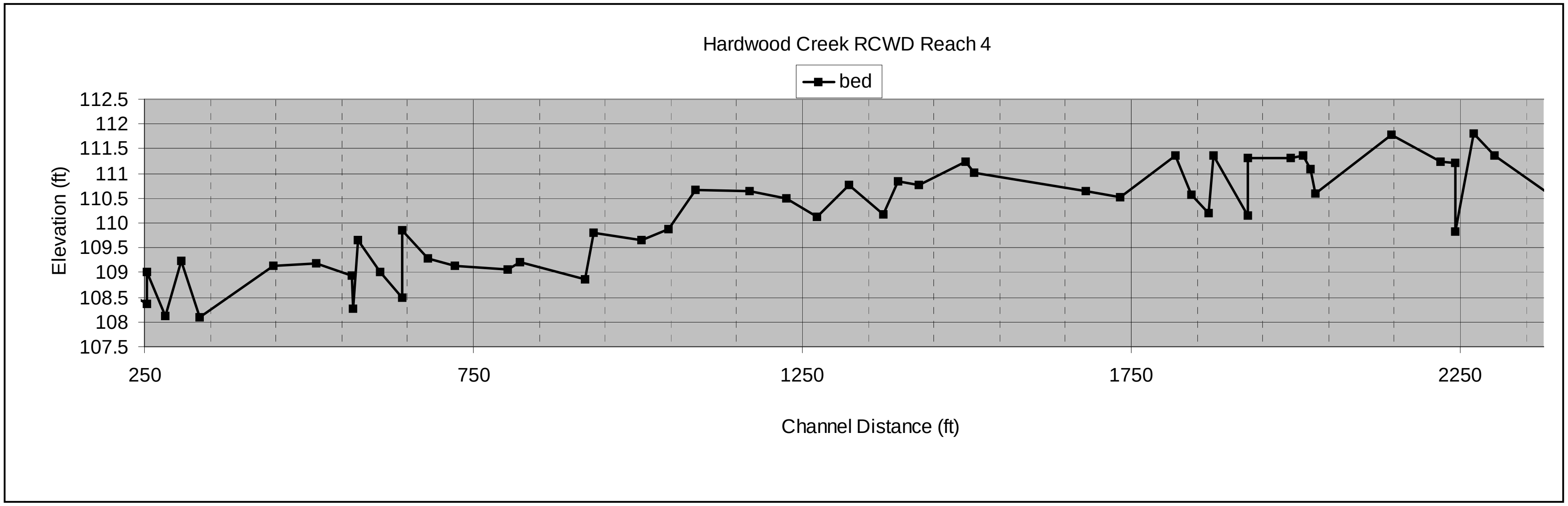


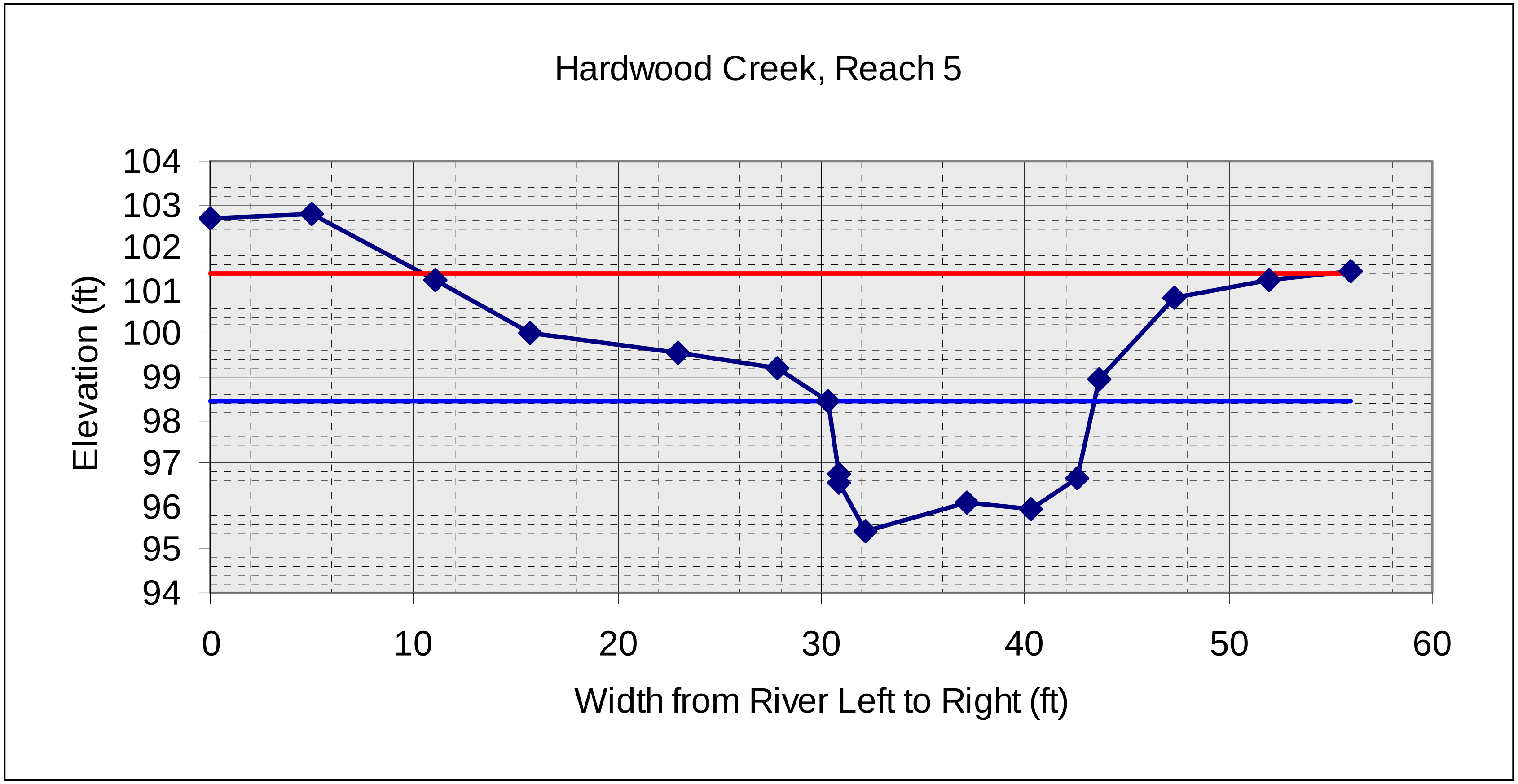
Hardwood Creek, Reach 3
Elevation (ft)
100
99
98
97
96
95
94
93
92
91
90
0
10
20
30
40
50
60
Width from River Left to Right (ft)



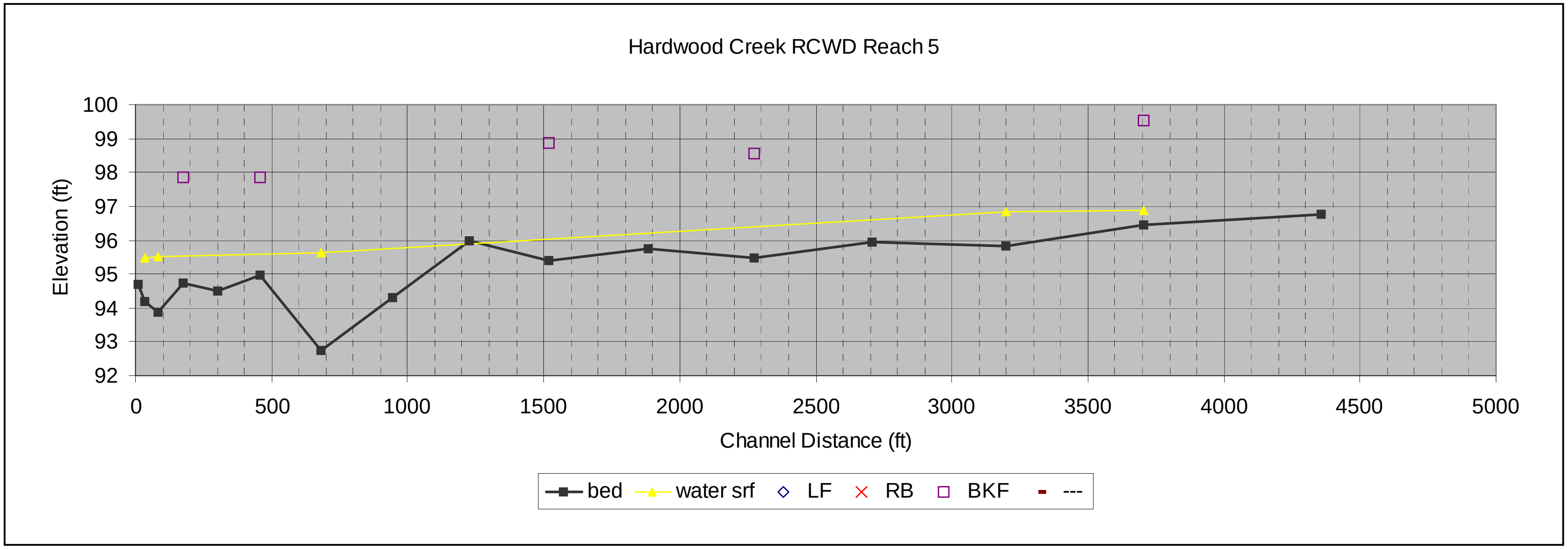
Hardwood Creek RCWD Reach 3
Elevation (ft)
96
95
94
93
92
91
90
89
0
200
400
600
800
1000
1200
Channel Distance (ft)
bed
water srf
LF
RB
BKF


Hardwood Creek, Reach 4
Elevation (ft)
117
116
115
114
113
112
111
110
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
Width from River Left to Right (ft)

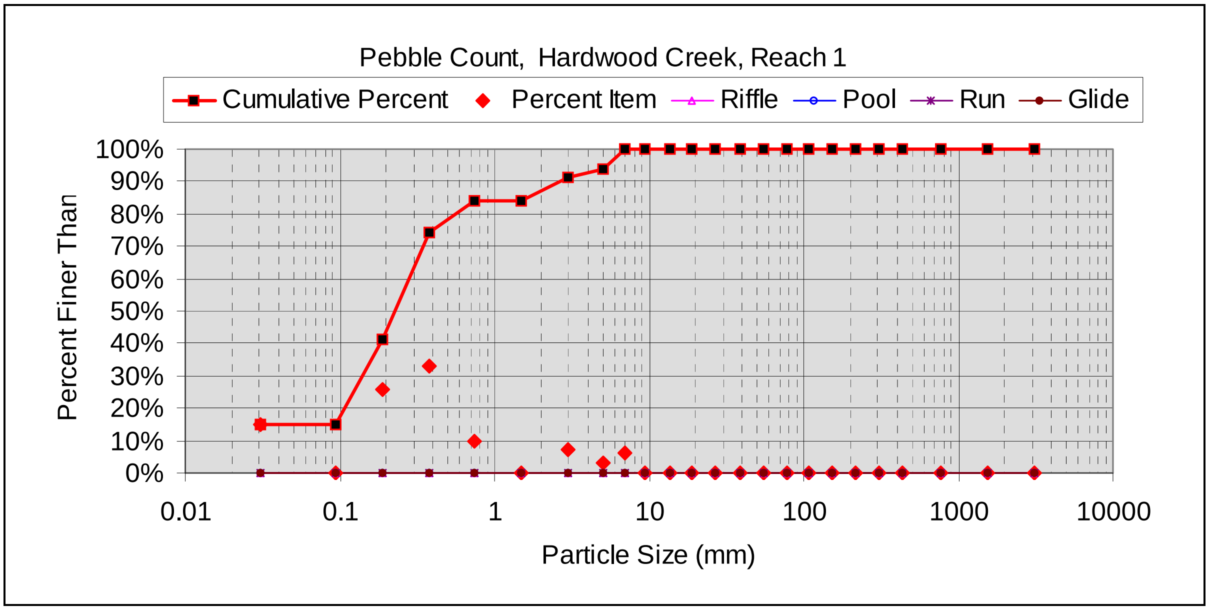

Hardwood Creek RCWD Reach 4
bed
112.5
112
111.5
111
110.5
110
109.5
109
108.5
108
107.5
Elevation (ft)
250
750
1250
1750
2250
Channel Distance (ft)

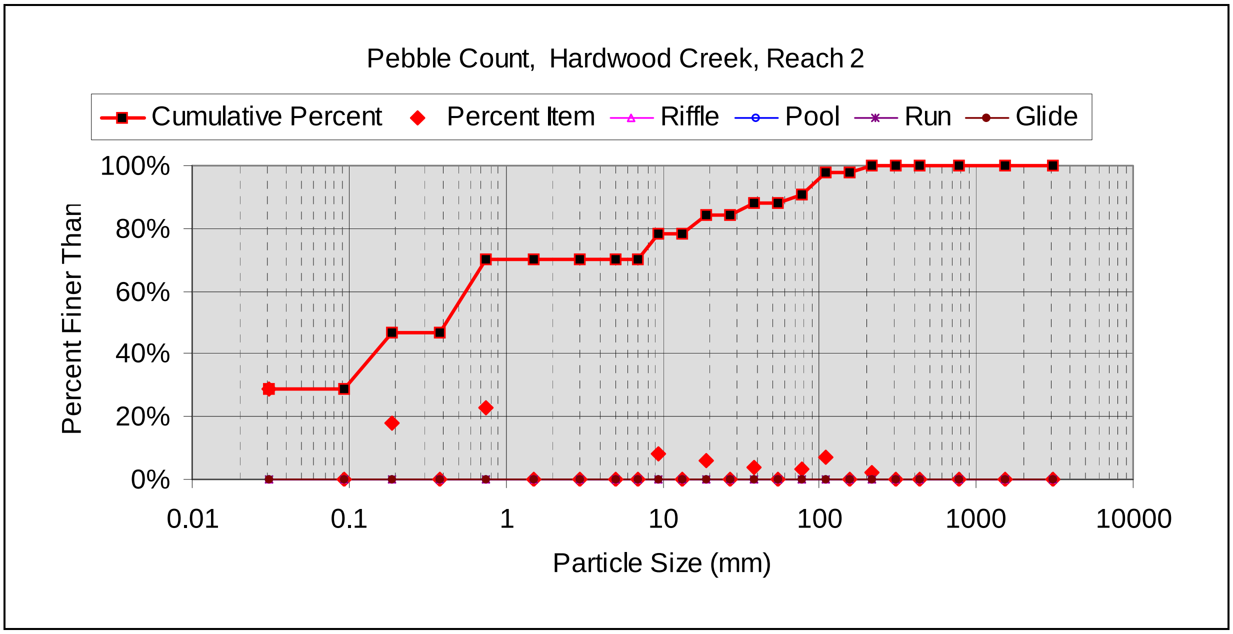


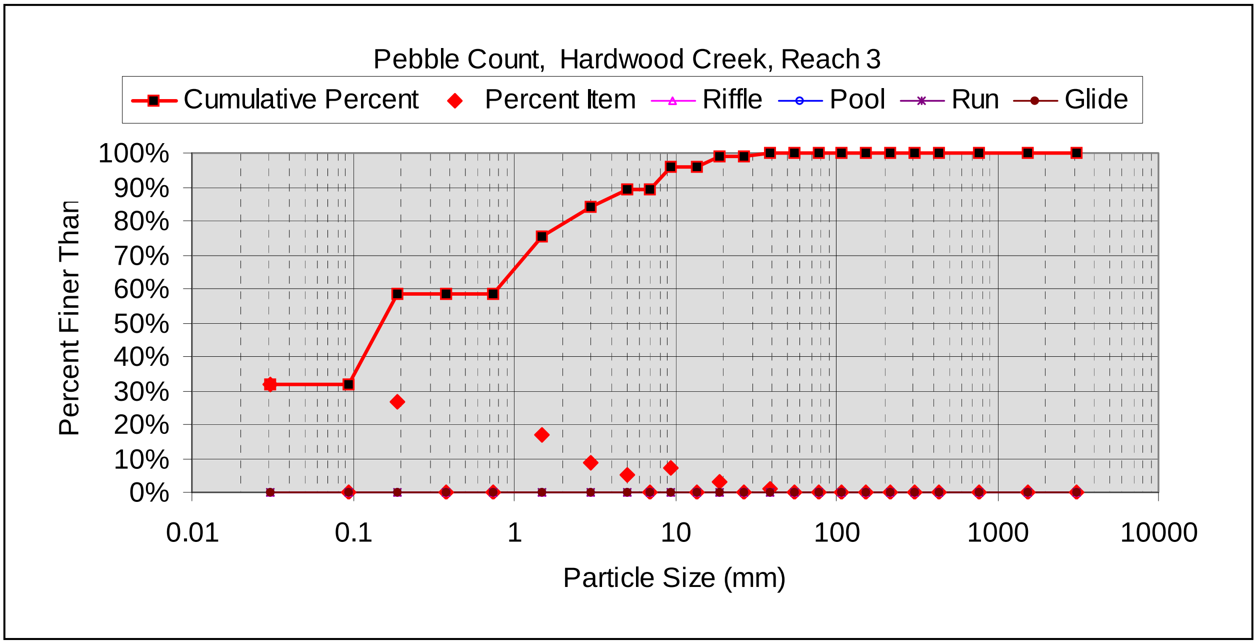
Hardwood Creek, Reach 5
Elevation (ft)
104
103
102
101
100
99
98
97
96
95
94
0
10
20
30
40
50
60
Width from River Left to Right (ft)

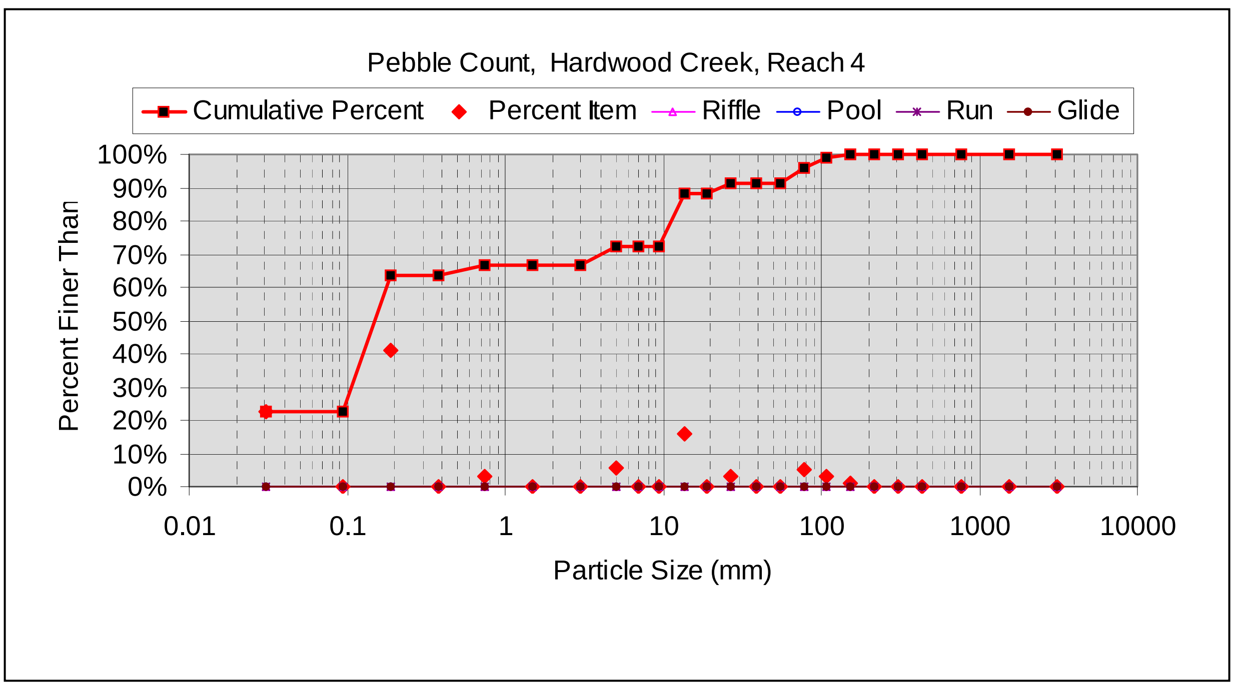


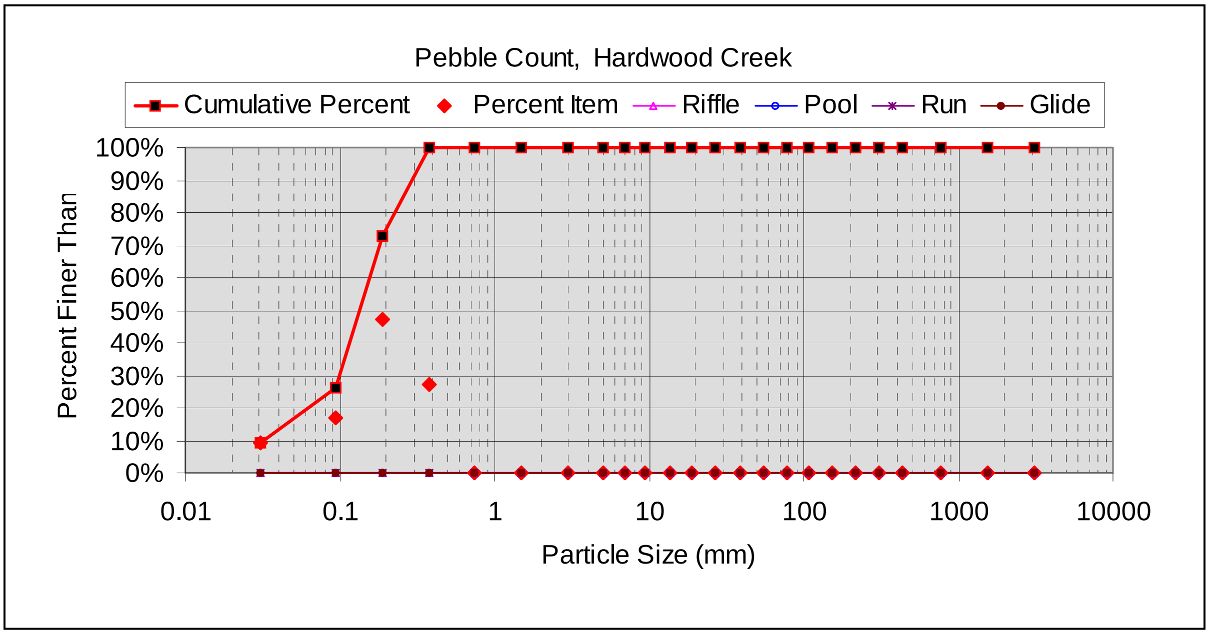
Hardwood Creek RCWD Reach 5
Elevation (ft)
100
99
98
97
96
95
94
93
92
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Channel Distance (ft)
bed
water srf
LF
RB
BKF


Pebble Count, Hardwood Creek, Reach 1
Cumulative Percent
Percent Item
Riffle
Pool
Run
Glide
Percent Finer Than
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.01
0.1
1
10
100
1000
10000
Particle Size (mm)


Pebble Count, Hardwood Creek, Reach 2
Cumulative Percent
Percent Item
Riffle
Pool
Run
Glide
Percent Finer Than
100%
80%
60%
40%
20%
0%
0.01
0.1
1
10
100
1000
10000
Particle Size (mm)


Pebble Count, Hardwood Creek, Reach 3
Cumulative Percent
Percent Item
Riffle
Pool
Run
Glide
Percent Finer Than
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.01
0.1
1
10
100
1000
10000
Particle Size (mm)


Pebble Count, Hardwood Creek, Reach 4
Cumulative Percent
Percent Item
Riffle
Pool
Run
Glide
Percent Finer Than
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.01
0.1
1
10
100
1000
10000
Particle Size (mm)


Pebble Count, Hardwood Creek
Cumulative Percent
Percent Item
Riffle
Pool
Run
Glide
Percent Finer Than
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.01
0.1
1
10
100
1000
10000
Particle Size (mm)

D. LAB REPORTS

MINNESOTA VALLEY TESTING LABORATORIES, INC.
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35 W. Lincoln Way ~ Nevada, IA 50201 ~ 800-362-0855 ~ Fax 515-382-3885

MEMBER ACIL

Report Date: 13 Aug 2001
Work Order #: 11-1014
Account #: 012893

BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-1 0-1 FT
Soil Laboratory Number: 01-D24530

ANALYSES	Results	
pH	7.9	units
Bray-I Phosphorus	6	ppm
Olsen Phosphorus	7	ppm
Moisture, % Gravimetric	47.5	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

MINNESOTA VALLEY TESTING LABORATORIES, INC.
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Date Received: 9 Aug 2001
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ANALYSES	Results	
pH	7.9	units
Bray-I Phosphorus	6	ppm
Olsen Phosphorus	7	ppm
Moisture, % Gravimetric	47.5	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

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BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-1 0-1.1 FT PEAT
Soil Laboratory Number: 01-D24531

ANALYSES	Results	
pH	7.1	units
Bray-I Phosphorus	11	ppm
Olsen Phosphorus	10	ppm
Moisture, % Gravimetric	863	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

MINNESOTA VALLEY TESTING LABORATORIES, INC.
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EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-1 0-1.1 FT PEAT
Soil Laboratory Number: 01-D24531

ANALYSES	Results	
pH	7.1	units
Bray-I Phosphorus	11	ppm
Olsen Phosphorus	10	ppm
Moisture, % Gravimetric	863	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

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EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-1 1-2 FT
Soil Laboratory Number: 01-D24532

ANALYSES	Results	
pH	8.8	units
Bray-I Phosphorus	8	ppm
Olsen Phosphorus	8	ppm
Moisture, % Gravimetric	19.7	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

MINNESOTA VALLEY TESTING LABORATORIES, INC.
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EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-1 1-2 FT
Soil Laboratory Number: 01-D24532

ANALYSES	Results	
pH	8.8	units
Bray-I Phosphorus	8	ppm
Olsen Phosphorus	8	ppm
Moisture, % Gravimetric	19.7	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

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BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-1 2-3 FT
Soil Laboratory Number: 01-D24533

ANALYSES	Results	
pH	8.7	units
Bray-I Phosphorus	8	ppm
Olsen Phosphorus	11	ppm
Moisture, % Gravimetric	27.4	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

MINNESOTA VALLEY TESTING LABORATORIES, INC.
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BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-1 2-3 FT
Soil Laboratory Number: 01-D24533

ANALYSES	Results	
pH	8.7	units
Bray-I Phosphorus	8	ppm
Olsen Phosphorus	11	ppm
Moisture, % Gravimetric	27.4	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

MINNESOTA VALLEY TESTING LABORATORIES, INC.
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MEMBER ACIL

Report Date: 13 Aug 2001
Work Order #: 11-1014
Account #: 012893

BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-1 3-4 FT
Soil Laboratory Number: 01-D24534

ANALYSES	Results	
pH	8.6	units
Bray-I Phosphorus	8	ppm
Olsen Phosphorus	6	ppm
Moisture, % Gravimetric	18.8	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

MINNESOTA VALLEY TESTING LABORATORIES, INC.
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3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-1 3-4 FT
Soil Laboratory Number: 01-D24534

ANALYSES	Results	
pH	8.6	units
Bray-I Phosphorus	8	ppm
Olsen Phosphorus	6	ppm
Moisture, % Gravimetric	18.8	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

MINNESOTA VALLEY TESTING LABORATORIES, INC.
1126 N. Front St. ~ New Ulm, MN 56073 ~ 800-782-3557 ~ Fax 507-359-2890
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Report Date: 13 Aug 2001
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Account #: 012893

BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-2 0-1 FT
Soil Laboratory Number: 01-D24535

ANALYSES	Results	
pH	5.6	units
Buffer Index	6.1	units
Bray-I Phosphorus	19	ppm
Olsen Phosphorus	16	ppm
Moisture, % Gravimetric	92.6	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 2000 for 6 inch plow depth
Lime Needs as 100% ENP (lbs/A) to pH 6.5 3000 for 6 inch plow depth

MINNESOTA VALLEY TESTING LABORATORIES, INC.
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1411 S. 12th St. ~ Bismarck, ND 58502 ~ 800-279-6885 ~ Fax 701-258-9724
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Report Date: 13 Aug 2001
Work Order #: 11-1014
Account #: 012893

BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-2 0-1 FT
Soil Laboratory Number: 01-D24535

ANALYSES	Results	
pH	5.6	units
Buffer Index	6.1	units
Bray-I Phosphorus	19	ppm
Olsen Phosphorus	16	ppm
Moisture, % Gravimetric	92.6	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 2000 for 6 inch plow depth
Lime Needs as 100% ENP (lbs/A) to pH 6.5 3000 for 6 inch plow depth

Report Date: 13 Aug 2001
Work Order #: 11-1014
Account #: 012893

BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-2 1-2 FT
Soil Laboratory Number: 01-D24536

ANALYSES	Results	
pH	5.6	units
Buffer Index	6.4	units
Bray-I Phosphorus	11	ppm
Olsen Phosphorus	14	ppm
Moisture, % Gravimetric	29.8	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 2000 for 6 inch plow depth
Lime Needs as 100% ENP (lbs/A) to pH 6.5 2500 for 6 inch plow depth

MINNESOTA VALLEY TESTING LABORATORIES, INC.
MVTL
1126 N. Front St. ~ New Ulm, MN 56073 ~ 800-782-3557 ~ Fax 507-359-2890
1411 S. 12th St. ~ Bismarck, ND 58502 ~ 800-279-6885 ~ Fax 701-258-9724
710 S 14th St. ~ Grand Forks, ND 58201 ~ 800-272-7645 ~ Fax 701-772-0028
35 W. Lincoln Way ~ Nevada, IA 50201 ~ 800-362-0855 ~ Fax 515-382-3885
MEMBER ACIL

Report Date: 13 Aug 2001
Work Order #: 11-1014
Account #: 012893

BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-2 1-2 FT
Soil Laboratory Number: 01-D24536

ANALYSES	Results	
pH	5.6	units
Buffer Index	6.4	units
Bray-I Phosphorus	11	ppm
Olsen Phosphorus	14	ppm
Moisture, % Gravimetric	29.8	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 2000 for 6 inch plow depth
Lime Needs as 100% ENP (lbs/A) to pH 6.5 2500 for 6 inch plow depth

MINNESOTA VALLEY TESTING LABORATORIES, INC.
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MEMBER ACIL

Report Date: 13 Aug 2001
Work Order #: 11-1014
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BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-2 2-3 FT
Soil Laboratory Number: 01-D24537

ANALYSES	Results	
pH	8.1	units
Bray-I Phosphorus	14	ppm
Olsen Phosphorus	10	ppm
Moisture, % Gravimetric	15.4	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

Report Date: 13 Aug 2001
Work Order #: 11-1014
Account #: 012893

BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-2 2-3 FT
Soil Laboratory Number: 01-D24537

ANALYSES	Results	
pH	8.1	units
Bray-I Phosphorus	14	ppm
Olsen Phosphorus	10	ppm
Moisture, % Gravimetric	15.4	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

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Report Date: 13 Aug 2001
Work Order #: 11-1014
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BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-2 3-4 FT
Soil Laboratory Number: 01-D24538

ANALYSES	Results	
pH	8.2	units
Bray-I Phosphorus	13	ppm
Olsen Phosphorus	8	ppm
Moisture, % Gravimetric	18.9	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

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35 W. Lincoln Way ~ Nevada, IA 50201 ~ 800-362-0855 ~ Fax 515-382-3885

MEMBER ACIL

Report Date: 13 Aug 2001
Work Order #: 11-1014
Account #: 012893

BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-2 3-4 FT
Soil Laboratory Number: 01-D24538

ANALYSES	Results	
pH	8.2	units
Bray-I Phosphorus	13	ppm
Olsen Phosphorus	8	ppm
Moisture, % Gravimetric	18.9	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

MINNESOTA VALLEY TESTING LABORATORIES, INC.
1126 N. Front St. ~ New Ulm, MN 56073 ~ 800-782-3557 ~ Fax 507-359-2890
1411 S. 12th St. ~ Bismarck, ND 58502 ~ 800-279-6885 ~ Fax 701-258-9724
710 S 14th St. ~ Grand Forks, ND 58201 ~ 800-272-7645 ~ Fax 701-772-0028
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BETH CLUBB
EMMONS & OLIVIER RESOURCES INC
3825 LAKE ELMO AVE N
LAKE ELMO MN 55042

Date Received: 9 Aug 2001
Date Sampled: 30 Jul 2001

Project Number: 103-09

Soil Sample Identification: 61-2 4-5 FT
Soil Laboratory Number: 01-D24539

ANALYSES	Results	
pH	8.2	units
Bray-I Phosphorus	10	ppm
Olsen Phosphorus	8	ppm
Moisture, % Gravimetric	17.5	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

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ANALYSES	Results	
pH	8.2	units
Bray-I Phosphorus	10	ppm
Olsen Phosphorus	8	ppm
Moisture, % Gravimetric	17.5	%

Lime Needs as 100% ENP (lbs/A) to pH 6.0 No lime required.
Lime Needs as 100% ENP (lbs/A) to pH 6.5 No lime required.

ANALYTICAL DATA REPORT

Report to: *Marcey Westrick*

Study Name: *RCWD - Lamotte*

Laboratory Reference No: *Soil 10*

Date Received: *07/27/2001*

Sample Type: *Soil*

Date of Report: *08/10/2001*

Sample	Moisture (%) dry wt. Basis	Moisture (%) wet wt. Basis		pH	Bray-P (ppm)	Olsen-P (ppm)
1 0-1	10.2	9.2		5.7 / 5.7	8 / 8	5 / 5
1 1-2	7.9	7.4		6.5	5	3
1 2-3	14.4	12.6		8.1	1	1
1 3-4	15.3	13.2		8.3	1	1
1 4-5	15.9	13.8		8.3	1	1
1 5-6	15.6	13.5		8.3	1	2
1 6-7	16.6	14.2		8.4	1	2
1 7-8	16.8	14.4		8.3	1	2
1 8-9	17.1	14.6		8.3	1	2
1 9-10	12.2	10.9		8.3	1	3
1 10-11	16.6	14.3		8.3	1	3
1 11-12	16.9	14.4		8.3	1	4
2 0-1	100.4	50.1		6.3	43	89
2 1-2	35.2	26.1		7.3	20	16
2 2-3	32.8	24.7		7.9	20	13
2 3-4	21.6	17.8		8.2	1	7
2 4-5	17.1	14.6		8.5	5	6
2 5-6	18.7	15.7		8.3	1	4
2 6-7	19.1	16.0		8.4	1	4
2 7-8	18.4	15.5		8.4	1	8
2 8-9	17.9	15.2		8.4	1	6
2 9-10	17.8	15.1		8.4	1	4
Analyst	S.L.			A.F.	S.L.	A.F.

UNIVERSITY OF MINNESOTA

Department of Soil Science

Research Analytical Laboratory
135 Crop Research Building
University of Minnesota
St. Paul, MN 55108

Phone: (612)625-3101

DATARPT.XLS

E. Chironomidae of Hardwood Creek in Relation to Recent and Past Ditching Practices

INTERIM REPORT

Chironomidae of Hardwood Creek in Relation to Recent and Past Ditching Practices

by

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28 February 2005

Introduction

In this document the community structure of Chironomidae is detailed in relation to recent and past ditching practices in Hardwood Creek. Data for this study were generated using an innovative, rapid bioassessment field methodology using collections of surface-floating pupal exuviae (SFPE) to assess Chironomidae in Hardwood 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 the samples SFPE of Chironomidae. This report summarizes interim results for samples collected in April, June and September, 2004. Additional samples were collected in May, July, August, October and November, 2004. However, samples from these months have not yet been fully analyzed. Consequently, the results provided in this interim report, although based on extensive data sets, should be considered as preliminary in scope. Raw data by sample site and sample date are included in appendix form.

Locations of Sample Sites

Table 1 provides the locations of eight sites that have been sampled for SFPE during this project. Four of the sites are located in downstream sections of Hardwood Creek that have not been ditched (H-2 & H-1.2) or were ditched very long ago (H-1.1 & H-1). Two of the sites in the upper part of the watershed are located on stretches of Hardwood Creek that were ditched during winter 2003-2004 (H-1.5U & H-1.4). Two additional sites, H-1.5D and H-1.3, are located on stretches that have been ditched more recently than H-1 and H1.1, but significantly longer ago than H-1.5U and H-1.4.

Table 1: Locations of sample sites on Hardwood Creek.

Sample Site	Latitude	Longitude	Elevation
Site H-2 (Never ditched)	**N 45° 12.0’**	**W 93° 2.4’**	**907 ft**
Site H-1.2 (Never ditched)	**N 45° 11.8’**	**W 93° 1.5’**	**918 ft**
Site H-1.1 (Ditched long ago)	**N 45° 11.8’**	**W 92° 59.9’**	**927 ft**
Site H-1 (Ditched long ago)	**N 45° 12.5’**	**W 92° 58.7’**	**931 ft**
Site 1.NEW (Ditched, no pupal exuviae collected)	**N 45° 12.7’**	**W 92° 58.1’**	**932 ft**
Site 1.3 (More recently ditched)	**N 45° 12.2’**	**W 92° 57.4’**	**933 ft**
Site 1.4 (Ditched in 2004)	**N 45° 12.3’**	**W 92° 56.7’**	**934 ft**
Site 1.5D (More recently ditched)	**N 45° 11.0’**	**W 92° 57.3’**	**936 ft**
Site 1.5U (Ditched in 2004)	**N 45° 12.5’**	**W 92° 57.4’**	**938 ft**

Results of sampling in Hardwood Creek are compared to data from previous studies of Chironomidae composition and emergence patterns for Minnehaha Creek at Bridge Street in

Minnetonka and Brown's Creek along the north edge of Stillwater to provide a broader context for comparison. The locations of these two sites are provided in Table 2.

Table 2: Locations of sample sites on Brown's Creek and Minnehaha Creek.

Minnehaha Creek at Bridge Street	**N 44° 56.5'**	**W 93° 26.7'**	**931 ft**
Brown's Creek along North edge of Stillwater	**N 45° 4.6'**	**W 92° 48.6'**	**718 ft**

Methods

Methodology for Collecting Surface-Floating Pupal Exuviae of Chironomidae (SFPE)

In this project 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 from Collections of SFPE

The following five metrics were calculated for each of the sample sites investigated in this project: (1) cumulative species richness (April, June & September) by sample site; (2) Brillouin's Diversity Index (based on cumulative totals of all samples per site); (3) biotic index values primarily based on species tolerances used for the Midwest (Ohio) or Upper Midwest (WI); (4) the ratio of total specimens of Chironomini to Orthocladiinae and (5) the percentage of taxa per site that are considered to be primarily lotic in terms of habitat preference, primarily lentic in terms of habitat preference or are considered to be habitat generalists. The cumulative total number of specimens on which the metrics are based is also provided by sample site.

Cumulative Species Richness- Cumulative species richness represents the total number of species present in collections on both sample dates for a given sample site. There is considerable difference in the species of Chironomidae that emerge at different times of the year so it is necessary to combine data from different sample dates to determine this metric. *This metric is sensitive to the seasonal changes in emergence and could change significantly when samples for May, July, August, October and November are included in the final data set.*

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. *No comprehensive empirical data set from a wide array of streams in Minnesota exists for species diversity values based on collections of SFPE. Consequently the values for streams in Kansas are used as reference levels for interpreting the calculations provided in this report.*

Biotic Index- Individual species-level or genus-level tolerances are required to calculate biotic index values for collections of macroinvertebrates. Barbour *et al.* (1999) discuss the concepts and underlying assumptions related to calculating biotic indices, and provide lists of taxa and their associated tolerance values for organic enrichment that have been developed for several regions of the United States. Two regions, the Midwest Region and Upper Midwest Region, are close to our project area and values for taxa in these two regions can logically serve as estimates of tolerance that should be appropriate for our biota. The values for the Midwest were developed in Ohio and those for the Upper Midwest primarily derive from research by William Hilsenhoff working on streams and rivers in Wisconsin. On the basis of geographic proximity the values for the Upper Midwest would seem to be the most appropriate, however several of the Chironomidae that occur in Minnesota are considered as more tolerant of organic enrichment in the scheme developed by Hilsenhoff compared to the tolerance values provided for Ohio. *Because of this disparity in the two schemes, the biotic index values are calculated using the tabled species tolerance values for the Midwest or for the Upper Midwest that seem most appropriate based on best professional judgment*.

Hilsenhoff (1987) provided a table for interpreting biotic index values. According to his scheme, index values between 0.00 and 3.50 are considered to represent excellent water quality. Index values between 3.51 and 4.50 are considered to represent very good water quality, with possible slight organic enrichment. Index values between 4.51 and 5.50 are considered to represent good water quality, with some organic enrichment. Index values between 5.51 and 6.50 are considered to represent fair water quality, with fairly significant organic enrichment. Index values between 6.51 and 7.50 are considered to represent fairly poor water quality, with significant organic enrichment. Index values between 7.51 and 8.50 are considered to represent poor water quality, with very significant organic enrichment. Index values between 8.51 and 10.00 are considered to represent very poor water quality, with severe organic enrichment.

Ratio of Chironomini to Orthocladiinae- The family Chironomidae is divided into eleven subfamilies that are further divided into tribes, genera and species. Oliver *et al.* (1990) recorded 205 genera and 1051 species for North America, but recent descriptions of new species and revisionary monographs increase the total to approximately 1200 species. The species belong to seven subfamilies and 14 tribes. Several species of some of the subfamilies are restricted to aquatic habitats that are high in average Oxygen concentrations and these species are conspicuously absent or reduced in number in habitats that have lower Oxygen concentrations, either naturally or as a result of organic loading. Examples of these subfamilies are Diamesinae, Prodiamesinae and Orthocladiinae. In contrast, one of the subfamilies, Chironominae, contains several species that have high concentrations of hemoglobins as larvae and, consequently, can survive lowered concentrations of dissolved Oxygen in surface waters. Many of the species within the tribe Chironomini, which is one of three tribes of the subfamily Chironominae, often predominate in low Oxygen habitats and can dominate the chironomid community in streams that are organically enriched (e.g., Ferrington 1987, 1989, 1990; Ferrington and Crisp 1989). Consequently it is helpful to determine the percent of species and specimens of Chironomini and Orthocladiinae for each sample site when evaluating water quality conditions using collections of SFPE to assess Chironomidae.

In Minnesota species of Chironomidae that are classified into two other tribes of Chironominae, the tribe Tanytarsini and the tribe Pseudochironomini, are known to occur. The tribe Pseudochironomini consists of only one genus in North America, *Pseudochironomus*, and the species typically are not common in habitats similar to the ones investigated in this project. Species of the other Tribe, Tanytarsini, commonly occur in springs and small streams with higher Oxygen concentrations so they can be considered, along with Orthocladiinae, as indicators of habitats that lack increased levels of organic enrichment.

Orthocladiinae generally comprise about 50% of taxa and usually a majority of specimens (>50%) in unimpacted small order streams similar to Hardwood Creek. However, the actual values are influenced by type of substrate, velocity and time of year that samples are collected. Repeated collections on at least monthly intervals generally provide adequate resolution of the composition and relative abundances of Orthocladiinae and Chironomini. Slower velocities typically result in lower species and numbers of Orthocladiinae, combined with corresponding increases in Chironomini. Similarly, stream substrates that are predominantly sand and/or fine particulate organic matter or muds favor higher values for Chironomini and lower values for Orthocladiinae. Higher current velocities, more coarse substrates and/or well-developed riffles can result in higher values for Orthocladiinae and correspondingly lower values of Chironomini.

Habitat Preferences: Ditching the channel of a stream can profoundly change the in-stream habitat conditions, substrate composition and hydrology. Aquatic insects have a variety of morphological and behavioral adaptations the enable them to persist in an array of different habitats and substrates, however individual species are often very strongly tied to narrow ranges of habitat, substrate and hydrology. Two general categories of habits, lentic and lotic, refer to standing water and flowing water habitats. Depending on the underlying geology of stream beds, ditching can shift in-stream habitat conditions to more strongly resemble lotic conditions or lentic conditions. Ditching through peat deposits can be considered as producing stretches of slow-flowing water, relatively deeper channels and a predominance of fine grained silt or silt/mud substrates. The net effect of these three changes in hydrology, depth and substrate particle size is to produce stretches that are shifted to conditions more characteristic of lentic habitats. It can be expected that these stretches will have a greater proportion of species that are characteristic of lentic habitats compared to the insects in non-ditched sections, or sections ditched in the more distant past. In order to test these assumptions, the percent of Chironomidae taxa collected at each site have been calculated based on whether they show a strong tendency to predominate in lotic or lentic habitats, or can be considered to be habitat generalists that are likely to persist in both types of settings (Table 5).

Analysis of Faunal Similarities Among Sample Sites

A numerical analysis of the similarities of Chironomidae composition across all sample 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 8 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 28 unique comparisons of sample sites taken two at a time.

The values for Jaccard's Coefficient are used to evaluate similarities of site pairs, and to compare individual site pairs to predictions based upon the River Continuum Hypothesis. This hypothesis predicts that streams and rivers present a continuum of changing conditions that influence the community structure of aquatic macroinvertebrates, including Chironomidae, in a predictable manner. One prediction of the hypothesis is that the community structure of macroinvertebrates at adjacent sites should be more similar to each other than sites that are situated more distantly along the stream being investigated, assuming no complicating factors such as human modification of channel structure and/or pollution-related effects.

To test the predictions of the River Continuum Hypothesis a null hypothesis is created that assumes the ranks of all pairs of sample sites are randomly assorted. Under the null hypothesis any pairs of sample sites can be highly similar, moderately similar or very dissimilar. The River Continuum Hypothesis forms the basis of alternative hypothesis and, in Hardwood Creek, can be tested by comparing the rank similarities of adjacent sample sites.

Under the alternative hypothesis, sites that are adjacent to each other should be most similar and have ranks of 1 through 7 if the macroinvertebrate communities of the stream sites conform to predictions. However, if ditching is strongly influencing the macroinvertebrate community structure, then the most similar sites should be those sites that are in the downstream sections of stream that have no history of ditching (H-2 through H-1) and the sites in the upper portion of the stream that have been ditched (H-3 through H-1.5U). Comparisons of sites among these two groups should not have high coefficients of similarity.

Methods to test the similarities of sites are based on non-metric, sum of ranks tests. To test the assumption of adjacent sites being most similar, it is necessary to determine the rank similarity of the sites. If adjacent are most similar their ranks should be 1, 2, 3, 4, 5, 6, and 7. The sums of ranks should equal 28. In theory, if the ranks of similarities of adjacent sites deviate strongly from predictions their sum of ranks will be much larger than 28. The maximum sum of ranks that can be obtained corresponds to a condition where adjacent sample site pairs are the least similar pairs in terms of macroinvertebrate community compositions, with ranks of 28, 27, 26, 25, 24, 23 and 22, summing to 175. To perform the test, the actual sum of ranks for similarities of adjacent sample sites is calculated and the probability of obtaining the rank sum is determined.

Results and Discusion

Highway 61 roughly bisects Hardwood Creek into equal lengths of stream that differ markedly in physical structure related to recent and past ditching activities. The downstream portions of Hardwood Creek (Site H-1 to Site H-2) appear to have never been ditched or were ditched long ago. At these sites the stream substrates consist predominantly of clean sands or sand/gravel areas in erosional zones. Channel meanders are present, especially from Site H-1.1 downstream to Site H-2, and pools have finer sediments overlying sands. By contrast, sites upstream of H-1 clearly show physical signs of more recent ditching. Soft, unconsolidated silts and mud substrate predominate, and the stream channel has minimal to no meandering, especially at sites H-1.3, H-1.4 and H-1.5U.

Table 3: Summary of metrics for collections of surface-floating pupal exuviae.

Sample Site	Numbers of Specimens Collected	Cumulative Species Richness	Brillouin's Diversity Index (nats)	Biotic Index Based on Tolerances to Organic Enrichment OH (WI)
Site H-2 (Never ditched)	**224**	**36**	**2.742**	**4.24 (6.33)**
Site H-1.2 (Never ditched)	**713**	**34**	**1.475***	**4.65 (6.07)**
Site H-1.1 (Ditched long ago)	**272**	**40**	**2.836**	**4.16 (6.13)**
Site H-1 (Ditched long ago)	**633**	**47**	**2.776**	**3.91 (6.01)**
Site H-1.3 (More recently ditched)	**394**	**23**	**1.395**	**3.66 (6.21)**
Site H-1.4 (Ditched in 2004)	**365**	**27**	**2.178**	**4.05 (6.16)**
Site H-1.5D (More recently ditched)	**442**	**26**	**1.329**	**4.45 (8.55)**
Site H-1.5U (Ditched in 2004)	**315**	**30**	**2.525**	**4.50 (6.93)**
Minnehaha Creek at Bridge Street	**1536**	**79**	**3.083**	**3.27 (4.86)**
Brown's Creek along North edge of Stillwater	**1478**	**47**	**2.237**	**2.66 (4.07)**

The average numbers of SFPE collected per site in April, June and September 2004 do not differ significantly for sites in the area upstream of H-1 relative to the sites from H-1 to H-2 (Table 3). Although the two sites with highest numbers of SFPE occur in the lower portion of the stream, the other two sites in this potion have the lowest cumulative numbers of exuviae. *Consequently it does not appear that ditching has markedly reduced the secondary productivity of Chironomidae at sites that have been more recently modified by ditching relative to the sites in the lower portion of the stream. All sites on Hardwood Creek, however, have far fewer SFPE than were collected from Minnehaha Creek at bridge street and from Brown's Creek along the North edge of Stillwater. Thus it appears that the overall productivity of Hardwood Creek is lower than these two comparison streams.*

The species richnesses of sites in the lower portion of Hardwood Creek are consistently and markedly higher than the species richnesses detected at sites in the upper portion where the modifications from ditching are more obvious. All sites in Hardwood Creek have species richness values that are substantially less than the 79 species detected for April, June and

September in Minnehaha Creek near Bridge Street. Site 1.1 in the lower portion of Hardwood Creek has the highest richness at 47 species, which is the same value as detected for similar months in Brown's Creek. Although the species richness values are equal the observed species composition and relative abundance of taxa markedly differs.

The three highest Brillouin's Diversity Index values are for sites in the lower portion of Hardwood Creek, and are indicative of excellent to very good water quality when applying the interpretive standards for streams in Kansas. The remaining site in the lower portion of Hardwood Creek, Site H-1.2, has an unexpectedly low index value. This site, however, has not been ditched and has very good habitat heterogeneity. Closer inspection of the data for this site shows that one species accounts for 65% of the specimens collected. The taxon is the genus *Eukiefferiella*, an Orthocladiinae midge that predominantly occurs in lotic habitats and is relatively intolerant to organic enrichment. In April this species was very abundant and it can be concluded that the sample date coincided with an early, large spring emergence of an overwintering generation. The high numbers of this species influence the evenness component of the diversity index, resulting in the low value for this site. In cases where a single species is implicated as strongly influencing the calculated value of a diversity index, the count for the species can be (artificially) reduced by one order of magnitude and the index re-calculated to determine how strongly the single species influences the metric. At this site *Eukiefferiella* is represented by 467 exuviae. Reducing the value to 47 and recalculating the index yields a value of 2.464 bits, resulting in a value that is more consistent with the pattern of species richness for this site.

Brillouin's Index values for the two most recently ditched sites in the upper portion of Hardwood Creek, Site H-1.4 and Site H1.5U are unexpectedly high and, according to the standards applied for interpreting this index in Kansas streams, appear to indicate excellent to very good water quality. Closer inspection, however, of the species collected at this site show that several species are more characteristic of lentic habitats, are habitat generalists, or are semi-terrestrial species that or likely to be more common in boggy habitats. *The combination of these species with a subset of predominantly lotic species results in the elevated index values. The two remaining sites in the upper portion of the stream have the two lowest calculated index values, signifying possible reduced habitat and/or water quality.*

Five of the eight index values calculated for sites on Hardwood Creek fall within the range of values calculated for Minnehaha Creek at Bridge Street (3.083 bits) and Brown's Creek along the North edge of Stillwater (2.237 bits).

The two sets of Biotic Index (BI) values show similar trends but substantially different magnitudes. BI values calculated with species tolerances developed for the Mid West (OH) range from 3.66 to 4.65 and are consistently lower than the BI values obtained when tolerance values developed for the Upper Mid West (WI) are used. However, both the mean BI values for sites in the lower and upper portions of Hardwood Creek are nearly identical when Mid West Tolerance values are used (4.24 versus 4.16, respectively), and only average 6.13 and 6.96 when tolerance values for the Upper Mid West are substituted. By contrast, the corresponding BI values for Minnehaha Creek at Bridge Street and Brown's Creek along the North edge of Stillwater are 3.27 and 2.66 (OH) and 4.86 and 4.07 (WI), respectively. It appears as if all sites on Hardwood

Creek are experiencing greater organic enrichment than the Minnehaha Creek and Brown's Creek sites. No sites, however, along Hardwood Creek stand out as significantly more enriched. *In light of the BI values being very similar at sites on Hardwood Creek, it is possible to hypothesize that the reduced Brillouin's Index values for sites H-1.4 and H-1.5D is related to deteriorated habitat quality rather than changes in water quality.*

The numbers of species and percentage composition of Orthocladiinae, Chironomini, Tanytarsini are provided in Table 4. The column on the right of Table 4 also provides the ratio of Chironomini to Orthocladiinae taxa and specimens (in parens) by sample site. In small streams with excellent to very good water and habitat quality the ratios of Chironomini to Orthocladiinae are generally 1.0 or less when based on taxa and 3.0 or less when based on specimens. Streams that are stressed by higher levels of organic loading these two ratios can exceed 3.0 and 30.0, respectively. None of the ratios suggest very high levels of organic loadings.

Table 4: Summary of taxonomic composition for SFPE samples.

Sample Site	Orthocladiinae Species and (% Specimens)		Chironomini Species and (% Specimens)		Tanytarsini Species and (% Specimens)		Ratio of Chironomini to Orthocladiinae	
							Taxa	(Specimens)
Site H-2	**14**	**(34.8%)**	**12**	**(29.0%)**	**8**	**(33.5%)**	**0.86**	**(0.83)**
Site H-1.2	**13**	**(85.8%)**	**8**	**(2.0%)**	**8**	**(11.5%)**	**0.62**	**(0.02)**
Site H-1.1	**12**	**(39.3%)**	**15**	**(21.7%)**	**6**	**(30.9%)**	**1.25**	**(0.55)**
Site H-1	**15**	**(60.3%)**	**15**	**(8.8%)**	**9**	**(23.1%)**	**1.00**	**(0.15)**
Site H-1.3	**9**	**(84.3%)**	**4**	**(6.6%)**	**6**	**(7.6%)**	**0.44**	**(0.08)**
Site H-1.4	**8**	**(12.2%)**	**12**	**(19.7%)**	**5**	**(63.0%)**	**1.50**	**(1.60)**
Site H-1.5D	**6**	**(12.7%)**	**10**	**(74.2%)**	**6**	**(6.8%)**	**1.67**	**(5.86)**
Site H-1.5U	**9**	**(40.0%)**	**11**	**(27.0%)**	**8**	**(29.8%)**	**1.22**	**(0.67)**
Minnehaha Creek	**26**	**(49.0%)**	**19**	**(28.4%)**	**16**	**(19.8%)**	**0.73**	**(0.40)**
Brown's Creek	**30**	**(87.3%)**	**3**	**(1.5%)**	**4**	**(0.2%)**	**0.10**	**(0.02)**

Alterations of physical habitat associated with ditching are clearly indicated by the habitat preferences of species that occur at sites in the upper portion of Hardwood Creek (Table 5). Changes of the in-stream habitat conditions as a function of ditching include reduction of habitat heterogeneity, quantitative changes in substrate particle size and modification of hydrology. *Areas of stream most recently ditched are characterized by elongated stretches of slow-flowing water, relatively deeper channel conditions and predominance of fine-grained silt or silt/mud substrates. Chironomidae in these areas consist a higher incidence of species that show a strong tendency to occur in lentic habitats or are considered to be habitat generalists. In addition, several species that are semi-aquatic or common in boggy or saturated soils also occurred at the upstream sites.*

Table 5: Species and percent of specimens (in parens) of Chironomidae categorized by habitat preferences

Sample Site	Species that predominate in lotic habitats	Species that predominate in lentic habitats	Species that are considered to be habitat generalists	Species that are semi - aquatic or common in bogs/saturated soils
Site H-2	**15 (58.0%)**	**10 (16.1%)**	**11 (25.9%)**	**1 (<0.01%)**
Site H-1.2	**20 (88.9%)**	**7 (3.0%)**	**7 (8.1%)**	**0 (0.0%)**
Site H-1.1	**18 (52.9%)**	**11 (18.8%)**	**11 (28.3%)**	**0 (0.0%)**
Site H-1	**23 (57.0%)**	**12 (10.6%)**	**12 (32.4%)**	**0 (0.0%)**
Site H-1.3	**7 (79.2%)**	**7 (10.7%)**	**9 (10.2%)**	**1 (<0.01%)**
Site H-1.4	**6 (9.3%)**	**13 (28.8%)**	**8 (61.9%)**	**3 (0.02%)**
Site H-1.5D	**9 (7.7%)**	**13 (87.6%)**	**4 (4.8%)**	**0 (0.0%)**
Site H-1.5U	**6 (19.4%)**	**15 (62.5%)**	**8 (18.1%)**	**3 (0.04%)**
Minnehaha Creek				
Brown's Creek				

Results of the numerical analysis of the similarities of Chironomidae composition across all eight sample sites based on Jaccard's Coefficient are presented in Table 6. Values below the diagonal represent the raw coefficient scores. Numbers above the diagonal indicate the rank similarities among pairs of sample sites.

Table 6: Similarity of taxonomic composition among pairs of sample sites based on Jaccard's Coefficient of Similarity

Sample Sites	Site H-2	Site H-1.2	Site H-1.1	Site H-1	Site H-1.3	Site H-1.4	Site H-1.5D	Site H-1.5U
Site H-2	-----	7	5	3	14	21	27	24.5*
Site H-1.2	0.458	-----	9	4	16	24.5*	17.5*	28
Site H-1.1	0.490	0.423	-----	1	15	20	19	23
Site H-1	0.566	0.528	0.642	-----	13	22	17.5*	26
Site H-1.3	0.341	0.326	0.340	0.346	-----	8	10	11.5*
Site H-1.4	0.260	0.245	0.264	0.254	0.429	-----	11.5*	2
Site H-1.5D	0.216	0.304	0.269	0.304	0.400	0.395	-----	6
Site H-1.5U	0.245	0.208	0.250	0.222	0.395	0.629	0.474	-----

* Denotes tied ranks

Based on the River Continuum Hypothesis that moving-water systems represent a continuum of changing conditions from headwaters to downstream areas, it is logical to expect that adjacent sample sites would exhibit the greatest degrees of similarities in terms of invertebrate community composition if ditching activities were not substantially altering community structure of Chironomidae. Therefore, it can be predicted that sample sites closest to the diagonal should have the highest values of Jaccard's Coefficient unless other extraneous stresses associated with ditching are operating to shift community structure. The seven most similar pairs of sample sites should be sites: H-2 & H-1.2; H-1.2 & H-1.1; H-1.1 & H-1; H-1 & H-1.3; H-1.3 & H-1.4; H-1.4 & H-1.5D; and H-1.5 D & H-1.5U. Although it is not possible to predict which of these seven pairs of sites should be most similar, the sum of their rank similarities should be 28 (i.e., 1 + 2 + 3 + 4 + 5 + 6 + 7). Alternatively, the least similar sites should be the most upstream/most downstream pair of sites (H-2 & H-1.5U), and the next two least similar pairs of sites should be sites H-2 & H-1.5D and H-1.2 & H-1.5U. The sum of their respective ranks should be 81 (i. e., 28+27+26).

From Table 6 it can be seen that the most similar pair of sites is located on the diagonal, sites H-1 & H-1.1 (0.642). Two additional site pairs on the diagonal conform to expectations, with sites H-1.5D & H-1.5U ranking as the sixth most similar pair of sites (0.474) and H-2 & H-1.2 ranking as the seventh most similar pair of sites (0.458). However, the four remaining pairs of sites along the diagonal do not conform to expectations, with ranks of 8, 9, 11.5 (tie ranking) and 13. The sum of ranks for pairs of sites adjacent to the diagonal is 55.5, signifying that the ranks do not depart from a random assortment of similarities. *Consequently it can be concluded that the similarities among adjacent pairs of sample sites do not conform to predictions of the River Continuum Concept, and factors other than proximity of sample sites are influencing the similarities observed among pairs of sites.*

The similarity of composition at each of the eight sample sites was also calculated using Jaccard's Coefficient versus emergence data for April, June and September in both Brown's Creek and at Bridge Street on Minnehaha Creek. The coefficient values are provided in Table 7.

Table 7: Similarity of taxonomic composition among sample sites on Hardwood Creek relative to Bridge Street on Minnehaha Creek and Brown's Creek in Stillwater as Measured by Jaccard's Coefficient.

Sample Sites	**Site H-2**	**Site H-1.2**	**Site H-1.1**	**Site H-1**	**Site H-1.3**	**Site H-1.4**	**Site H-1.5D**	**Site H-1.5U**
Minnehaha Creek	**0.207**	**0.182**	**0.225**	**0.231**	**0.243**	**0.194**	**0.196**	**0.205**
Brown's Creek	**0.109**	**0.238**	**0.173**	**0.206**	**0.106**	**0.128**	**0.157**	**0.091**

Averaged across all eight sample sites, emergence similarity in Hardwood Creek and Minnehaha Creek during April, June and September is only 0.210. The average similarity with Brown's Creek is only 0.151. *These low similarities demonstrate that the Chironomidae composition at sample sites on Hardwood Creek strongly deviates from the composition expected for a stream flowing through a large urban area and also a trout stream adjacent to a smaller urbanizing area.*

Based upon results shown in Table 6 and Table 7 we must conclude that community structure of Chironomidae in Hardwood Creek does not conform to predictions of the River Continuum Hypothesis and is very different from the community structure of two other streams that have been investigated in the Metro area using similar methodology. An alternative question that can be asked is if the similarities of sample sites in Hardwood Creek support a hypothesis of ditching as strongly influencing community structure. In order to examine this question the average similarities of all site pairs in the lower portion of the creek and the upper portion of the creek have been calculated. The average of similarities of site pairs in the lower portion of the creek is 0.518 and the average of similarities of site pairs in the upper portion of the creek is 0.454. By contrast the average of similarities of site pairs between sites that are in the upper and lower portions of the stream, and represent comparisons of sites that have dramatically differing histories of ditching, are much lower at 0.275. *Based on these results it is logical to conclude that ditching has had a substantial role in structuring the community composition of Chironomidae at sites along Hardwood Creek. Implications of this conclusion are that differing expectations of community structure for ditched versus non-ditched stretches of the creek appropriate for the stream, and the differences will persist if the current management practices are continued.*

Literature Cited

Barbour, M. T., J. Gerritsen, B. D. Snyder and J. B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates, and fish, Second Edition. EPA 841-B-99-002. U. S. Environmental Protection Agency, Office of Water; Washington, D. C.

Barton, David R., Donald R. Oliver and Mary E. Dillon. 1995. A comparison of pupal exuviae and larval Chironomidae for biomonitoring of the impacts of agricultural practices on surface water quality. Pp. 125-132. In: *Chironomids: From Genes to Ecosystems.* Peter S. Cranston (Ed.). CSIRO Publications, Melbourne 482 pp.

Blackwood, Mary Anne, Sara M. Hall and Leonard C. Ferrington, Jr. 1995. Emergence of Chironomidae from Springs in the Central High Plains Region of the United States. Pp 132-151, In *Biodiversity of Aquatic Insects and Other Invertebrates in Springs*. L. C. Ferrington, Jr. (Ed.). Special Publication No. 1 of the Journal of the Kansas Entomological Society, 165 pp.

Boerger, Hans. 1981. Species composition, abundance and emergence phenology of midges (Deiptera[sic]: Chironomidae) in a brown-water stream of west-central Alberta, Canada. Hydrobiologia 80: 7-30.

Brundin, Lars. 1966. Transantarctic relationships and their significance, evidenced by chironomid midges. With a monograph of the subfamilies Podonominae and Aphroteniinae and the austral ***Heptagyiae.*** K. Svenska Vetensk Akademie Handlungen. 11: 1-472.

Chou, Ronald, Y. M., Leonard C. Ferrington Jr., Barbara L. Hayford and Heidi M. Smith. 1999. Composition and phenology of Chironomidae (Diptera) from an intermittent stream in Kansas. Archives für Hydrobiologie 141(1): 35-64.

Coffman, William P. 1973. Energy flow in a woodland stream ecosystem: II. The taxonomic composition and phenology of the Chironomidae as determined by the collection of pupal exuviae. Archives für Hydrobiologie 71: 281-322.

Coffman, William P. 1974. Seasonal differences in the diel emergence of a lotic chironomid community. Entomologica Tidskre Supplement 95: 42-48.

Coffman, William P. 1989. Factors that determine the species richness of lotic communities of Chironomidae. Acta Biologica Debrecina Supplementum Oecologica Hungarica 3: 95-100.

Coffman, William P. and Leonard C. Ferrington, Jr. 1984. Chironomidae, Chapter 25. Pp. 551-652, In *An Introduction to the Aquatic Insects of North America, Second Edition*, R. W. Merritt and K. W. Cummins, (Eds.). Kendall/Hunt Publishing Company, Dubuque, Iowa. 722 pp.

Coffman, William P. and Leonard C. Ferrington, Jr. 1996. Chironomidae, Chapter 26. Pp. 635-748, In *An Introduction to the Aquatic Insects of North America, Third Edition*, R. W. Merritt and K. W. Cummins, (Eds.). Kendall/Hunt Publishing Company, Dubuque, Iowa. 862 pp.

Coler, Barbara C. 1984. Community responses of Chironomidae (Diptera) to organic enrichment in a small Kansas stream. Unpublished Master's Thesis, University of Kansas. Lawrence, Kansas. 81 pp.

Cranston, Peter S., P. D. Cooper, Rod A. Hardwick, C. L. Humphrey and Peter L. Dostine. 1997. Tropical acid streams- the chironomid (Diptera) response in northern Australia. Freshwater Biology 37: 473-483.

Ferrington, Leonard C. Jr. 1986. Microhabitat preferences of larvae of three Orthocladiinae species (Diptera: Chironomidae) in Big Springs, a sand-bottom spring in the high plains of western Kansas. Entomologica Scandinavica Supplement 29:361-368.

Ferrington, Leonard C. Jr. 1987. Collection and Identification of Floating Pupal Exuviae of Chironomidae for Use in Studies of Surface Water Quality. Prepared for U. S. EPA, Region VII, Kansas City, KS as SOP No. FW130A. 39 pp. + appendix.

Ferrington, Leonard C. Jr. 1989. Assessment of the Effects of B.t.i. Applications for the Control of Midgefly Larvae, *Chironomus riparius*, in Little Mill Creek, Johnson Co., Ks. Grant completion report. KBS Report # 41. 16 pp. + appendix.

Ferrington, Leonard C., Jr. 1990. Abundance and Longitudinal Distribution of *Chironomus riparius* near the Middle Basin WWTP in Johnson County, Kansas. Grant Completion Report for Johnson County Wastewater District.

Ferrington, Leonard C., Jr. 1993a. Endangered rivers: a case history of the Arkansas River in the Central Plains. Aquatic Conservation: Marine and Freshwater Ecosystems 3: 305-316.

Ferrington, Leonard C., Jr. 1993b. Water Chemistry, Sediment Chemistry, Fish and Macroinvertebrate Communities of the Galena Superfund Subsite of the Tri-State Mining District. Report Number 56. Kansas Biological Survey, Lawrence, Kansas.

Ferrington, Leonard C., Jr. 1994. Characterization of Chironomidae in Five Wetlands in Minnesota. Grant Completion Report. Technical Publication of Kansas Biological Survey.

Ferrington, Leonard C. Jr. 1998. Generic Composition of the chironomid fauna in springs of North America. Pp. 141-156. In: *Studies in Crenobiology: The biology of springs and springbrooks*, L. Botosaneanu (ed.). Backhuys Publishers, Leiden 261 pp.

Ferrington, Leonard C. Jr. 2000. Hibernal emergence patterns of Chironomidae in lotic habitats of Kansas versus ambient air and water temperatures. Pp. 375-382. In: *Late Twentieth Century Research on Chironomidae: An Anthology from the 13th International Symposium on Chironomidae.* Odwin Hoffrichter (ed.). Shaker Verlag, Aachen, 661 pp.

Ferrington, Leonard C., Jr. Mary Anne Blackwood, Christopher A. Wright, Norman H. Crisp, Jeffry L. Kavanaugh and Franz J. Schmidt. 1991. A Protocol for Using Surface-Floating Pupal Exuviae of Chironomidae for Rapid Bioassessment of Changing Water Quality. Pp.181-190. In: *Sediment and Stream Water Quality in a Changing Environment: Trends and Explanations*. IAHS Publication Number 203. 374 pp.

Ferrington, Leonard C., Jr. and Norman H. Crisp 1989. Water chemistry characteristics of receiving streams and the occurrence of *Chironomus riparius* and other Chironomidae in Kansas. Acta Biologica Debrecina Supplementum OecoIogica Hungarica 3: 115-126.

Ferrington, Leonard C., Jr. and David S. Goldhammer. 1992. The Biological Significance of Capillary Fringe Habitat in Large Sandy-Bottomed Rivers of the Central Plains. pp. 203-225. In: *Proceedings of Symposium on Aquatic Resources in Semi-Arid Environments.* Bohart and Bothwell (Eds.). N.H.R.I. Symposium Series 7. 375 pp.

Ferrington, Leonard C., Jr., Karen M. Buzby and Edwin C. Masteller. 1993. Composition and temporal abundance of Chironomidae emergence from a tropical rainforest stream at El Verde, Puerto Rico. Journal of the Kansas Entomological Society 66(2): 167-180.

Ferrington, Leonard C., Jr. Mary Anne Blackwood, Christopher A. Wright, Tracey M. Anderson, and David S. Goldhammer. 1994. Sediment transfers and representativeness of mesocosm test fauna. Pp. 179-200, In: *Aquatic Mesocosm Studies in Ecological Risk Assessment*. Robert L. Graney, James H. Kennedy and John H. Rodgers (Eds.). Lewis Publishers, Boca Raton, FL 723 pp.

Ferrington, Leonard C. Jr., Rathi G. Kavanaugh, Franz J. Schmidt and Jeffry L. Kavanaugh. 1995. Habitat Separation Among Chironomidae (Diptera) in Big Springs. Pp. 152-165, In: *Biodiversity of Aquatic Insects and Other Invertebrates in Springs*. Leonard C. Ferrington, Jr. (Ed.). Special Publication No. 1 of the Journal of the Kansas Entomological Society, 165 pp.

Goldhammer, David S. and Leonard C. Ferrington, Jr. 1992. Emergence of Aquatic Insects from Epirhreic Zones of Capillary Fringe Habitats in the Cimarron River, Kansas. pp. 155-164. In: *Proceedings of the First International Conference on Ground Water Ecology*. Stanford, J.A. and J.J. Simons (Eds.) American Water Resources Association Bethesda, Maryland. 420 pp.

Hardwick, Rod A., P. D. Cooper, Peter S. Cranston, C. L. Humphrey and Peter L. Dostine. 1995. Spatial and temporal distribution patterns of drifting pupal exuviae of Chironomidae (Diptera) in streams of tropical northern Australia. Freshwater Biology 34: 569-578.

Hilsenhoff, W. L. 1987. An improved biotic index of organic stream pollution. The Great Lakes Entomologist 20(1): 31-39.

Humphries, C. F. 1938. The chironomid fauna of the Grosser Plöner See, the relative density of its members and their emergence periods. Archives für Hydrobiologie 33: 535-584.

Kavanaugh, Jeffry L. 1988. Community composition and emergence phenology of Chironomidae (Diptera) jn prairie streams of different flow regimes. Unpublished Master's thesis, University of Kansas. Lawrence, Kansas. 77 pp.

Kavanaugh, Rathi C. 1988. Decomposition studies of Chironomidae pupal exuviae (Chironomidae: Diptera). Unpublished Master's thesis, University of Kansas, Lawrence, Kansas 104 pp.

Langton, P.H. 1991 A key to pupal exuviae of West Palaearctic Chironomidae. 386pp. Privately published at 3 St Felix Road, Ramsey Forty Foot, Huntingdon, Cambridgeshire, PE17 1YH, UK.

Lehman, Jens. 1971. Die Chironomiden der Fulda. Archives für Hydrobiologie, Supplement 37: 466-555.

McGill, J. D., R. S. Wilson, & A. M. Brake. 1979. The use of chironomid pupae exuviae in the surveillance of sewage pollution within a drainage system. Water Research 13: 887-894.

Reiss, Friedrich 1968. Okologische und systematische Untersuchungen an Chironomiden (Diptera) des Bodensees. Ein beitrag zur lakustrischen Chironomidenfauna des nordlichen Alpenvorlandes. Archives für Hydrobiologie 64: 176-323.

Ruse, Leslie P. 1993. Correlations between chironomid pupal skin collections and habitats recorded from a chalk stream. Netherlands Journal of Aquatic Ecology 26: 411-417.

Ruse, Leslie P. 1995a. Chironomid community structure deduced from larvae and pupal exuviae of a chalk stream. Hydrobiologia 315: 135-142.

Ruse, Leslie P. 1995b. Chironomid emergence from a chalk stream during a three year period. Archives für Hydrobiologie 133: 223-244.

Ruse, Leslie P., Scott J. Herrmann and James E. Sublette. 2000. Chironomidae (Diptera) species distribution related to environmental characteristics of the metal-polluted Arkansas River, Colorado. Western North American Naturalist 60(1): 34-56.

Ruse, Leslie P. and Ronald S. Wilson. 1984. The monitoring of river water quality within the Great Ouse Basin using the chironomid exuvial analysis technique. Water Pollution Controls 83: 116-135.

Thienemann, August. 1910. Das Sammeln von Puppenhauten der Chironomiden Eine bitte um Mitarbeit. Archives für Hydrobiologie 6: 2-214.

Thienemann, August. 1954. *Chironomus*. Leben, Verbreitung und wirtschaftliche Bedeutung der Chironomidae. Binnegewässer 20: 1-834.

Wartinbee. David C. and William P. Coffman. 1976. Quantitative determination of chironomid emergence from enclosed channels in a small lotic ecosystem American Midland Naturalist. 95: 479-485.

Wiederholm, Torgney (Ed.). 1986. Chironomidae of the Holarctic Region: Keys and diagnoses. Part 2. Pupae Entomologica scandinavica Supplement 28: 1-482.

Wilson, Ronald S. 1977. Chironomid pupal exuviae in the River Chew. Freshwater Biology. 7(l): 9-17.

Wilson, Ronald S. 1980. Classifying rivers using pupal exuviae. Pp.209-216. In: *Chironomidae Ecology, Systematics, Cytology and Physiology*, D. A. Murray (ed.). Proceedings of the 7th International Symposium on Chironomidae. Pergammon Press, Dublin. 354 pp.

Wilson, Ronald S. 1987. Chironomid communities in the River Trent in relation to water chemistry. Entomologica Scandinavica Supplement 29: 387-393

Wilson, Ronald S. 1989. The modification of chironomid pupal exuvial assemblages by sewage effluent in rivers within the Bristol Avon catchment, England. Acta Biologica Debrecina Supplementum OecoIogica Hungarica 3: 367-376.

Wilson, Ronald S. and P. L. Bright. 1973. The use of chironomid pupal exuviae for characterizing streams. Freshwater Biology. 3: 283-302.

Wilson, Ronald S. and J. D. McGill. 1977. A new method of monitoring water quality in a stream receiving sewage effluent, using chironomid pupal exuviae. Water Research. 11: 959-962.

Wilson, Ronald S. and J. D. McGill. 1982. A practical key to the genera of pupal exuviae of the British Chironomidae (Diptera, Insecta). University of Bristol Press. UK. 62 pp.

Wilson, Ronald S. and S. E. Wilson. 1983. A reconnaissance of the River Rhine using Chironomidae pupal exuviae (Insecta: Diptera). Memoirs of the American Entomological Society 34: 361-385.

Wright, Christopher A. and Leonard C. Ferrington, Jr. 1996. Analysis of Chlordane-impacted streams using chironomid pupal exuviae (Diptera: Chironomidae). Hydrobiologia 318: 69-77.

7. References

Allan, J. D. 1995. Stream Ecology - Structure and function of running waters. Chapman and Hall, U.K.

Allan, J. D., and A. S. Flecker. 1993. Biodiversity conservation in running waters: identifying the major factors that threaten destruction of riverine species and ecosystems. *BioScience* 43:33–43.

Allan, J. D., D. L. Erickson, and J. Fay. 1997. The influence of catchment land use on stream integrity across multiple spatial scales. *Freshwater Biology* 37: 149–161.

Barbour, M., J. Stribling, J. Gerritsen, J.R. Karr. 1996. Biological Criteria: Technical Guidance for Streams and Small Rivers, revised ed. EPA 822-B-96-001. US EPA, Office of Water, Washington, DC.

Brookes, A. 1988. Channelized Rivers: Perspectives for Environmental Management. John Wiley & Sons, Chichester.

Gorman, O.T., J.R. Karr. 1978. Habitat Structure and Stream Fish Communities. *Ecology*. 59(3):507-515.

McCollor, S and S. Heiskary. 1993. Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions, Addendum to: Descriptive Characteristics of the Seven Ecoregions of Minnesota. Minnesota Pollution Control Agency, Water Quality Division.

Prévost, M., A.P. Plamondon, and P. Belleau. 1998. Effects of drainage of a forested peatland on water quality and quantity. *Journal of Hydrology* 214:130-143.

RCWD (Rice Creek Watershed District). 2004. Washington County Judicial Ditch #2 Repair Report. Prepared by Emmons & Olivier Resources, Inc.

Rhoads, BL, JS Schwartz, S Porter. 2003. Stream geomorphology, bank vegetation, and three-dimensional habitat hydraulics for fish in Midwestern agricultural streams. *Water Resources Research* 39(8): 1218.

Rosgen, D. 1996. Applied river morphology. Wildlife Hydrology, Pagosa Springs, CO

Saunders, D.L., J.J. Meeuwig, and A.C.J. Vincent. 2002. Freshwater Protected Areas: Strategies for conservation. *Conservation Biology* 16(1): 30-41.

Washington County. 2003. Integrating Groundwater and Surface Water Management in Northern Washington County. Prepared by Emmons & Olivier Resources, Inc.

Appendix C. CONCEPTS Modeling for the Hardwood Creek TMDL Study

1. Introduction

The CONCEPTS model was created in support of the Hardwood Creek TMDL. Total suspended solids (TSS) was identified as one of the stressors impacting the biota, and loading allocations for TSS will be established as part of the TMDL. The two main sediment sources are watershed loading and instream erosion. The CONCEPTS model was developed to quantify instream erosion and to help establish the instream TSS goal.

2. Modeling Approach

The CONCEPTS model extends from the Hardwood Creek outlet at Peltier Lake (in the City of Lino Lakes) upstream to Highway 61 (Hugo). The model does not extend upstream of Highway 61 due to the change in substrate from predominately sand to peat; CONCEPTS does not reliably simulate channel erosion in very peaty areas.

The CONCEPTS model relies on flow input from an XP-SWMM model previously created for JD2 (RCWD 2004). Flows were input at the upstream boundary condition and at three locations along the downstream modeled reach. This XP-SWMM model was updated and adapted to simulate different channel modification and land use scenarios. Modeling scenarios #1 through #4 (described below) evaluate changes in instream erosion and sediment transport as a result of changes in flow, but not as a direct result of the channel modification practices on sediment transport (such as channel maintenance).

Model scenarios

Five different scenarios were modeled using CONCEPTS: existing, maintained channel, stable stream rehabilitation, future conditions, and restored scenario. The first four listed here involve changes to the XP-SWMM model upstream of Highway 61, the last scenario incorporates changes in CONCEPTS to simulate in-stream restoration practices that have been implemented since 2005.

1. Existing condition: calibrated to 2002 monitoring data; baseline condition.
2. Maintained channel: assumes that full maintenance of JD2 upstream of Highway 61 occurs.
3. Stable stream rehabilitation: creates a properly sized meandered base channel lower than the existing channel, a connected and properly sized floodplain also lower than the existing floodplain, and a stable meander pattern. Scenarios 1, 2, 3 and 4 are discussed in greater detail in the Washington County Judicial Ditch #2 Repair Report (RCWD 2004).
4. Future land use: models the existing channel under a 2020 development scenario with changes made to the runoff characteristics of the land based on changing land use and implementing current RCWD rules for infiltration and rate control.
5. Restored channel: represents the instream stabilization practices implemented in lower Hardwood Creek since 2005, involving primarily live stakes and rock vanes. These model updates make this model the current conditions (2007) model. To account for these changes in the CONCEPTS model, the Manning's value and erodibility of the channel and banks in these locations were changed. In all instances the manning's value was increased to 0.035 and the practices were considered fully maintained and effective at preventing erosion.

3. CONCEPTS Model Description

The CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) model is a computer model that simulates open channel hydraulics, sediment transport, channel morphology, and geotechnical processes of bank failure by tracking bed changes and channel widening. Bank erosion accounts for basal scour and mass wasting of cohesive banks. CONCEPTS simulates transport of cohesive and cohesionless sediments, both in suspension and on the bed, and selectively by size classes. It can predict the dynamic response of flow and sediment transport to in-stream structures. The model was developed at the Agricultural Research Service's National Sedimentation Laboratory (NSL) in Oxford, Mississippi.

3A. Hydraulics

CONCEPTS uses the Saint Venant equations, also called the dynamic wave model, and the diffusion wave model for unsteady, gradually-varying, one-dimensional, open-channel flow. To increase model efficiency and stability, CONCEPTS automatically selects the dynamic or diffusion wave model based upon the flow depth, bed slope, and time-of-rise of the flood-wave.

Upstream boundary conditions are provided through a user-supplied hydrograph. The user has the option of using the loop rating curve for downstream boundary conditions or supplying a discharge rating curve.

3B. Bed Erosion and Sediment Transport

CONCEPTS recognizes that sediment transport rates are a function of flow hydraulics, bed composition, and upstream sediment supply. The rate of erosion or deposition is based upon the difference between sediment being transported and sediment transport capacity, with the relationship dependant upon whether the material is cohesive or cohesionless. Sediment transport capacity is calculated for 13 different size classes of particle.

3C. Streambank Erosion

Streambank erosion occurs in a wide variety of geomorphic contexts and is usually accompanied by changes in other morphological parameters such as channel depth, roughness, bed material composition, riparian vegetation, and energy slope. To predict the detachment of soils from the streambank, CONCEPTS uses an excess shear stress relationship developed and tested by Hanson and Simon (2001). Bank stability is analyzed based on equilibrium of forces.

4. Model Inputs

4A. Field Data Collection Survey Data

Cross Sections

Sixty seven cross sections were surveyed along Hardwood Creek between Highway 61 and the inlet to Peltier Lake. Cross section locations were chosen to adequately characterize the creek channel geometry throughout the study area. Seven of the cross sections along the creek immediately west of 35E were surveyed in July 2005 for a potential Rice Creek Watershed District restoration project at the "Carlson Site." Two cross sections at the Carlson location were resurveyed in 2007 as part of this project to identify changes in creek geometry. Sixty two unique cross sections were developed specifically for this study. Figure 1 illustrates the distribution of surveyed cross sections in the project area.

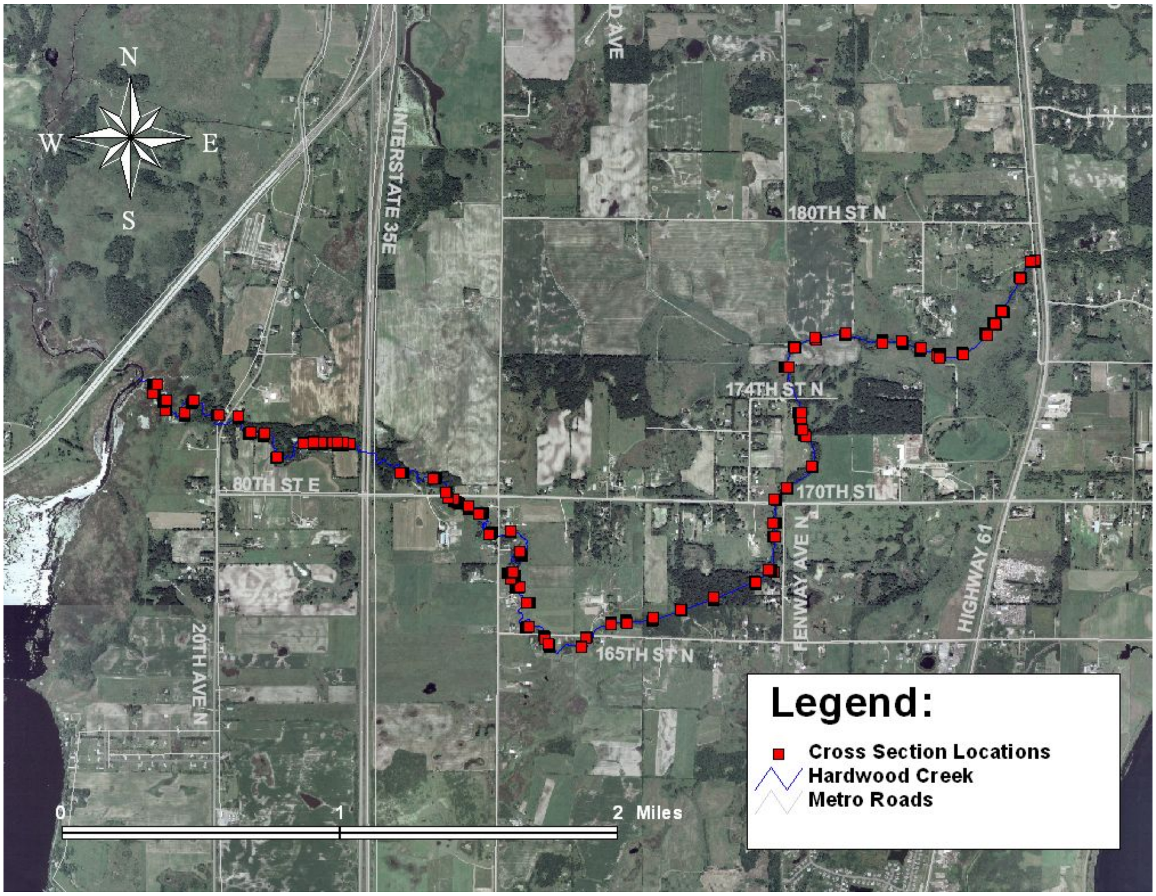


Figure 1. Surveyed cross section locations on Hardwood Creek

Cross sectional geometry was measured using survey grade Digital Global Positioning Satellite (DGPS) equipment in open areas and total station in areas lacking satellite coverage. For sites lacking satellite coverage (under tree cover), temporary control was created using DGPS and cross sections were developed by turning to the area of interest. Permanent control points were shot each day of surveying to verify and/or document changes in shot elevation from published elevation. Two points were used for such verification, MN/DOT point OM and USGS point 909 ST P. Points were calibrated to the OM benchmark.

Each cross section consists of a number of points shot to adequately typify the channel geometry. Cross sections include ground points (outside of creek channel), top of bank, toe of slope, and stream bottom for each side of the thalweg, as well as stream thalweg. Some cross sections contain point on slope points for cross sections with sloped banks. Figure 2 illustrates points shot to represent cross sections.

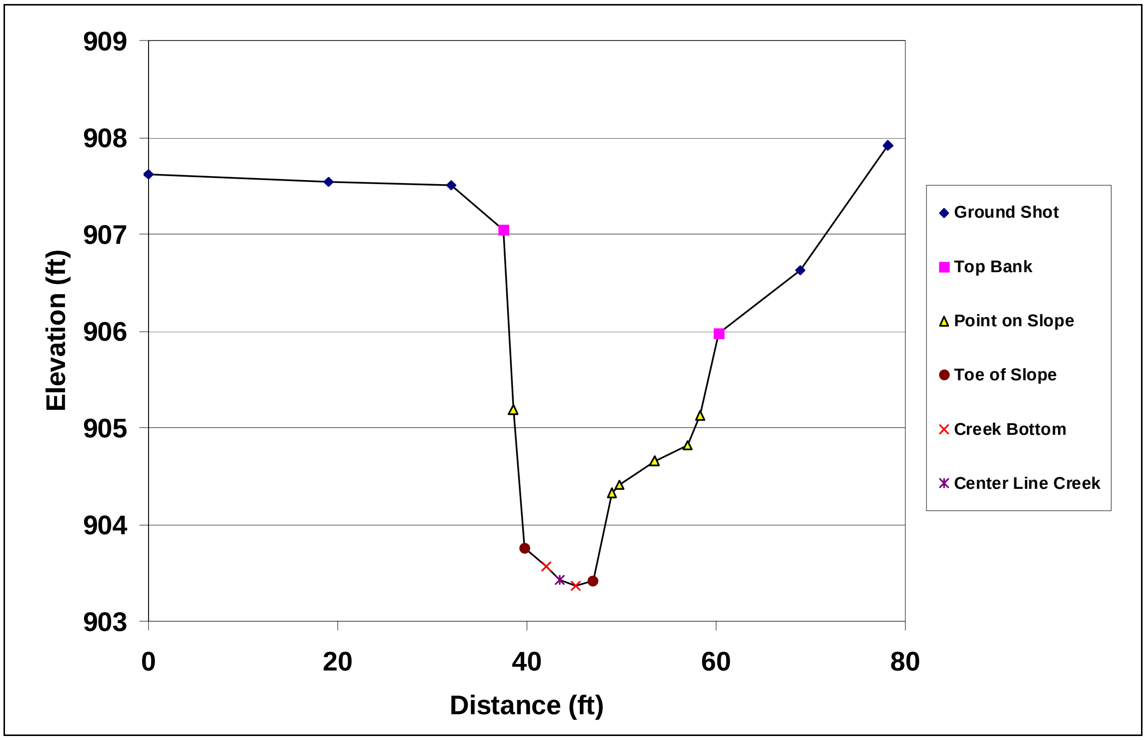


Figure 2. Typical surveyed cross section profile (Cross Section 29)

Soils

Streambed and streambank soils were collected and characterized at ten sites along Hardwood Creek between Highway 61 and the inlet to Peltier Lake. Soils were collected from both the streambed and stream banks with a 4 inch by 5 inch (0.033 ft^3) Density Drive Sampler. The sampler was used to determine the in-place density of soil by driving a thin-walled tube to obtain a soil sample of known volume as well as to collect minimally disturbed samples for triaxial testing. The collection protocol consisted of driving the thin walled tube into the bed or bank using the sampler steel drive head and sliding 10 lb hammer. The thin walled tube was then extracted by digging out a volume of soil that extended deeper than the thin walled tube using a hand held shovel. The tube was then sliced out of the soil volume by using flat bladed drywall tool. The size of the tool enabled the top and bottom of the sampling tube to be fully covered in the slicing process, ensuring no loss of sample material during handling. Soil and organic matter clinging to the side of the thin walled tube were then wiped clear with a cloth and the samples were stored in cellophane re-closeable bags, labeled, and taped to a board for transport to the lab.

Site locations were chosen to adequately cover the distance of the project area. Soil collection was not conducted in an area located between Highway 61 and 174th Street due to the presence of an extensive wetland along this reach of the creek. Figure 3 illustrates the distribution of soil collection and characterization sites in the project area and the predominant soil type based on material encountered during field work.

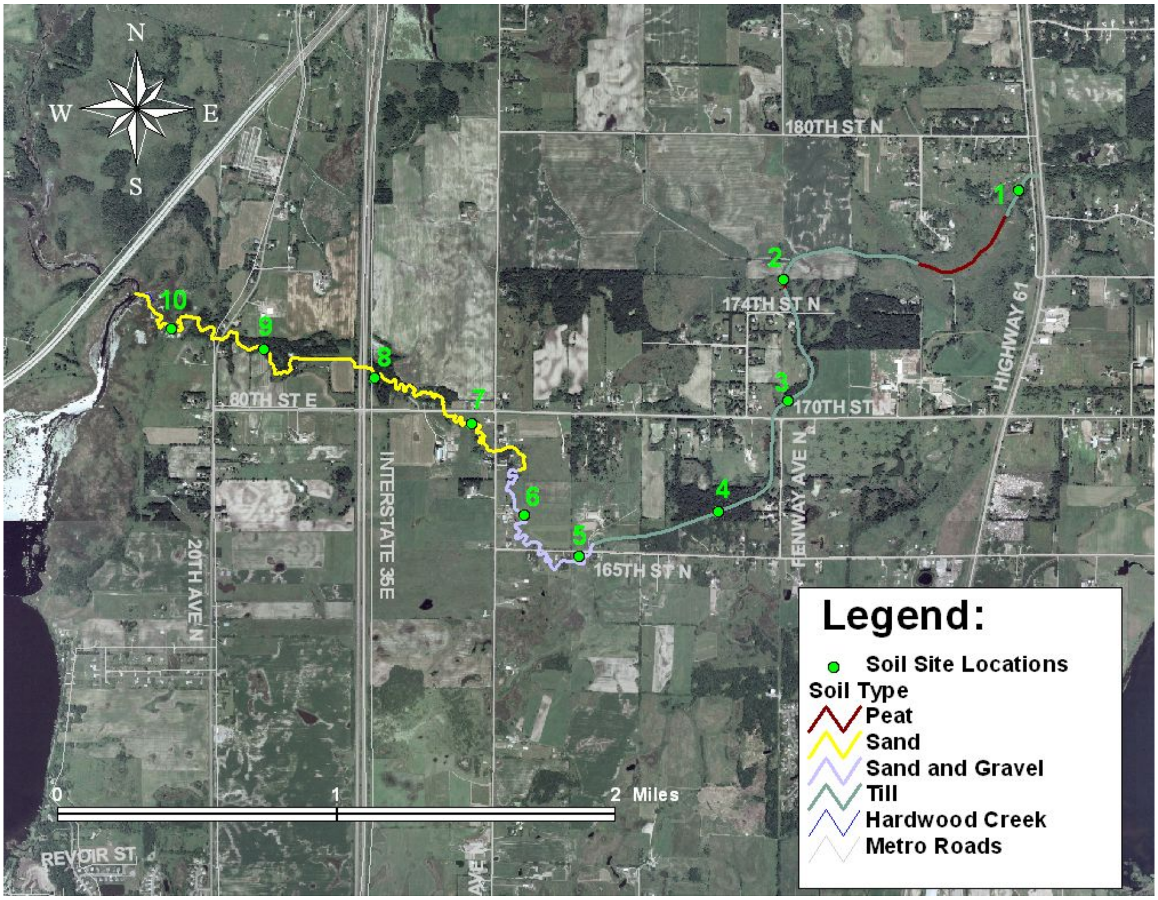


Figure 3. Soil collection sites and predominant soil type on Hardwood Creek

Torvane® Measurements

In-situ testing of bed and bank shear was conducted at soil sampling sites using a handheld Torvane® device. Three Torvane® measurements using the standard vane (stress range of 0-1 kg/cm^2) were taken for each soil characterization site. Bank sites typically had higher shear values than bed due to the presence of vegetal roots. Table 1 lists the shear values obtained using the Torvane® device. The Torvane® measurement is a measure of the soil's resistance to an applied shear, not a measurement of critical hydraulic shear stress. Torri et al. (1987) proposed a relationship between soil shear stress and hydraulic shear stress of $T_{cr} = \tau_c / \tau_s$, where T_{cr} is called the critical shear ratio, τ_c is the critical hydraulic shear stress and τ_s is the failure point as measured by the Torvane®. Torri et al. (1987) found that the best estimate of T_{cr} was 10^{-4}. This assertion was verified using data collected by Abdel-Rahamann (1964). The critical hydraulic shear values presented in Table 1 exhibit wide variability, which we attribute to the presence or absence of plant roots.

The erodibility parameter, K, is a measure of the rate of erosion once the critical threshold has been exceeded. Hanson and Simon (2001) observed the following relationship between erodibility and critical shear stress: $K = 0.1 * 10^{-6} \tau_c^{-0.5}$.

Table 1. Torvane® for materials at site locations along Hardwood Creek

Location	Material	Attempt 1 (kg/cm2)	Attempt 2 (kg/cm2)	Attempt 3 (kg/cm2)	Average Torvane (kg/cm2)	Average Torvane Shear (Pa)	Critical Hydraulic Shear (Pa)	Erodibility
Site 1	Bed	0.000	0.000	0.000	0.00	0	0.00	0.00E+00
	Bank	0.250	0.125	0.125	0.17	16344	1.63	7.82E-08
Site 2	Bed	0.000	0.000	0.000	0.00	0	0.00	0.00E+00
	Bank	0.125	0.100	0.100	0.11	10624	1.06	9.70E-08
Site 3	Bed	0.500	0.250	0.500	0.38	36775	3.68	5.21E-08
	Bank	0.400	0.600	0.500	0.50	49033	4.90	4.52E-08
Site 4	Bed	0.000	0.000	0.000	0.00	0	0.00	0.00E+00
	Bank	0.300	0.500	0.500	0.43	42495	4.25	4.85E-08
Site 5	Bed	0.000	0.000	0.000	0.00	0	0.00	0.00E+00
	Bank	0.250	0.250	0.250	0.25	24517	2.45	6.39E-08
Site 6	Bed	0.000	0.000	0.000	0.00	0	0.00	0.00E+00
	Bank	0.100	0.200	0.100	0.13	13076	1.31	8.75E-08
Site 7	Bed	0.000	0.000	0.000	0.00	0	0.00	0.00E+00
	Bank	0.600	0.800	0.600	0.67	65378	6.54	3.91E-08
Site 8	Bed	0.000	0.000	0.000	0.00	0	0.00	0.00E+00
	Bank	0.800	0.600	0.800	0.73	71915	7.19	3.73E-08
Site 9	Bed	0.000	0.000	0.000	0.00	0	0.00	0.00E+00
	Bank	0.900	1.000	0.900	0.93	91529	9.15	3.31E-08
Site 10	Bed	0.000	0.000	0.000	0.00	0	0.00	0.00E+00
	Bank	0.100	0.000	0.100	0.07	6538	0.65	1.24E-07

In addition to soil samples and shear values, photos (See 8: Photo Log) and notes were taken at each site to describe the channel morphology and any other interesting/notable features.

Laboratory Grain Size and Shear Values

Laboratory characterization of collected soils included ASTM D422 grain size/sieve analysis and ASTM D4767 triaxial testing by Soils Engineering Testing, Inc (SET). Twenty two samples were characterized by SET. Sample material ranged from silty sand to sand with silt and from organic clay to lean clay with sand and gravel. Variation in bed and bank composition is illustrated in the graphs of the ASTM D422. The results of ASTM D422 and D4767 are included in Section 8: Soil Testing Logs.

Bulk Density and Porosity Values

Bulk density values were determined by measuring the mass of the soil after oven drying the sample for 24 hours at 105°C and dividing by the volume of the sample collected in the sample tube. Subsets were weighed on an electronic scale in grams to two decimal places and dried for a period of 24 hours in a laboratory oven. Bulk density ($\rho_{b)}$ values are listed in Table 2.

Porosity was estimated from bulk density using the relationship:

$$n_T = 1 - \rho_b / \rho_s$$

where n_T is the total porosity, ρ_b is the bulk density, and ρ_s the assumed particle density of the solids.

Particle density was assumed to be 2650 kg m^{-3} for granular materials and 2700 kg m^{-3} for clays. Porosity values are listed in Table 2.

Table 2. Input values determined for site locations along Hardwood Creek

Location	Material	Entire Mass (kg.)	Volume (m3)	ρs	ρb (kg/m3)	Porosity nT
Site 1	Bed	1.67	0.0010	2650	1209.9	0.543
	Bank	1.31	0.0010	2650	792.9	0.701
Site 2	Bed	1.88	0.0010	2650	1494.6	0.436
	Bank	1.12	0.0010	2700	356.0	0.868
Site 3	Bed	1.91	0.0010	2650	1454.2	0.451
	Bank	1.33	0.0010	2700	649.5	0.759
Site 4	Bed	1.76	0.0010	2650	1316.0	0.503
	Bank	1.51	0.0010	2650	920.5	0.653
Site 5	Bed	2.12	0.0010	2650	1853.8	0.300
	Bank	1.86	0.0010	2650	1448.5	0.453
Site 6	Bed	2.04	0.0010	2650	1878.8	0.291
	Bank	1.35	0.0010	2700	880.8	0.674
Site 7	Bed	1.81	0.0010	2650	1368.7	0.483
	Bank	1.47	0.0010	2700	854.5	0.684
Site 8	Bed	1.82	0.0010	2650	1412.3	0.467
	Bank	1.60	0.0010	2650	1050.3	0.604
Site 9	Bed	1.62	0.0010	2650	1105.2	0.583
	Bank	1.68	0.0010	2650	1177.5	0.556
Site 10	Bed	1.86	0.0010	2650	1418.0	0.465
	Bank	1.32	0.0010	2700	526.0	0.805

4B. Model Parameterization

Model parameters were assigned based on the results of the soil tests described in the preceding section. The following describes each of the soil parameters. Figure 4 shows the input screen for the soil parameters. The numbered box in Figure 4 corresponds to the number below.

1. Particle density – Based on the assumed density as reported in the soil grain size distribution report.
2. Porosity – Estimated based on bulk density, as explained in the preceding section.
3. Critical shear stress – For banks, the critical shear was based on a value derived from the Torvane value. Since the bed material was essentially unconsolidated fine sand, the Torvane could not be used. For the beds, the critical shear stress was defined on the basis of typical published values.
4. Erodibility – Erodibility was estimated using the relationship provided in the preceding section.
5. Cohesion – The cohesion value was measured in the triaxial shear test.

6. Friction angle - The cohesion value was measured in the triaxial shear test.
7. Suction angle – Assigned a value of 17˚ based on guidance in the model documentation.
8. Particle size distribution – Results from the sieve and hydrometer analysis were used here.

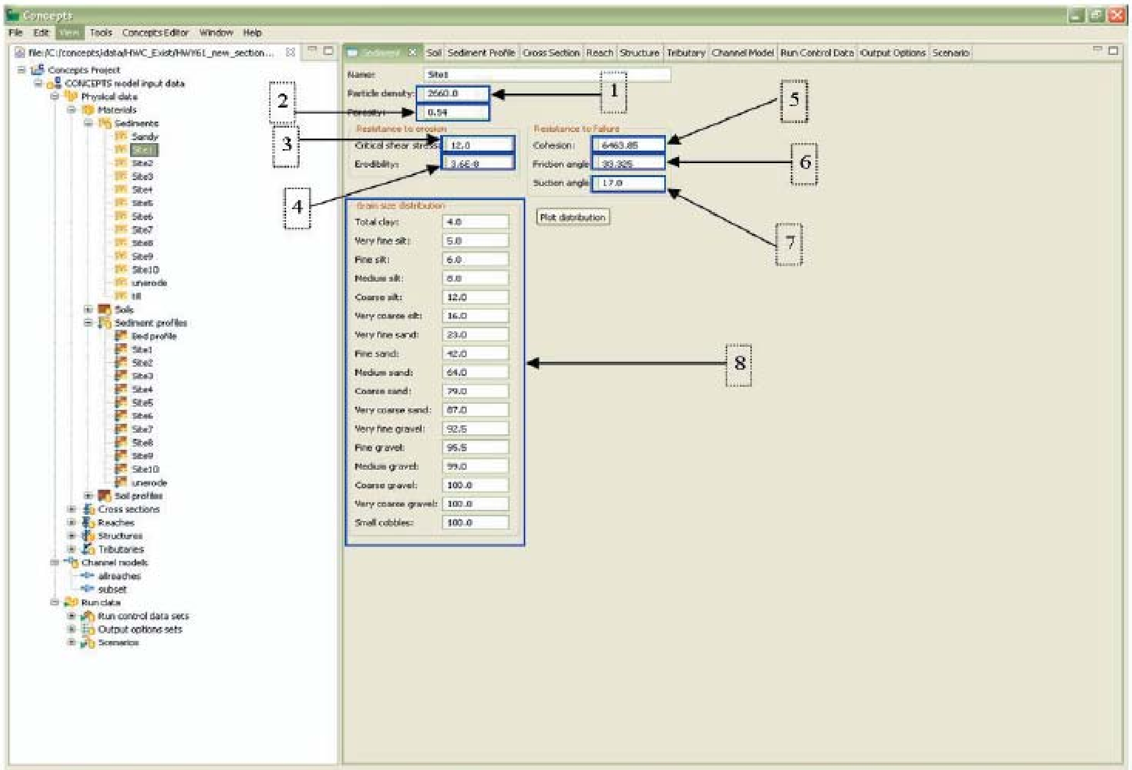


Figure 4. CONCEPTS sediment input parameters for channel beds

The streambank soil input contains two additional parameters, as shown in Figure 5. These parameters are:

9. Bulk density – Measured as described in the preceding section.
10. Permeability – Estimated using guidance in the model documentation.

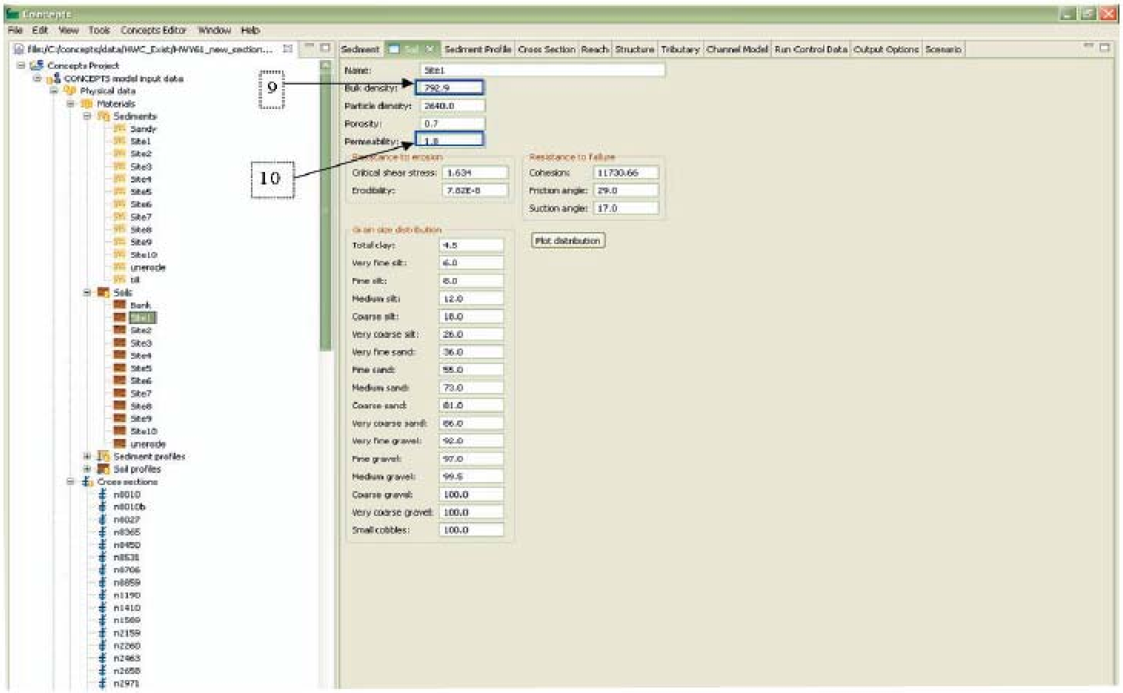


Figure 5. CONCEPTS soil input parameters for channel banks

The cross section input parameter screen is shown in Figure 6. Parameters for each of the 67 cross sections were assigned as follows:

11. River mile – The river kilometer was assigned using GIS. Highway 61 was taken as the upstream extent and assigned a value of 0. Each surveyed cross section was plotted in GIS and where the cross section intersected with the stream a cumulative river kilometer downstream from Highway 61 was assigned.
12. Station and elevation – Input from survey data. It should be noted that in CONCEPTS the water surface can only intersect the banks at two locations, thus any dips in the channel or floodplain must be eliminated.
13. Top and toe of left and right banks – Determined in survey.
14. Elevation of groundwater table – Groundwater elevation was assumed to be slightly above the toe of the stream. This corresponds to our experience and observation.
15. Manning's 'n' – Roughness values were assigned based on those in the XP-SWMM model for Hardwood Creek.
16. Boundary materials – The applicable test data were assigned for each cross section, using the midpoint between each sample location as the boundary for the applicable reach. Table 3 shows the application limits for each of the 10 sites tested.

Table 3. Application limits for bed and bank soil characteristics

SOIL TEST	Soil Test River Mile (KM)	Upstream Extents (KM)	Downstream Extents (KM)
1	0.131	UPSTREAM LIMIT	0.985
2	1.839	0.985	2.238
3	2.638	2.238	3.067
4	3.496	3.067	3.946
5	4.396	3.946	4.866
6	5.336	4.866	5.924
7	6.512	5.924	7.009
8	7.505	7.009	7.988
9	8.471	7.988	8.928
10	9.385	8.928	DOWNSTREAM LIMIT

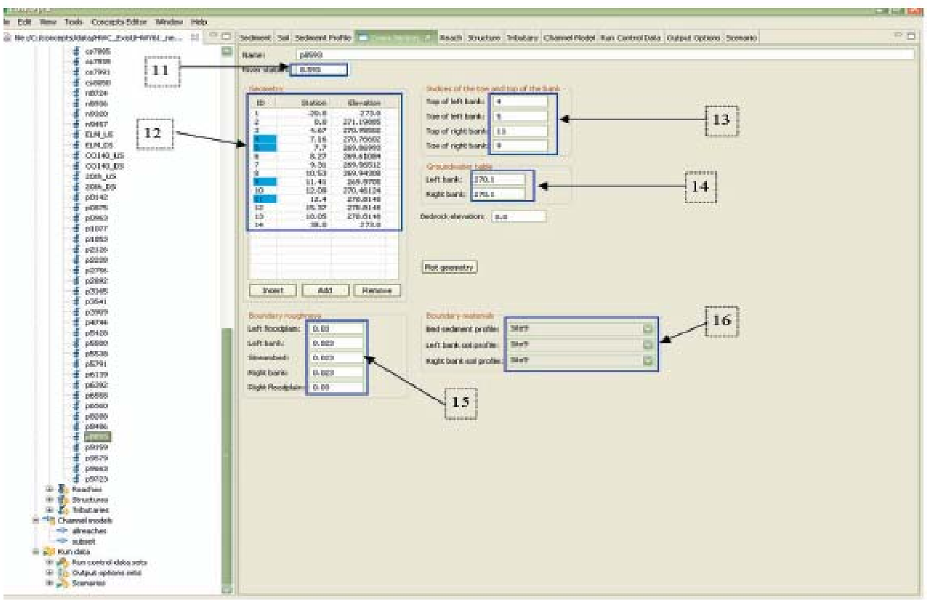


Figure 6. CONCEPTS cross section input parameters

Structures information was also included in the CONCEPTS model. Figure 7 shows the input screen for a box culvert. For each structure, the following information is required:

17. River station – The river station, or kilometer, was determined using GIS.
18. Roughness – The Manning's 'n' was determined from information in the XP-SWMM model.
19. Length – Length of the structure in meters from XP-SWMM.
20. Upstream and downstream invert – In meters, determined from XP-SWMM.
21. Upstream and downstream scour depth – Assumed to be 0.1 meters.

22. Entrance loss coefficient – Typical recommended values in model documentation were used.
23. FHWA Chart #: Applicable FHWA chart is selected.
24. FHWA Scale #: Applicable FHWA scale is selected.
25. Barrel span and rise: Structure dimensions in meters are input.

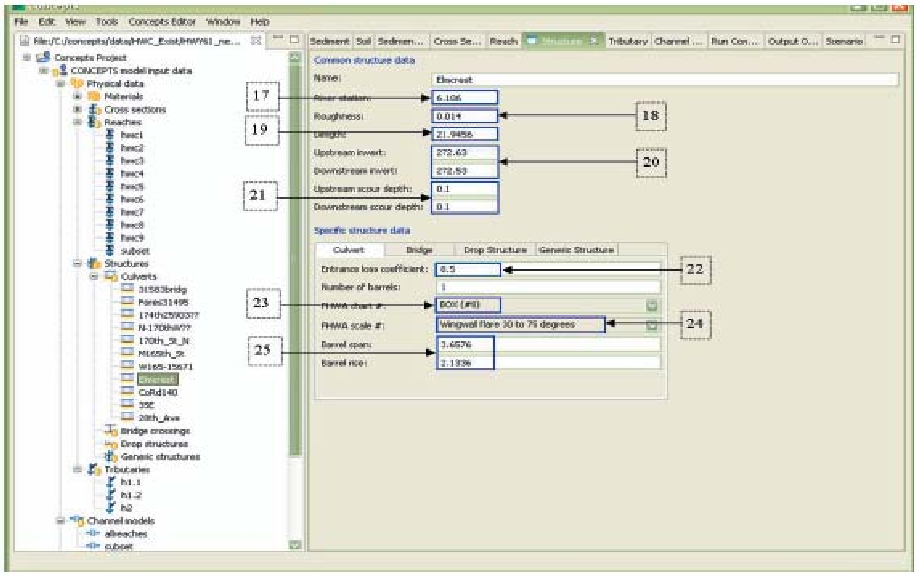


Figure 7. CONCEPTS structure input parameters

4C. Hardwood Creek XP-SWMM Model Updates

A hydrologic and hydraulic model of Hardwood Creek/JD2 was developed in XP-SWMM in connection with previous investigations. In the development of the model, more attention had previously been paid to the portion of the waterway upstream of Highway 61, both in terms of the quality of the cross section data and the number of scenarios evaluated.

For this project, it was determined that new survey data were needed in order to update and improve the quality of the XP-SWMM model for the segment between Highway 61 and Peltier Lake. A total of 67 new cross sections were surveyed, processed, and included in the revised XP-SWMM model. The links that had been representing Hardwood Creek in the prior version of the model were eliminated in favor of only including the new data of known quality.

Model parameters related to the production and delivery of runoff were not changed for the existing conditions modeling. The nodes representing subwatersheds were kept in the updated version of the model, and runoff flow from these nodes was directed to the hydraulic model of the creek at the corresponding locations. However, for the purposes of CONCEPTS modeling, it was necessary to change the existing conditions XP-SWMM model from an event-based to a continuous simulation. The model was run for two separate periods of time, from April 12 through September 30 of the years 2002 and 2003.

The new surveyed cross sections were also added to the stable stream rehabilitation model and run for the same periods of time in 2002 and 2003. Finally, the existing conditions model was modified in order to simulate future (2020) land use conditions, and re-run using the 2002 and 2003 precipitation data.

The original model was developed for the simulation of flows from relatively large storm events. Calibration was performed for 2002 at the Highway 61 location, Site H1 (Figure 8). The magnitude of peak flows is similar for most events; differences can be attributed to the precipitation data that were used to generate runoff in the XP-SWMM model. The precipitation data were obtained from the University of Minnesota's Climatology Working Group website. The two closest gaging stations were in Hugo and White Bear Lake, which were four and five miles away, respectively. Thus, the precipitation data that were used may not capture the magnitude and intensity of actual precipitation, leading to differences between the calibrated model flows and measured flows.

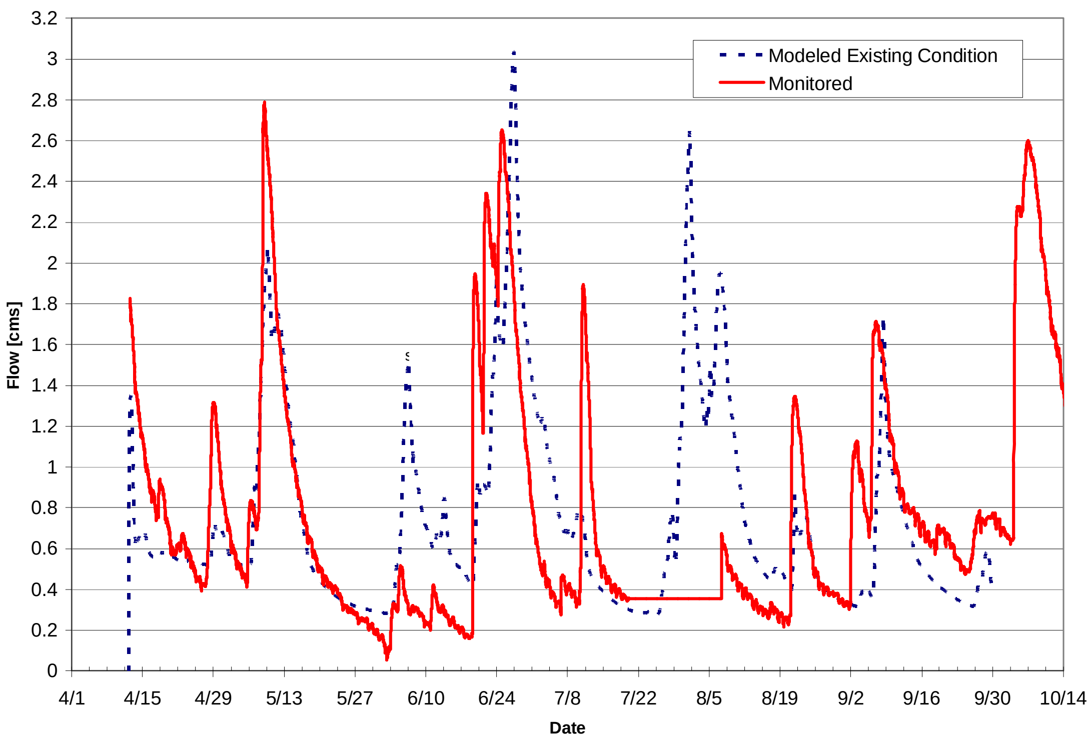


Figure 8. XP-SWMM model calibration results, 2002

Figure 9 and Figure 10 show the results of the XP-SWMM simulations at site H1 of the different management scenarios. Generally, the maintained channel simulation results in the greatest peak flow rates followed by the stable stream scenario. This is expected since both of the scenarios model a more hydraulically efficient channel than the pre-maintenance channel conditions.

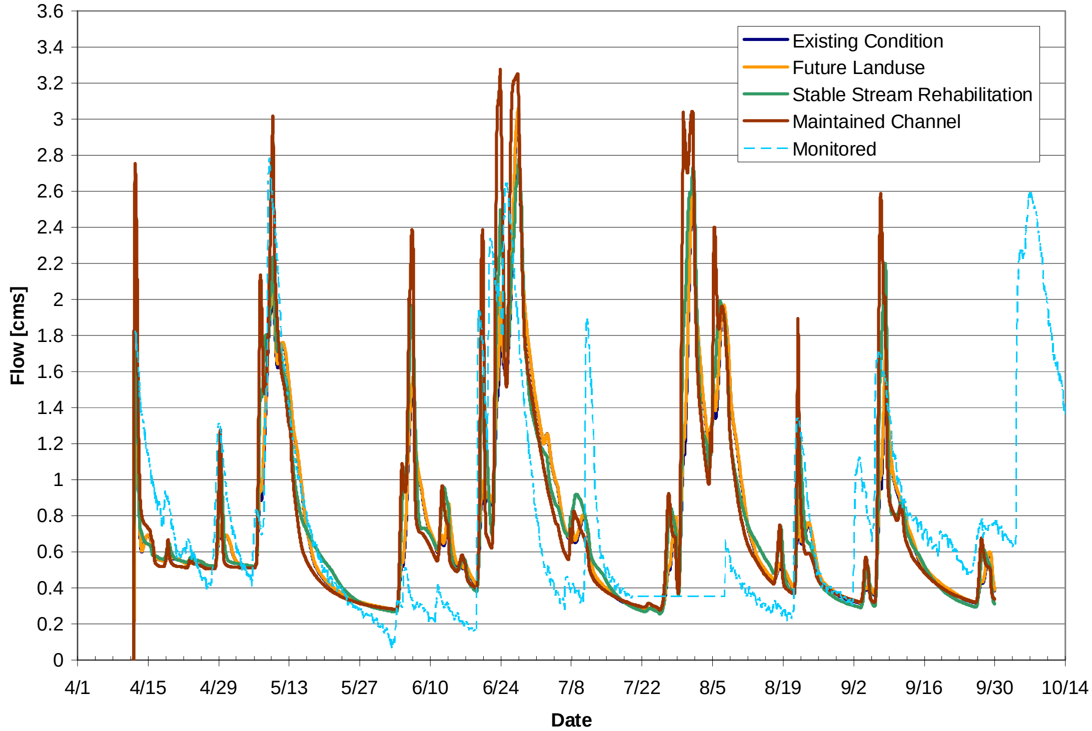


Figure 9. XP-SWMM hydrographs at Highway 61 (H1), 2002

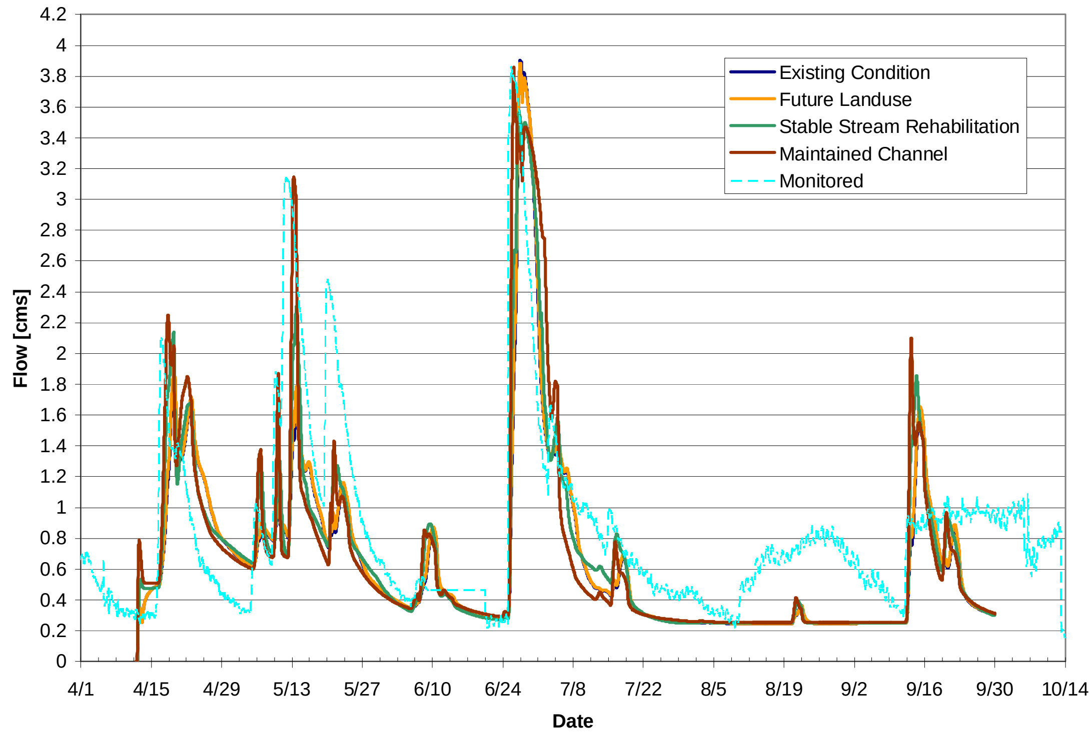


Figure 10. XP-SWMM hydrographs at Highway 61 (H1), 2003

5. Model Calibration

CONCEPTS has the ability to estimate erosion using either an excess shear or a Shields method. The Shields method was initially selected because it was thought to be more appropriate for a sandy bottom. However, using the Shields erosion method resulted in unrealistically large silt loads. Thus, the excess shear method was employed. Key calibration parameters were soil erodibility and critical shear stress.

Initial critical shear values were assigned on the basis of the Torvane measurements. However, Torvane measurements were not able to be taken in most of the beds. Therefore, estimates of critical shear stress were assigned based on literature values. This is within the range of prescribed values shown in Table 4. Values of shear stress were varied concurrently with soil erodibility for model calibration. A final bed critical shear stress of 2.25 Pascals was used in the model, which is very close to the average critical shear for fine, colloidal sand, and noncolloidal, sandy loam in Table 4. No attempt was made to vary the critical bed shear stress by reach. The measured critical shear stress for banks was used in the simulation, except for reaches 7, 8, and 9 where the critical shear stresses were judged to be too large. The average critical shear stress across all sites of 3.91 Pascals was used for these sites.

Table 4. Critical Shear Stress Ranges (from Chang, 1998)

Material	Critical Shear (Clear Water) [Pa]	Critical Shear (Water Transporting Colloidal Silts) [Pa]
Fine Sand, Colloidal	1.29	3.59
Sandy Loam, Noncolloidal	1.77	3.59
Silt Loam, Noncolloidal	2.3	5.27
Alluvial Silts, Noncolloidal	2.3	7.18
Alluvial Silts, Colloidal	12.45	22.03
Ordinary Firm Loam	3.59	7.18
Fine Gravel	3.59	15.32

For soil erodibility, the estimated values presented in Table 1 were used for bank soils. For the bed, the average of all estimates was used as a baseline. Final values were 50% greater than the baseline.

Hydrographs (at site H1, Figure 9 and Figure 10) from the XP-SWMM model were used as the upstream boundary condition for the CONCEPTS model. Flows from XP-SWMM were also input in CONCEPTS at two monitoring locations within the reach: H1.1 and H1.2. The final inflow to CONCEPTS was placed at H2 as the downstream boundary condition.

The baseline CONCEPTS model was calibrated to TSS data collected in 2002 at H2 (Figure 11). In order to compare CONCEPTS sediment transport to monitored TSS, the monitoring data were processed and distributed at daily intervals using LOADEST. The LOADEST model uses a number of regression equations to estimate daily TSS given a daily flow hydrograph and the TSS samples. Because the flow data at H2 were impacted by backwaters from Peltier Lake, modeled flows from the calibrated XP-SWMM model were used in place of the monitored flow data.

The LOADEST model does not account for events such as bank failures, which CONCEPTS models. This is shown in Figure 11 near October 10, where a CONCEPTS-modeled bank failure produces a large spike in the sedigraph.

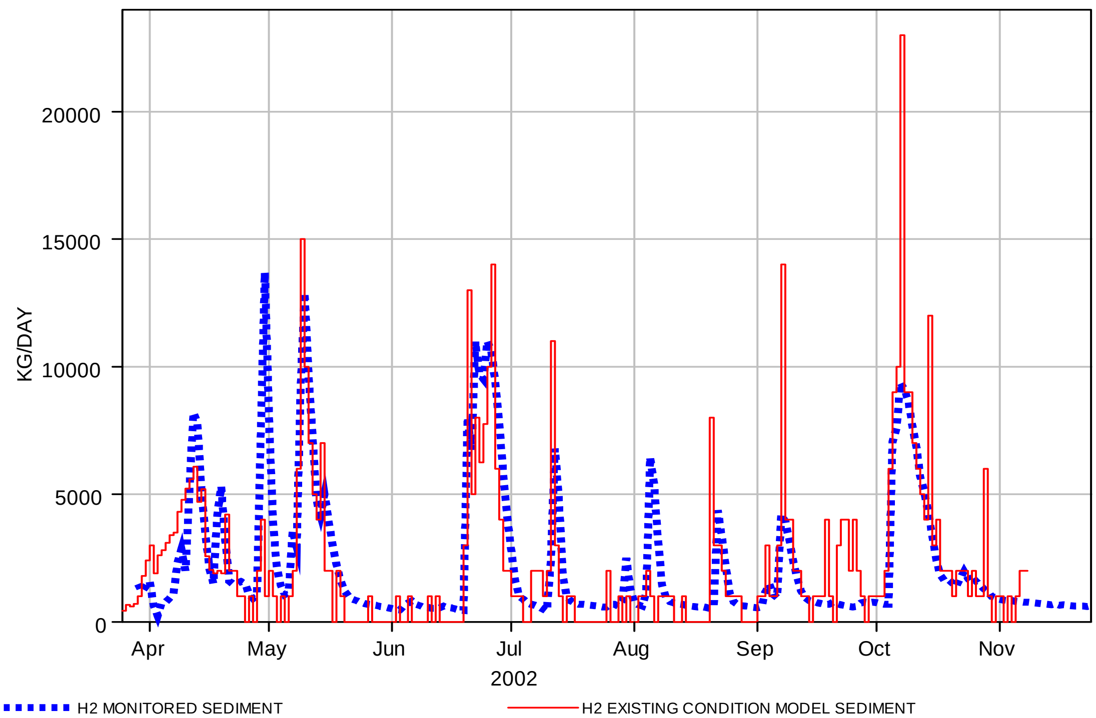


Figure 11. Calibrated and observed sediment yield. The monitored sediment curve consists of LOADEST output using XP-SWMM modeled flows and TSS monitored data as input. Modeled sediment curve is CONCEPTS modeling output.

6. Results

The modeled sediment yield leaving the system at monitoring site H2 differs in each of the modeled scenarios (Table 5). The restored scenario results in less sediment yield than the other modeled scenarios. The stable stream rehabilitation and the future land use scenario result in slightly higher sediment yields, and the maintained channel results in the greatest sediment yield.

Compared to the annual average TSS concentration under the existing conditions model of 22 mg/L, the TSS concentration in the maintained channel model is higher, at 28 mg/L, and both the stable stream and the future land use scenarios are approximately the same, at 23 mg/L (Table 5). The restored channel scenario has the lowest TSS concentration, 19 mg/L.

Table 5. Modeled sediment yield and concentration from Hardwood Creek

Scenario	Year	Sediment Leaving the System (1,000 kg)				TSS*		
		Silt	Sand	Gravel	Total	Av. Load (1,000 kg)	Annual Average (mg/L)	Ave Conc (mg/L)
Existing Condition	2002	212	70	18	300	268	19	22
	2003	231	116	24	372		25	
Maintained Channel	2002	302	136	27	465	363	27	28
	2003	277	145	26	448		29	
Stable Stream Restoration	2002	255	107	25	387	302	22	23
	2003	237	116	22	375		24	
Future Land Use	2002	237	95	23	355	290	21	23
	2003	238	120	25	382		25	
Restored Channel	2002	197	56	9	262	242	17	19
	2003	214	93	14	321		22	

*TSS consists of silt and fine sand where fine sand comprises 50% of the total transported sand.

Out of the total erosion occurring along Hardwood Creek, the bed erosion accounts for approximately 40%, and the bank erosion accounts for approximately 60% (

Table 6).

Table 6. Erosion sources along Hardwood Creek

Scenario	Year	Total Erosion along Reach (1,000 kg)				
		Bed	% Bed	Bank	% Bank	Total
Existing Condition	2002	95	48%	105	52%	200
	2003	82	41%	119	59%	200
Maintained Channel	2002	99	39%	156	61%	255
	2003	84	37%	144	63%	228
Stable Stream Restoration	2002	100	45%	124	55%	224
	2003	84	40%	127	60%	211
Future Land Use	2002	99	46%	117	54%	216
	2003	82	40%	122	60%	204
Restored Channel	2002	55	35%	104	65%	159
	2003	45	29%	109	71%	154

7. Photo Log

Site 1

Upstream **Downstream**

East bank **West bank**

Site 2

Upstream

Downstream

East bank

West bank

Site 3

Upstream **Downstream**

East bank **West bank**

Site 4

Upstream

Downstream

North bank

South bank

Site 5

Upstream

Downstream

North bank

South bank

Site 6

Upstream

Downstream

East bank

West bank

Site 7

Upstream

Downstream

East bank

West bank

Site 8

Upstream

Downstream

East bank

West bank

Site 9

Upstream

Downstream

North bank

South bank

Site 10

Upstream

Downstream

North bank

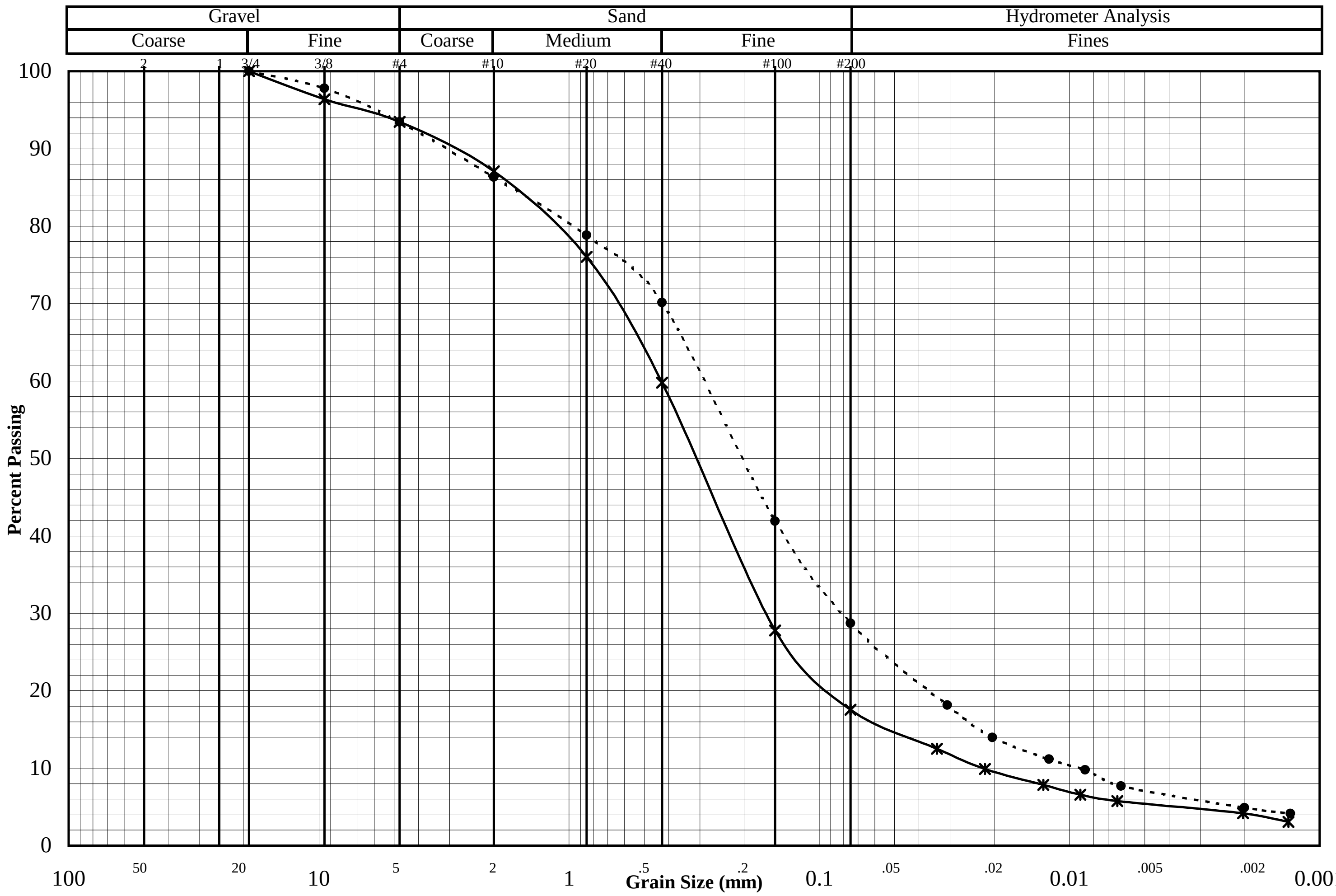
South bank

8. Soil Testing Logs

Grain Size Distribution ASTM D422

Project:	Concepts	Job No. :	**6079**
		Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/15/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	Site 1	Bed		Bag	Silty Sand w/a little gravel (SM)
●	Site 1	Bank		Bag	Silty Sand w/a little gravel and a trace of organic material (SM)
◇					



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content			
Dry Density (pcf)			
Specific Gravity	2.66*	2.64*	
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	609.0	351.4	
2"			
1.5"			
1"			
3/4"	100.0	100.0	
3/8"	96.4	97.8	
#4	93.4	93.5	
#10	87.1	86.3	
#20	76.0	78.8	
#40	59.8	70.1	
#100	27.8	41.9	
#200	17.5	28.7	

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

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SOIL ENGINEERING TESTING, INC.

Bloomington, Minnesota 55420-3436

Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts	Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/15/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
Spec 1	Site 1	Bed		Bag	Silty Sand w/a little gravel (SM)
Spec 2	Site 1	Bank		Bag	Silty Sand w/a little gravel and a trace of organic material (SM)
Spec 3					

Sieve Data

Specimen 1		Specimen 2		Specimen 3	
Particle Size (phi)	% Passing	Particle Size (phi)	% Passing	Particle Size (phi)	% Passing
-6	100.0	-6	100.0		
-5	100.0	-5	100.0		
-4	99.0	-4	99.5		
-3	95.5	-3	97.0		
-2	92.5	-2	92.0		
-1	87.0	-1	86.0		
0	79.0	0	81.0		
1	64.0	1	73.0		
2	42.0	2	55.0		
3	23.0	3	36.0		
4	16.0	4	26.0		
5	12.0	5	18.0		
6	8.0	6	12.0		
7	6.0	7	8.0		
8	5.0	8	6.0		
9	4.0	9	4.5		

Remarks

Specimen 1	Specimen 2	Specimen 3
Phi values determined graphically.	Phi values determined graphically.	

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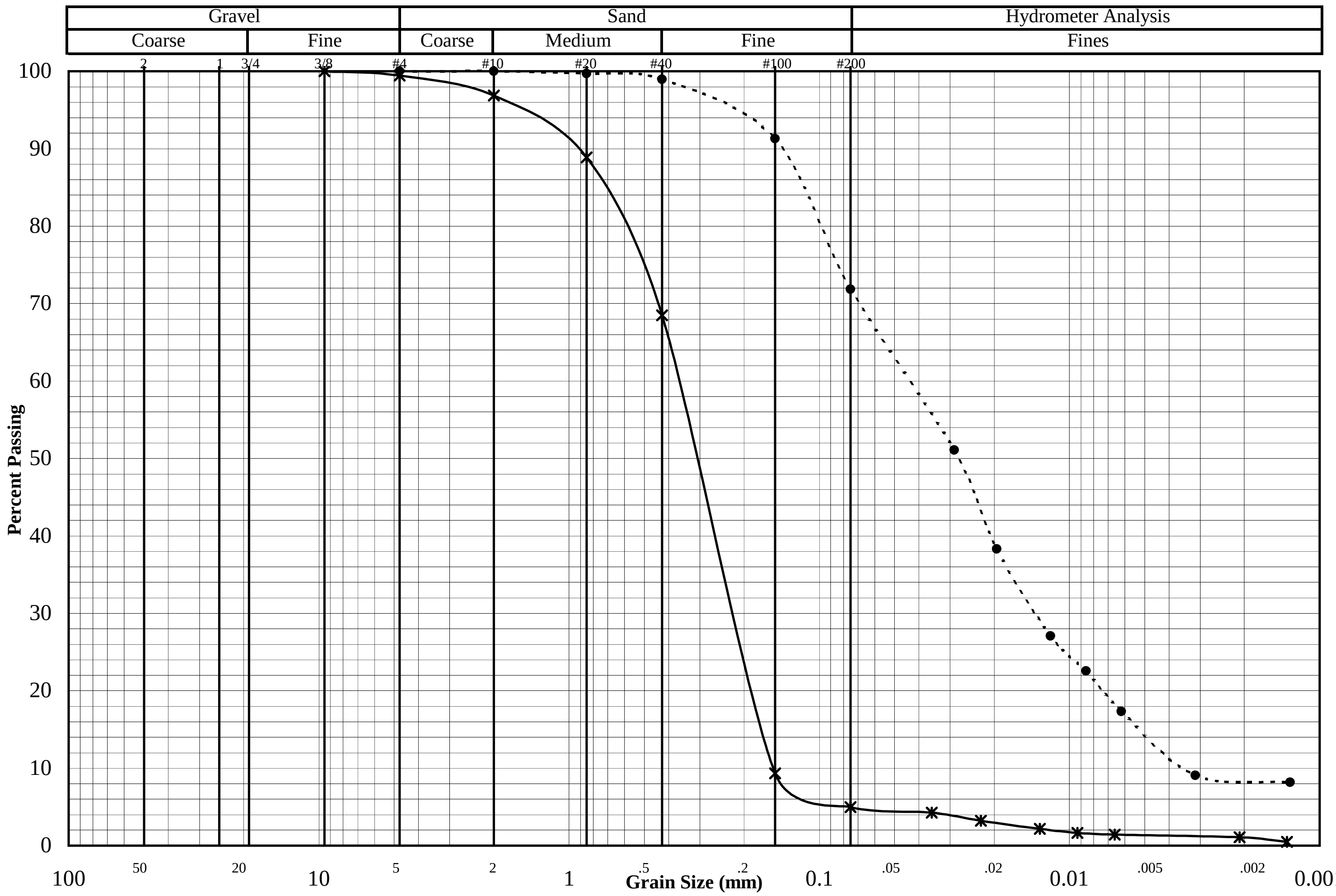
Bloomington, Minnesota 55420-3436

Grain Size Distribution ASTM D422

Project:	Concepts	Job No. :	**6079**
		Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/15/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	Site 2	Bed		Bag	Sand w/silt (SP-SM/SP)
●	Site 2	Bank		Bag	Organic Clay (OL/PT)
◇					



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content			
Dry Density (pcf)			
Specific Gravity	2.66*	2.64*	
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	587.9	188.5	
2"			
1.5"			
1"			
3/4"			
3/8"	100.0		
#4	99.4	100.0	
#10	96.9	100.0	
#20	88.9	99.7	
#40	68.5	99.0	
#100	9.3	91.3	
#200	5.0	71.8	

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

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SOIL ENGINEERING TESTING, INC.

Bloomington, Minnesota 55420-3436

Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts	Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/15/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
Spec 1	Site 2	Bed		Bag	Sand w/silt (SP-SM/SP)
Spec 2	Site 2	Bank		Bag	Organic Clay (OL/PT)
Spec 3					

Sieve Data

Specimen 1		Specimen 2		Specimen 3	
Particle Size (phi)	% Passing	Particle Size (phi)	% Passing	Particle Size (phi)	% Passing
-6	100.0	-6	100.0		
-5	100.0	-5	100.0		
-4	100.0	-4	100.0		
-3	99.8	-3	100.0		
-2	99.0	-2	100.0		
-1	97.0	-1	100.0		
0	91.0	0	99.9		
1	75.0	1	99.6		
2	34.0	2	96.0		
3	6.0	3	87.2		
4	5.0	4	67.0		
5	4.0	5	52.5		
6	2.2	6	31.5		
7	1.4	7	20.0		
8	1.1	8	10.0		
9	1.0	9	8.0		

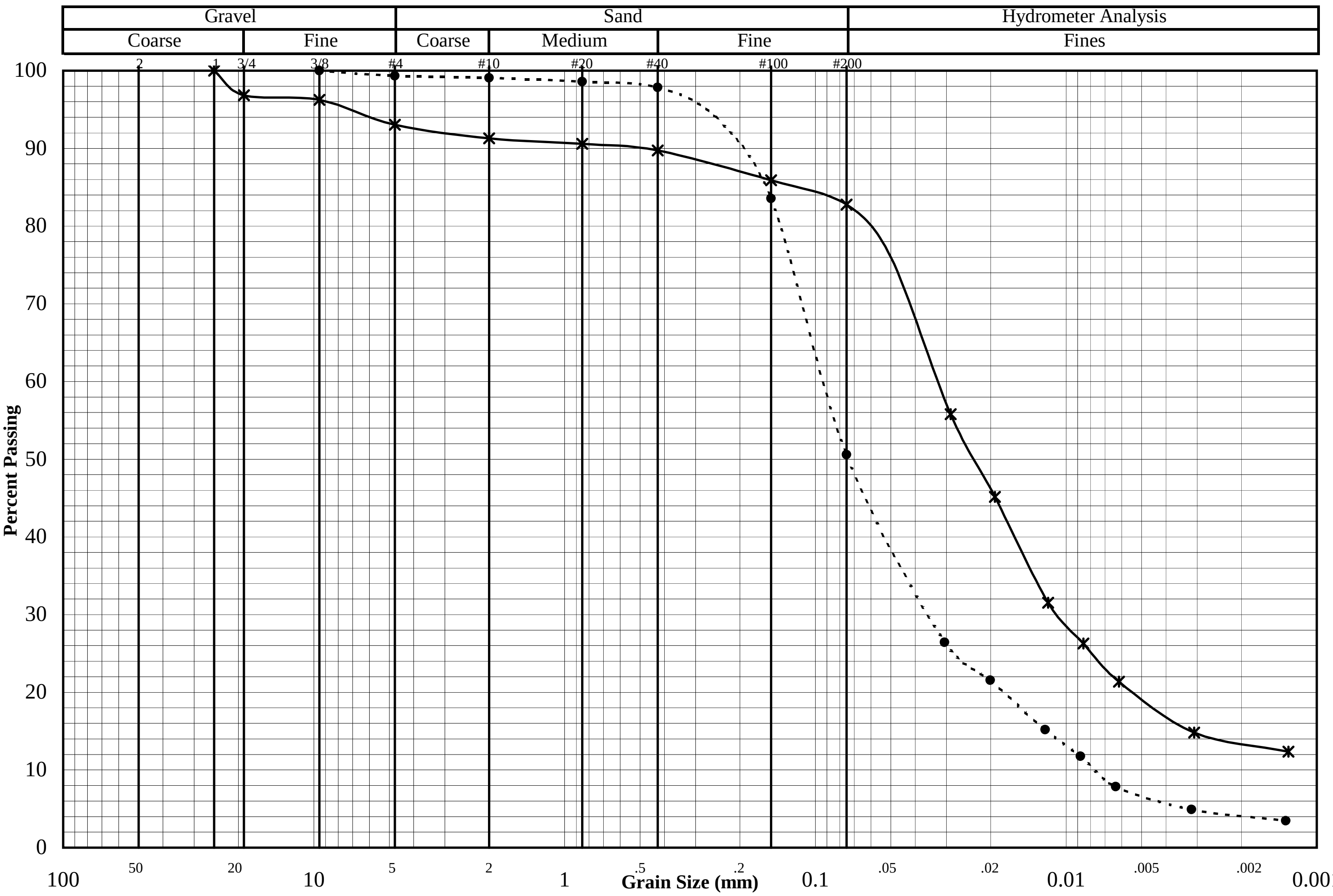
Remarks

Specimen 1	Specimen 2	Specimen 3
phi values determined graphically	phi values determined graphically	

Grain Size Distribution ASTM D422

Job No. :	**6079**		
Project:	Concepts	Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/15/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	Site 3	Bed		Bag	Lean Clay w/sand and a little gravel (CL)
●	Site 3	Bank		Bag	Sandy Organic Clay (OL)
◇					



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content			
Dry Density (pcf)			
Specific Gravity	2.67*	2.67*	
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	757.1	288.5	
2"			
1.5"			
1"	100.0		
3/4"	96.8		
3/8"	96.2	100.0	
#4	93.0	99.3	
#10	91.3	99.1	
#20	90.6	98.6	
#40	89.7	97.8	
#100	85.9	83.5	
#200	82.8	50.6	

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

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Bloomington, Minnesota 55420-3436

Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts			Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.			Report Date:	5/15/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
Spec 1	Site 3	Bed		Bag	Lean Clay w/sand and a little gravel (CL)
Spec 2	Site 3	Bank		Bag	Sandy Organic Clay (OL)
Spec 3					

Sieve Data

Specimen 1		Specimen 2		Specimen 3	
Particle Size (phi)	% Passing	Particle Size (phi)	% Passing	Particle Size (phi)	% Passing
-6	100.0	-6	100.0		
-5	100.0	-5	100.0		
-4	96.5	-4	100.0		
-3	95.5	-3	99.8		
-2	92.8	-2	99.2		
-1	91.3	-1	99.1		
0	91.0	0	98.9		
1	90.0	1	98.2		
2	87.5	2	93.2		
3	85.0	3	71.4		
4	80.0	4	41.8		
5	57.0	5	26.0		
6	36.0	6	17.0		
7	23.5	7	9.5		
8	15.5	8	5.0		
9	13.0	9	4.0		

Remarks

Specimen 1	Specimen 2	Specimen 3
phi values determined graphically	phi values determined graphically	

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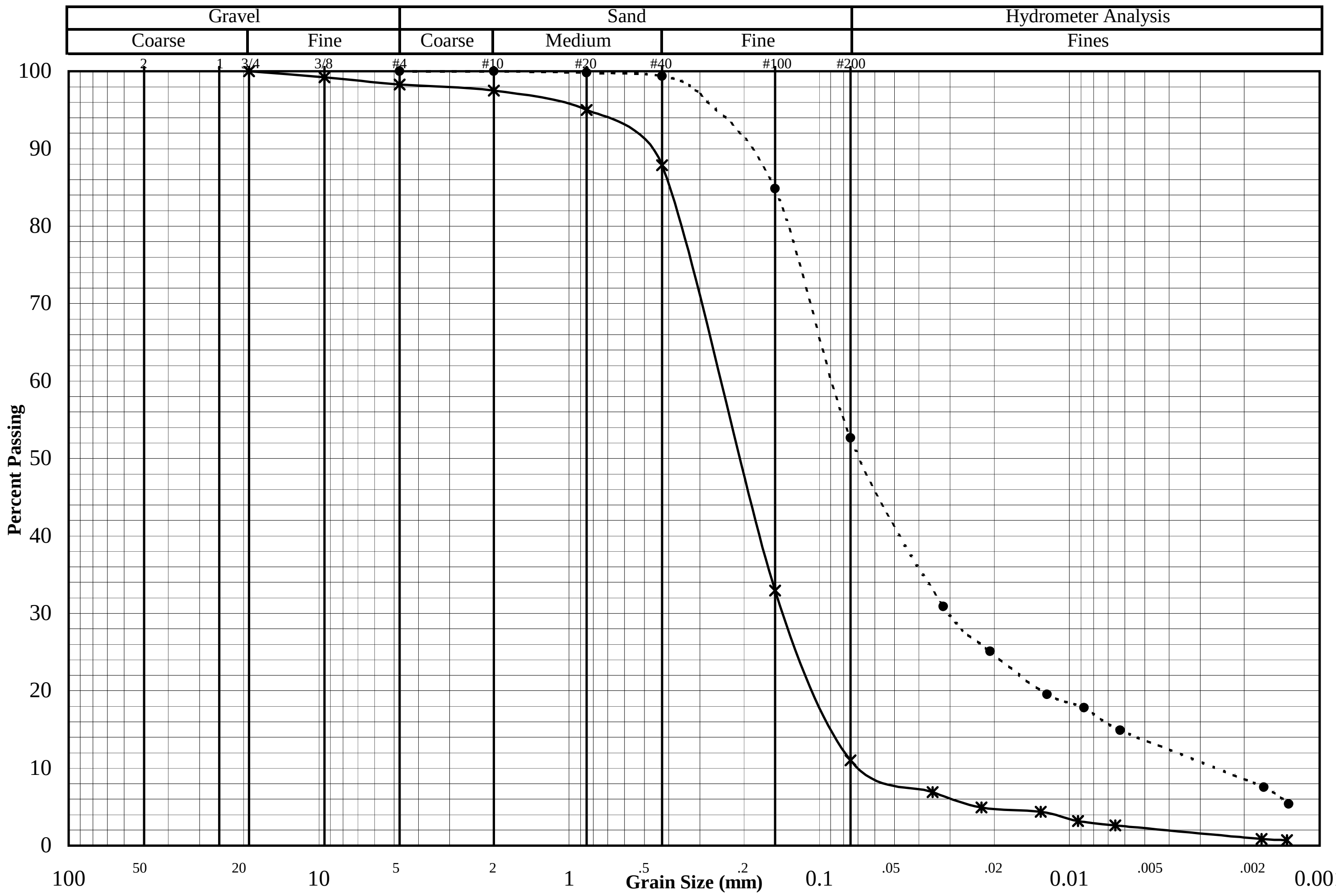
Grain Size Distribution ASTM D422

Project:	Concepts	Job No. :	**6079**
		Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/15/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	Site 4	Bed		Bag	Sand w/silt (SP-SM/SM)
●	Site 4	Bank		Bag	Sandy Silt (ML/CL-ML)
◇					



Other Tests	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content			
Dry Density (pcf)			
Specific Gravity	2.66*	2.64*	
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing	*	●	◇
Mass (g)	561.8	357.5	
2"			
1.5"			
1"			
3/4"	100.0		
3/8"	99.2		
#4	98.3	100.0	
#10	97.5	100.0	
#20	95.0	99.8	
#40	87.9	99.4	
#100	32.9	84.8	
#200	11.0	52.7	

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

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Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts	Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/15/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
Spec 1	Site 4	Bed		Bag	Sand w/silt (SP-SM/SM)
Spec 2	Site 4	Bank		Bag	Sandy Silt (ML/CL-ML)
Spec 3					

Sieve Data

Specimen 1		Specimen 2		Specimen 3	
Particle Size (phi)	% Passing	Particle Size (phi)	% Passing	Particle Size (phi)	% Passing
-6	100.0	-6	100.0		
-5	100.0	-5	100.0		
-4	99.8	-4	100.0		
-3	99.0	-3	100.0		
-2	98.0	-2	100.0		
-1	97.5	-1	100.0		
0	96.0	0	99.9		
1	91.5	1	99.7		
2	57.5	2	94.0		
3	23.5	3	74.0		
4	8.5	4	45.8		
5	6.0	5	29.8		
6	4.5	6	20.9		
7	3.0	7	16.0		
8	1.8	8	12.0		
9	1.0	9	7.9		

Remarks

Specimen 1	Specimen 2	Specimen 3
phi values determined graphically	phi values determined graphically	

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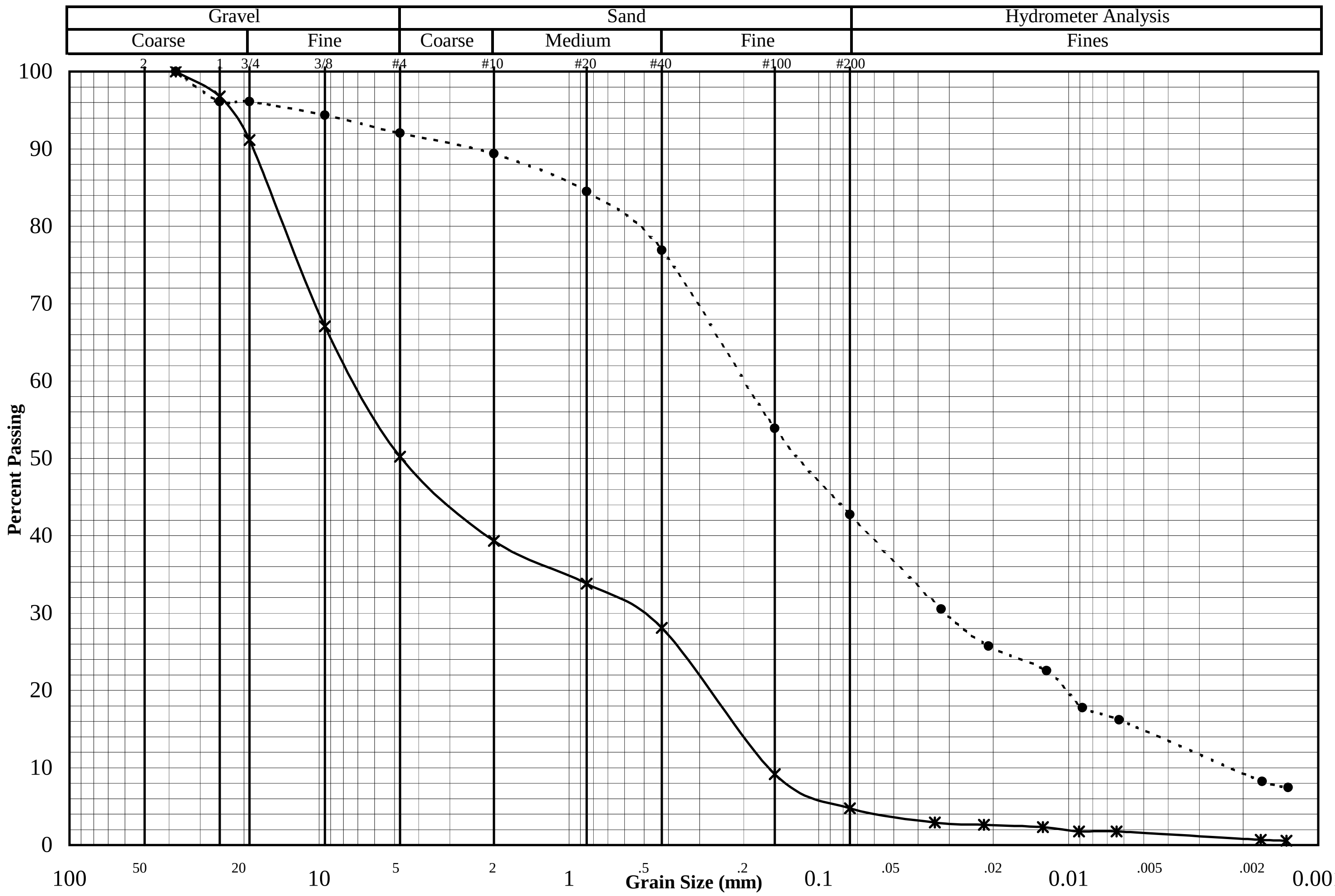
Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts	Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/16/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	Site 5	Bed		Bag	Gravel w/sand (GP)
●	Site 5	Bank		Bag	Clayey Sand w/a little gravel (SC)
◇					



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content			
Dry Density (pcf)			
Specific Gravity	2.66*	2.64*	
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	1455.1	541.7	
2"			
1.5"	100.0	100.0	
1"	96.8	96.1	
3/4"	91.1	96.1	
3/8"	67.0	94.3	
#4	50.2	92.0	
#10	39.3	89.4	
#20	33.8	84.5	
#40	28.1	76.9	
#100	9.2	53.9	
#200	4.8	42.7	

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

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Bloomington, Minnesota 55420-3436

Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts	Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/16/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
Spec 1	Site 5	Bed		Bag	Gravel w/sand (GP)
Spec 2	Site 5	Bank		Bag	Clayey Sand w/a little gravel (SC)
Spec 3					

Sieve Data

Specimen 1		Specimen 2		Specimen 3	
Particle Size (phi)	% Passing	Particle Size (phi)	% Passing	Particle Size (phi)	% Passing
-6	100.0	-6	100.0		
-5	99.0	-5	98.8		
-4	86.0	-4	95.9		
-3	62.0	-3	94.0		
-2	47.0	-2	91.5		
-1	39.3	-1	89.4		
0	35.0	0	85.6		
1	30.0	1	79.5		
2	17.2	2	64.9		
3	7.0	3	49.2		
4	4.0	4	39.1		
5	2.9	5	29.1		
6	2.2	6	23.5		
7	2.0	7	17.0		
8	1.3	8	13.0		
9	0.9	9	8.9		

Remarks

Specimen 1	Specimen 2	Specimen 3
phi values determined graphically	phi values determined graphically	

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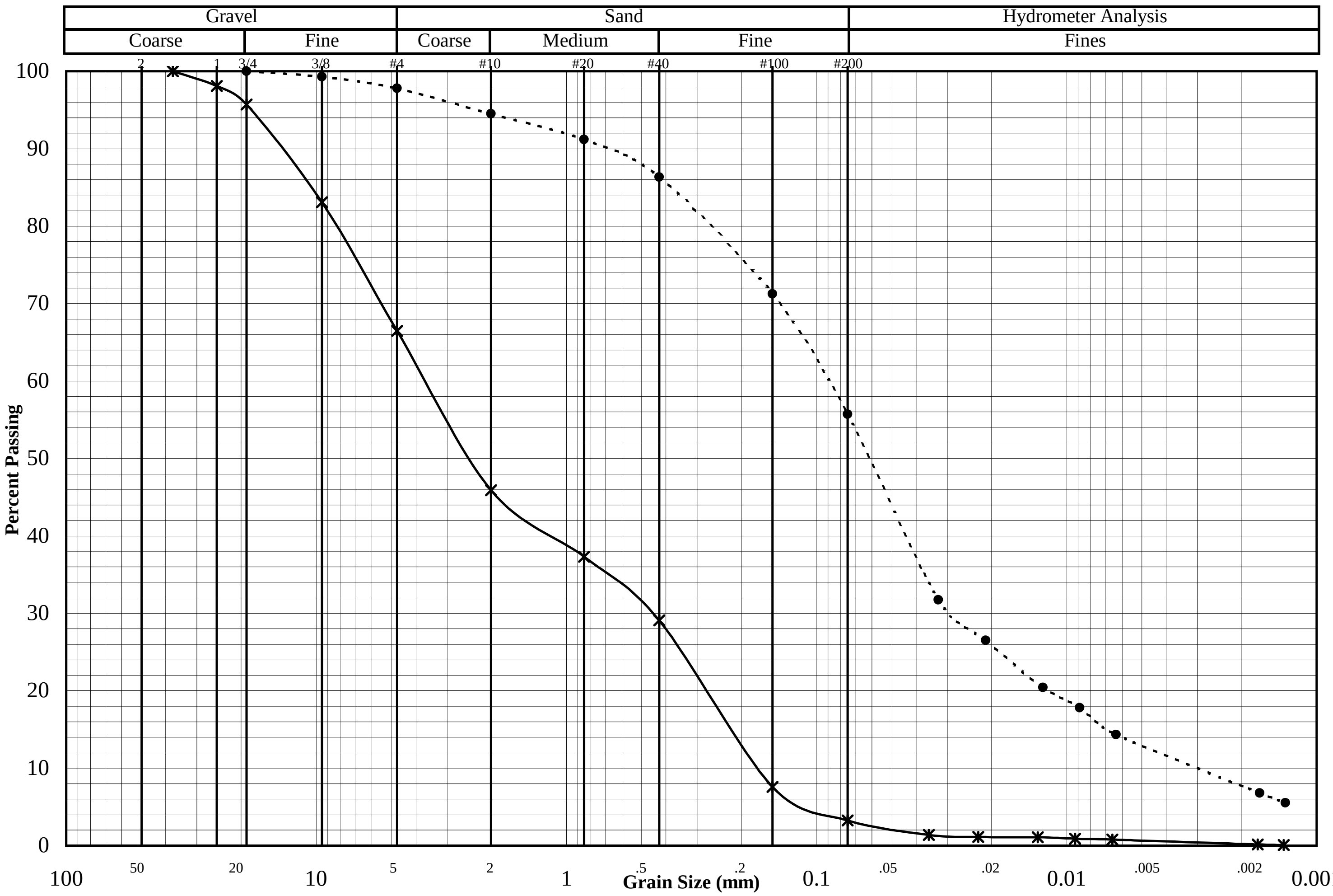
Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts	Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/16/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	Site 6	Bed		Bag	Sand w/gravel, fine to medium grained (SP)
●	Site 6	Bank		Bag	Sandy Lean Clay w/a trace of gravel & organic material (CL)
◇					



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content			
Dry Density (pcf)			
Specific Gravity	2.66*	2.64*	
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	1642.0	284.0	
2"			
1.5"	100.0		
1"	98.1		
3/4"	95.7	100.0	
3/8"	83.1	99.3	
#4	66.5	97.8	
#10	45.9	94.5	
#20	37.3	91.2	
#40	29.1	86.3	
#100	7.6	71.2	
#200	3.3	55.7	

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts	Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/16/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
Spec 1	Site 6	Bed		Bag	Sand w/gravel, fine to medium grained (SP)
Spec 2	Site 6	Bank		Bag	Sandy Lean Clay w/a trace of gravel & organic material (CL)
Spec 3					

Sieve Data

Specimen 1		Specimen 2		Specimen 3	
Particle Size (phi)	% Passing	Particle Size (phi)	% Passing	Particle Size (phi)	% Passing
-6	100.0	-6	100.0		
-5	99.1	-5	100.0		
-4	94.0	-4	99.9		
-3	79.0	-3	99.0		
-2	61.9	-2	97.0		
-1	45.9	-1	94.4		
0	39.0	0	92.0		
1	31.5	1	87.9		
2	17.0	2	78.5		
3	5.0	3	67.0		
4	2.8	4	49.0		
5	1.0	5	30.0		
6	0.9	6	21.4		
7	0.8	7	15.1		
8	0.4	8	11.0		
9	0.1	9	7.0		

Remarks

Specimen 1	Specimen 2	Specimen 3
phi values determined graphically	phi values determined graphically	

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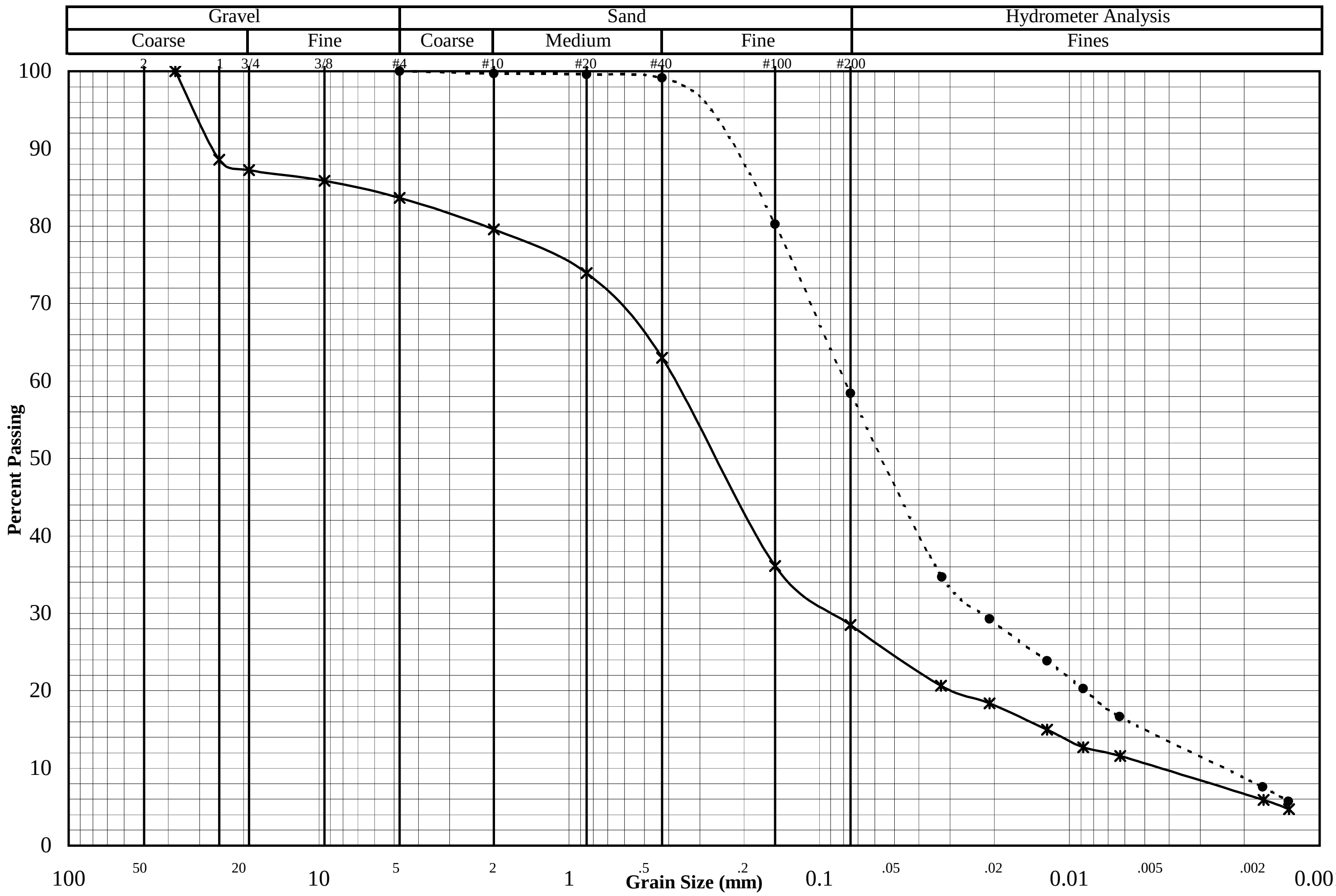
Grain Size Distribution ASTM D422

Project:	Concepts	Job No. :	6079
		Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/16/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	Site 7	Bed		Bag	Clayey Sand w/gravel (SC/SC-SM)
●	Site 7	Bank		Bag	Sandy Lean Clay w/organic material (CL)
◇					



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content			
Dry Density (pcf)			
Specific Gravity	2.66*	2.66*	
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	1242.0	446.0	
2"			
1.5"	100.0		
1"	88.6		
3/4"	87.2		
3/8"	85.8		
#4	83.6	100.0	
#10	79.6	99.7	
#20	73.9	99.6	
#40	63.0	99.2	
#100	36.1	80.3	
#200	28.5	58.4	

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts			Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.			Report Date:	5/16/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
Spec 1	Site 7	Bed		Bag	Clayey Sand w/gravel (SC/SC-SM)
Spec 2	Site 7	Bank		Bag	Sandy Lean Clay w/organic material (CL)
Spec 3					

Sieve Data

Specimen 1		Specimen 2		Specimen 3	
Particle Size (phi)	% Passing	Particle Size (phi)	% Passing	Particle Size (phi)	% Passing
-6	100.0	-6	100.0		
-5	97.0	-5	100.0		
-4	87.0	-4	100.0		
-3	85.5	-3	100.0		
-2	83.0	-2	99.9		
-1	79.6	-1	99.7		
0	75.0	0	99.6		
1	66.8	1	99.4		
2	48.0	2	91.8		
3	32.0	3	71.1		
4	26.2	4	51.6		
5	20.0	5	33.0		
6	15.6	6	25.0		
7	12.0	7	17.5		
8	9.0	8	13.0		
9	5.8	9	7.4		

Remarks

Specimen 1	Specimen 2	Specimen 3
phi values determined graphically	phi values determined graphically	

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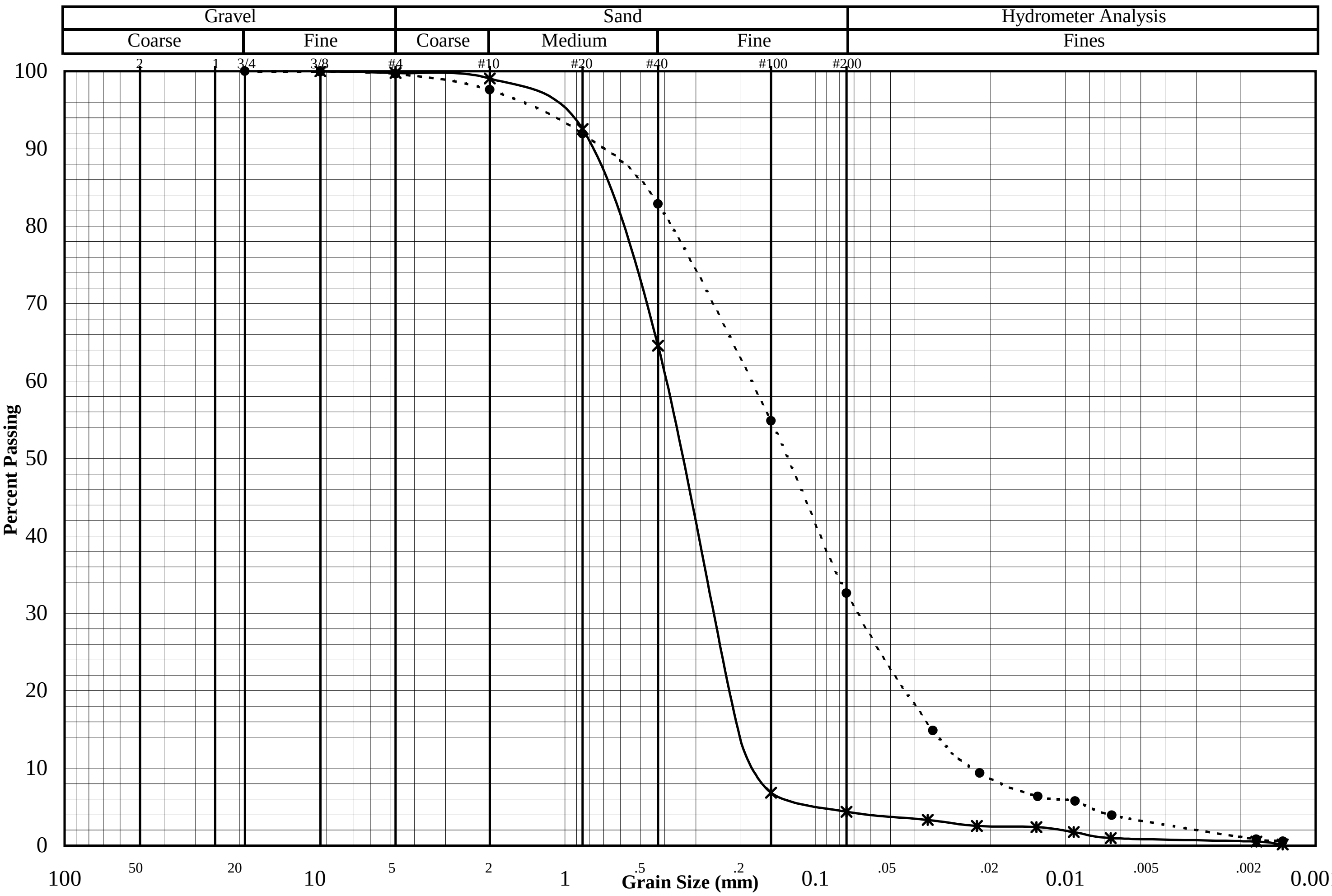
Grain Size Distribution ASTM D422

Project:	Concepts	Job No. :	6079
		Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/16/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	Site 8	Bed		Bag	Sand, fine to medium grained (SP)
●	Site 8	Bank		Bag	Silty Sand w/a trace of organic material (SM)
◇					



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content			
Dry Density (pcf)			
Specific Gravity	2.66*	2.66*	
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	490.6	571.7	
2"			
1.5"			
1"			
3/4"		100.0	
3/8"	100.0	99.9	
#4	99.8	99.7	
#10	99.1	97.6	
#20	92.5	91.9	
#40	64.6	82.9	
#100	6.8	54.8	
#200	4.4	32.6	

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

9301 Bryant Ave. South, Suite 107

SOIL ENGINEERING TESTING, INC.

Bloomington, Minnesota 55420-3436

Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts			Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.			Report Date:	5/16/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
Spec 1	Site 8	Bed		Bag	Sand, fine to medium grained (SP)
Spec 2	Site 8	Bank		Bag	Silty Sand w/a trace of organic material (SM)
Spec 3					

Sieve Data

Specimen 1		Specimen 2		Specimen 3	
Particle Size (phi)	% Passing	Particle Size (phi)	% Passing	Particle Size (phi)	% Passing
-6	100.0	-6	100.0		
-5	100.0	-5	100.0		
-4	100.0	-4	100.0		
-3	100.0	-3	100.0		
-2	100.0	-2	99.5		
-1	99.1	-1	97.6		
0	95.4	0	93.2		
1	73.0	1	86.0		
2	25.0	2	68.0		
3	5.6	3	46.0		
4	4.0	4	27.0		
5	3.1	5	13.0		
6	2.2	6	7.0		
7	1.0	7	4.2		
8	0.3	8	2.4		
9	0.2	9	0.9		

Remarks

Specimen 1	Specimen 2	Specimen 3

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SOIL ENGINEERING TESTING, INC.

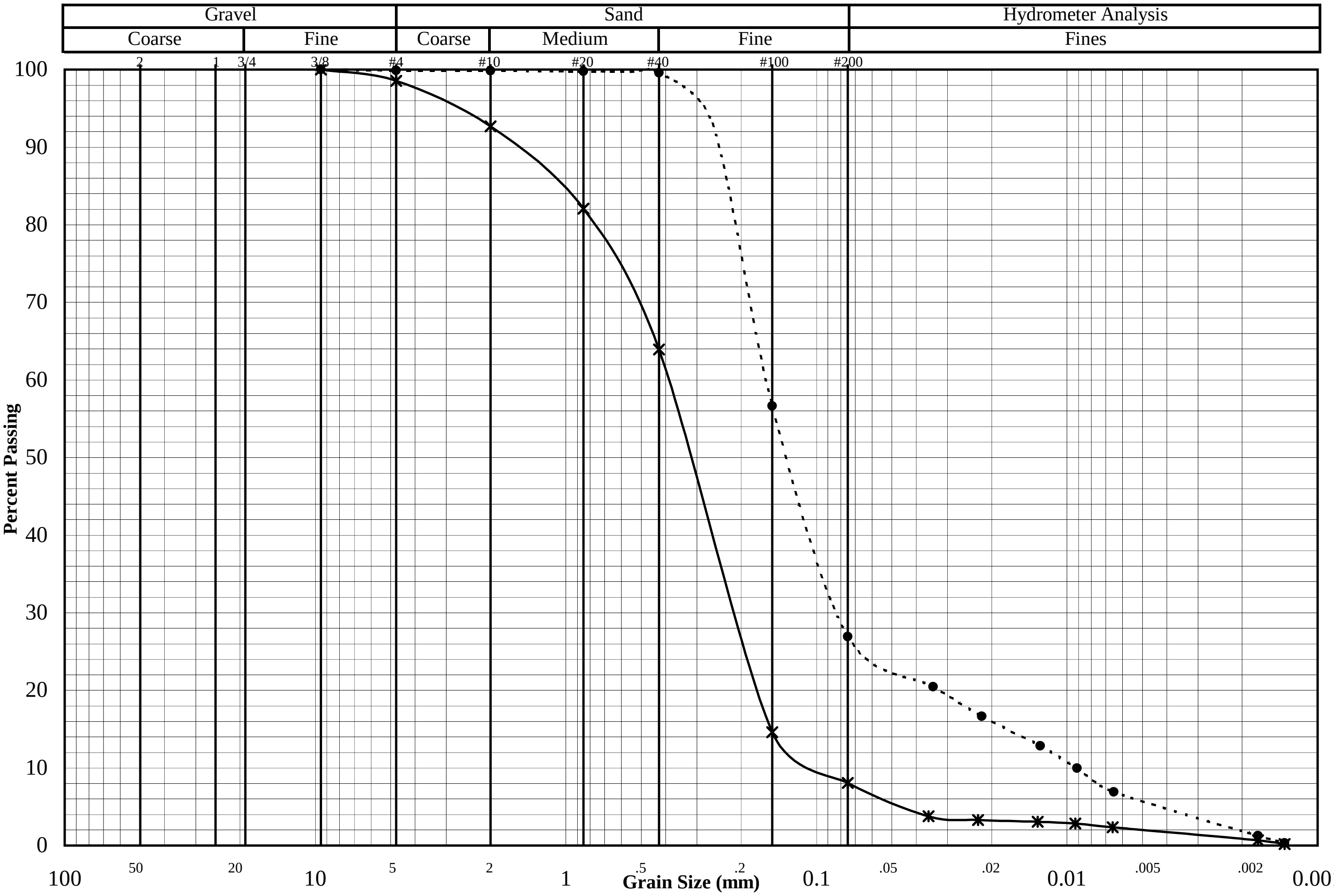
Bloomington, Minnesota 55420-3436

Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts	Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/16/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	Site 9	Bed		Bag	Sand w/silt, fine to medium grained (SP-SM)
●	Site 9	Bank		Bag	Silty Sand w/a trace of organic material (SM/SC-SM)
◇					



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content			
Dry Density (pcf)			
Specific Gravity	2.66*	2.66*	
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	401.0	481.0	
2"			
1.5"			
1"			
3/4"			
3/8"	100.0	100.0	
#4	98.6	* 99.9	
#10	92.7	* 99.8	
#20	82.1	99.8	
#40	63.9	99.6	
#100	14.6	56.6	
#200	8.1	26.9	

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

* Twigs

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SOIL ENGINEERING TESTING, INC.

Bloomington, Minnesota 55420-3436

Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts	Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/16/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
Spec 1	Site 9	Bed		Bag	Sand w/silt, fine to medium grained (SP-SM)
Spec 2	Site 9	Bank		Bag	Silty Sand w/a trace of organic material (SM/SC-SM)
Spec 3					

Sieve Data

Specimen 1		Specimen 2		Specimen 3	
Particle Size (phi)	% Passing	Particle Size (phi)	% Passing	Particle Size (phi)	% Passing
-6	100.0	-6	100.0		
-5	100.0	-5	100.0		
-4	100.0	-4	100.0		
-3	99.5	-3	100.0		
-2	97.7	-2	99.9		
-1	92.7	-1	99.8		
0	85.0	0	99.8		
1	69.0	1	99.7		
2	33.0	2	87.9		
3	10.9	3	47.0		
4	6.8	4	23.0		
5	3.2	5	19.0		
6	3.1	6	13.4		
7	2.6	7	7.2		
8	1.7	8	4.3		
9	0.6	9	1.2		

Remarks

Specimen 1	Specimen 2	Specimen 3
phi values determined graphically	phi values determined graphically	

SOIL ENGINEERING TESTING, INC.

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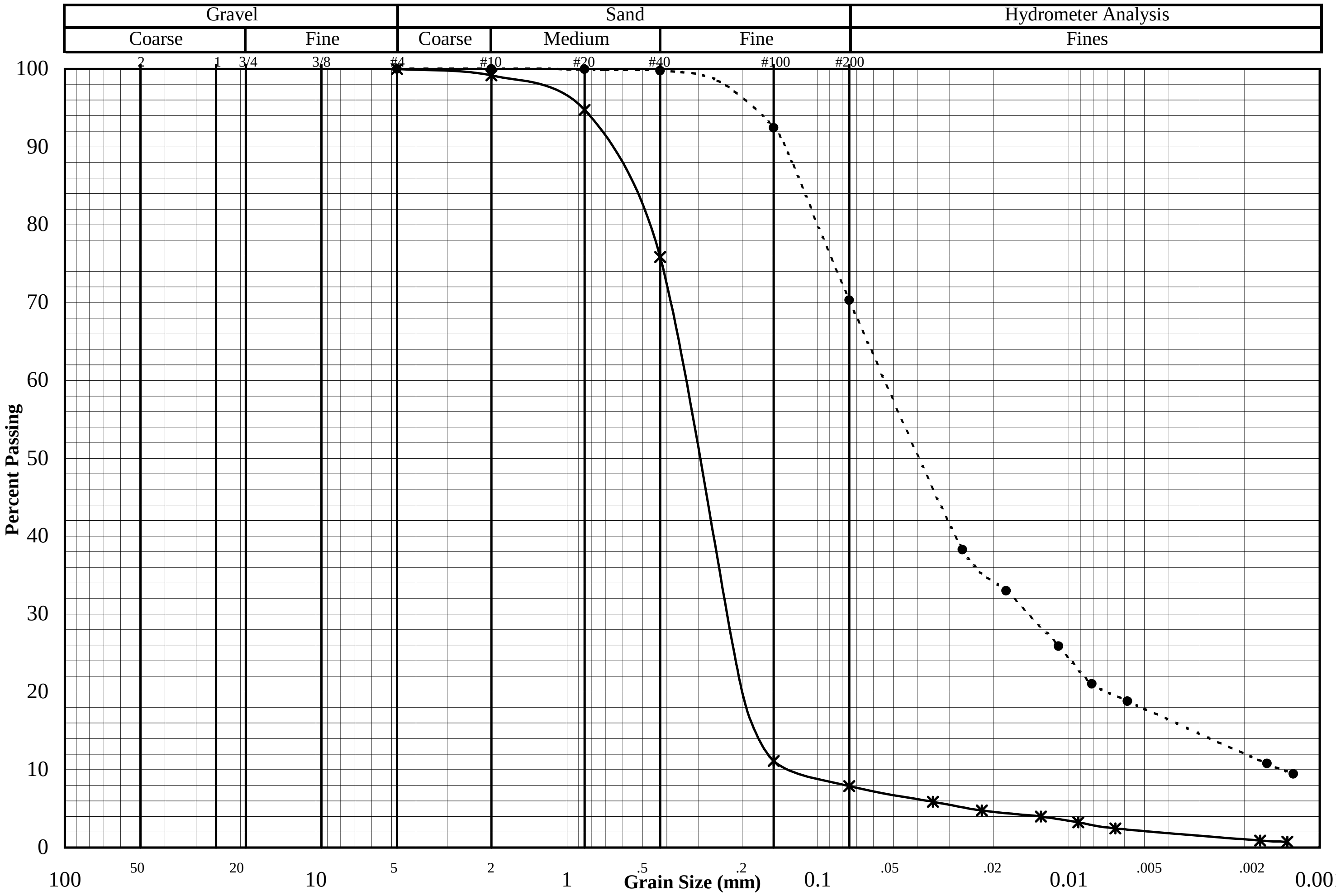
Bloomington, Minnesota 55420-3436

Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts	Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/16/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	Site 10	Bed		Bag	Sand w/silt, fine grained (SP-SM)
●	Site 10	Bank		Bag	Organic Clay w/sand (OL/PT)
◇					



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content			
Dry Density (pcf)			
Specific Gravity	2.66*	2.64*	
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	543.5	193.6	
2"			
1.5"			
1"			
3/4"			
3/8"			
#4	100.0	100.0	
#10	99.2	100.0	
#20	94.8	100.0	
#40	75.8	99.8	
#100	11.1	92.5	
#200	7.9	70.3	

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

Grain Size Distribution ASTM D422

Job No. : **6079**

Project:	Concepts	Test Date:	5/10/07
Reported To:	Emmons and Olivier Resources, Inc.	Report Date:	5/16/07

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
Spec 1	Site 10	Bed		Bag	Sand w/silt, fine grained (SP-SM)
Spec 2	Site 10	Bank		Bag	Organic Clay w/sand (OL/PT)
Spec 3					

Sieve Data

Specimen 1		Specimen 2		Specimen 3	
Particle Size (phi)	% Passing	Particle Size (phi)	% Passing	Particle Size (phi)	% Passing
-6	100.0	-6	100.0		
-5	100.0	-5	100.0		
-4	100.0	-4	100.0		
-3	100.0	-3	100.0		
-2	99.8	-2	100.0		
-1	99.2	-1	100.0		
0	96.8	0	100.0		
1	82.4	1	99.9		
2	33.0	2	98.5		
3	9.3	3	87.6		
4	7.2	4	63.0		
5	5.8	5	41.0		
6	4.1	6	29.2		
7	2.9	7	20.2		
8	1.7	8	15.8		
9	0.9	9	11.3		

Remarks

Specimen 1	Specimen 2	Specimen 3
phi values determined graphically	phi values determined graphically	

9301 Bryant Ave. South, Suite 107

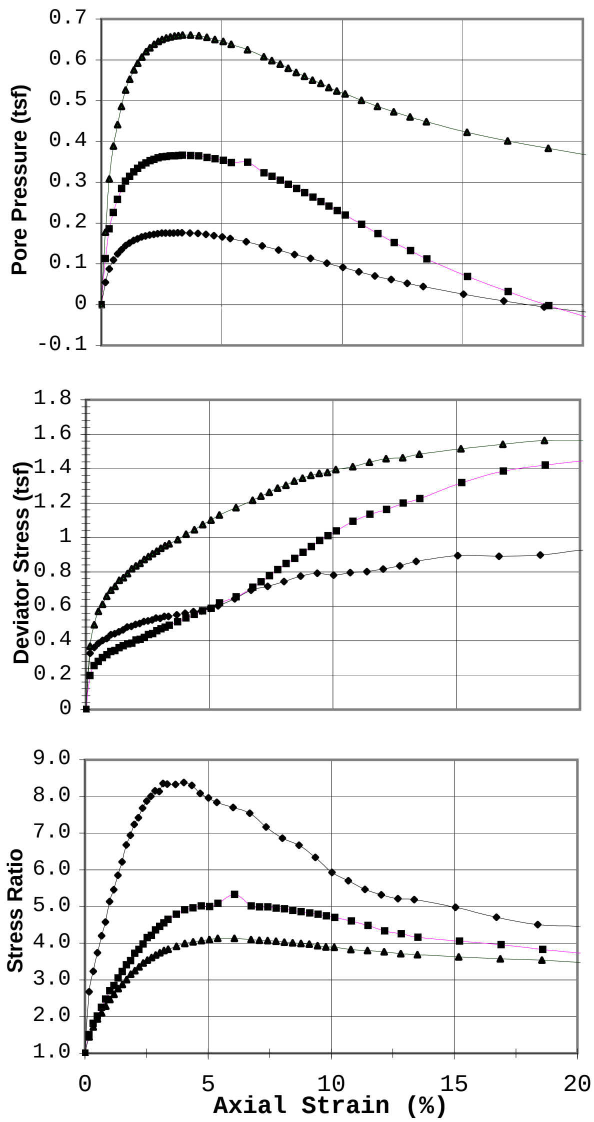
SOIL ENGINEERING TESTING, INC.

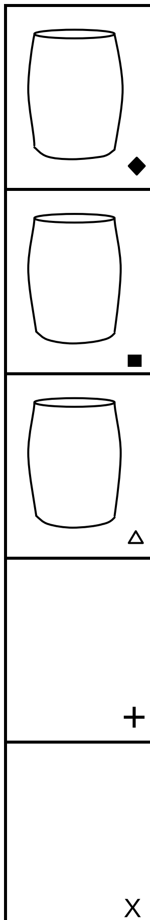
Bloomington, Minnesota 55420-3436

TRIAXIAL TEST ASTM: D 4767

Job No. **6079-A**
Date: **6/7/07**

Project: **Concepts**
Boring #: **Site #3** Sample #: **1** Type: **Cylinder** Depth (ft):
Soil Type: **Lean Clay (CL)**





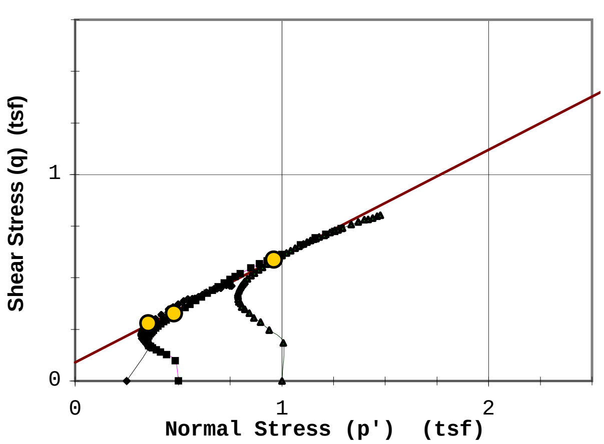
Failure Criterion:	Max. Stress Ratio
Angle of internal friction, ϕ' =	**31.0 °**
Apparent Cohesion, c' =	**0.10 (tsf)**

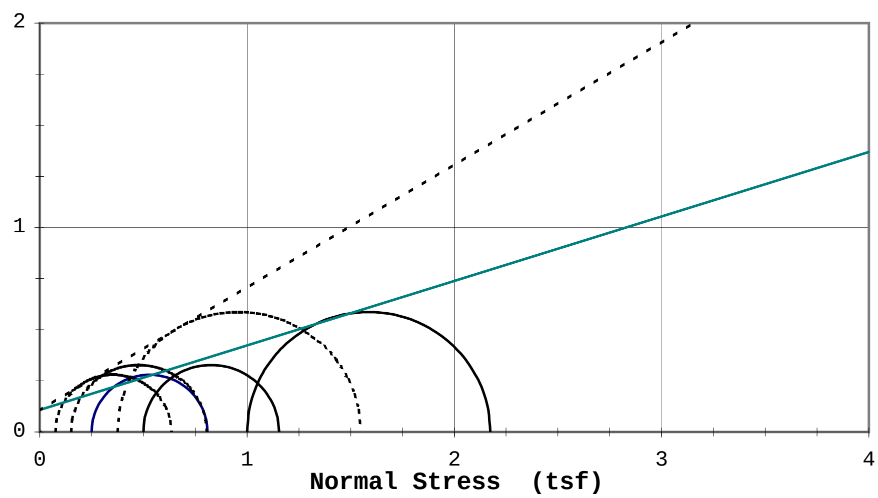
Test Date:	6/1/07	Liquid Limit:	
Test Type:	CU w/pp	Plastic Limit:	
Strain Rate (in/min):	0.003	Plasticity Index:	
Strain Rate (%/min):	0.100	Spec. Gravity (Assumed):	2.68

Before Consolidation	A	B	C	D	E
Diameter (in)	1.45	1.45	1.45		
Height (in)	2.99	2.98	3.00		
Water Content (%)	25.1	24.9	26.8		
Dry Density (pcf)	100.5	100.8	96.8		
Void Ratio	0.67	0.66	0.73		
After Consolidation					
Diameter (in)	1.44	1.43	1.42		
Height (in)	2.99	2.96	2.96		
Water Content (%)	23.9	22.6	23.7		
Dry Density (pcf)	102.0	104.2	102.3		
Void Ratio	0.64	0.61	0.64		
Back Pressure (tsf)	5.8	5.8	5.8		
Minor Principal Stress (tsf)	0.25	0.50	1.00		
Max. Deviator Stress (tsf)	0.94	1.48	1.61		
Ultimate Deviator Stress (tsf)	0.92	1.48	1.61		
Deviator Stress at Failure (tsf)	0.56	0.65	1.17		
Max. Pore Pressure Buildup (tsf)	0.18	0.37	0.66		
Pore Pressure Parameter "B"	1.0	1.0	1.0		
Pct. Axial Strain at Failure	4.0	6.1	6.1		

"These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design"

Remarks: Radial drainage strips applied to trimmed specimen; Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.





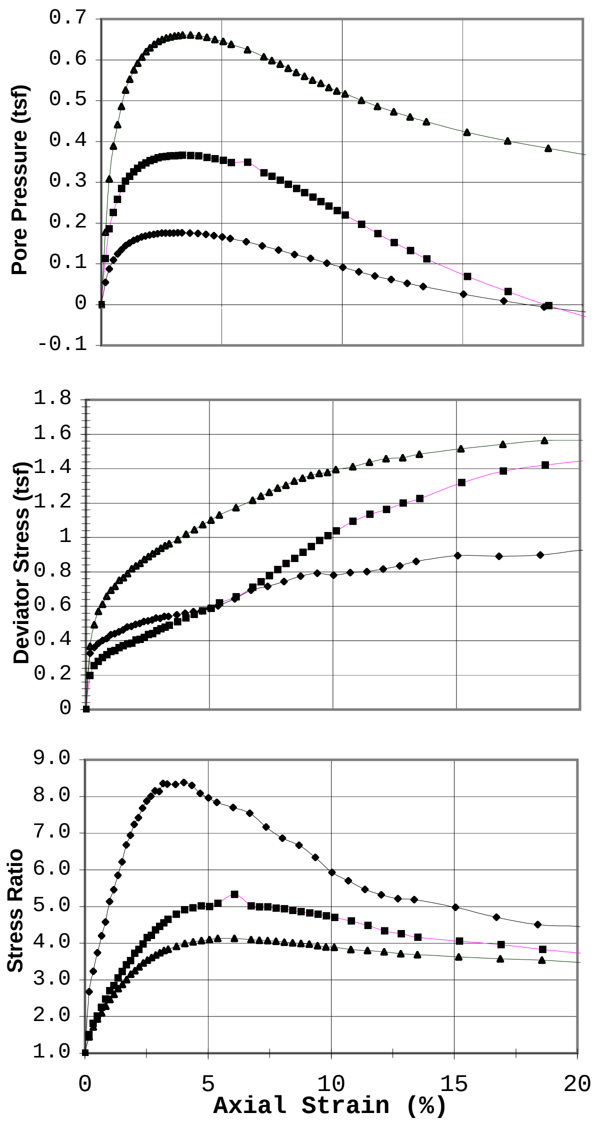
Rupture Envelope at Failure	
α = 27.3 °	a = 0.1 (tsf)

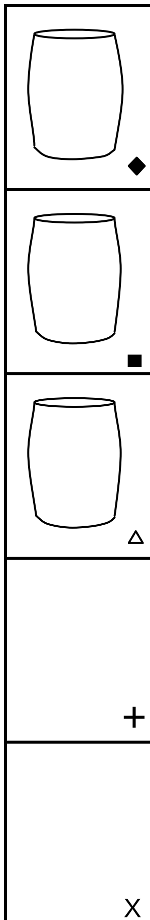
------------	Effective ϕ':	31.0 °	c'=	0.10 (tsf)
________	Total ϕ':	17.5 °	c=	0.11 (tsf)

TRIAXIAL TEST ASTM: D 4767

Job No. **6079-A**
Date: **6/7/07**

Project: **Concepts**
Boring #: **Site #3** Sample #: **1** Type: **Cylinder** Depth (ft):
Soil Type: **Lean Clay (CL)**





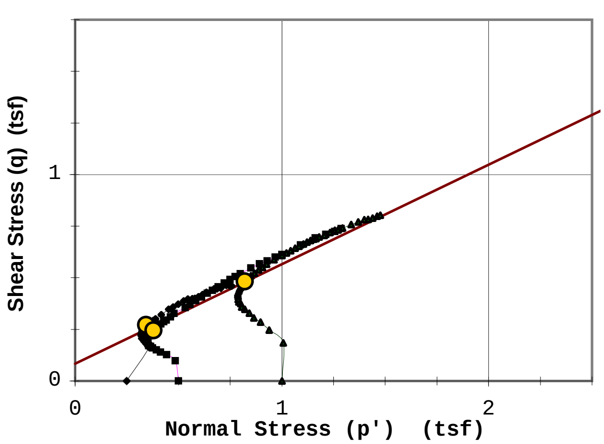
Failure Criterion:	**Max. Pore Pressure**
Angle of internal friction, ϕ '=	**28.8 °**
Apparent Cohesion, c '=	**0.10 (tsf)**

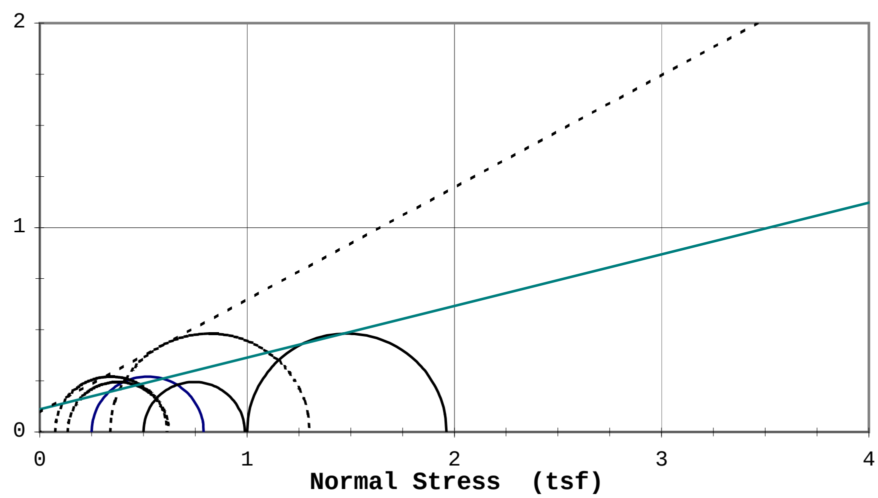
Test Date:	6/1/07	Liquid Limit:	
Test Type:	CU w/pp	Plastic Limit:	
Strain Rate (in/min):	0.003	Plasticity Index:	
Strain Rate (%/min):	0.100	Spec. Gravity (Assumed):	2.68

Before Consolidation	A	B	C	D	E
Diameter (in)	1.45	1.45	1.45		
Height (in)	2.99	2.98	3.00		
Water Content (%)	25.1	24.9	26.8		
Dry Density (pcf)	100.5	100.8	96.8		
Void Ratio	0.67	0.66	0.73		
After Consolidation					
Diameter (in)	1.44	1.43	1.42		
Height (in)	2.99	2.96	2.96		
Water Content (%)	23.9	22.6	23.7		
Dry Density (pcf)	102.0	104.2	102.3		
Void Ratio	0.64	0.61	0.64		
Back Pressure (tsf)	5.8	5.8	5.8		
Minor Principal Stress (tsf)	0.25	0.50	1.00		
Max. Deviator Stress (tsf)	0.94	1.48	1.61		
Ultimate Deviator Stress (tsf)	0.92	1.48	1.61		
Deviator Stress at Failure (tsf)	0.54	0.49	0.96		
Max. Pore Pressure Buildup (tsf)	0.18	0.37	0.66		
Pore Pressure Parameter "B"	1.0	1.0	1.0		
Pct. Axial Strain at Failure	3.2	3.4	3.4		

"These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design"

Remarks: Radial drainage strips applied to trimmed specimen; Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.





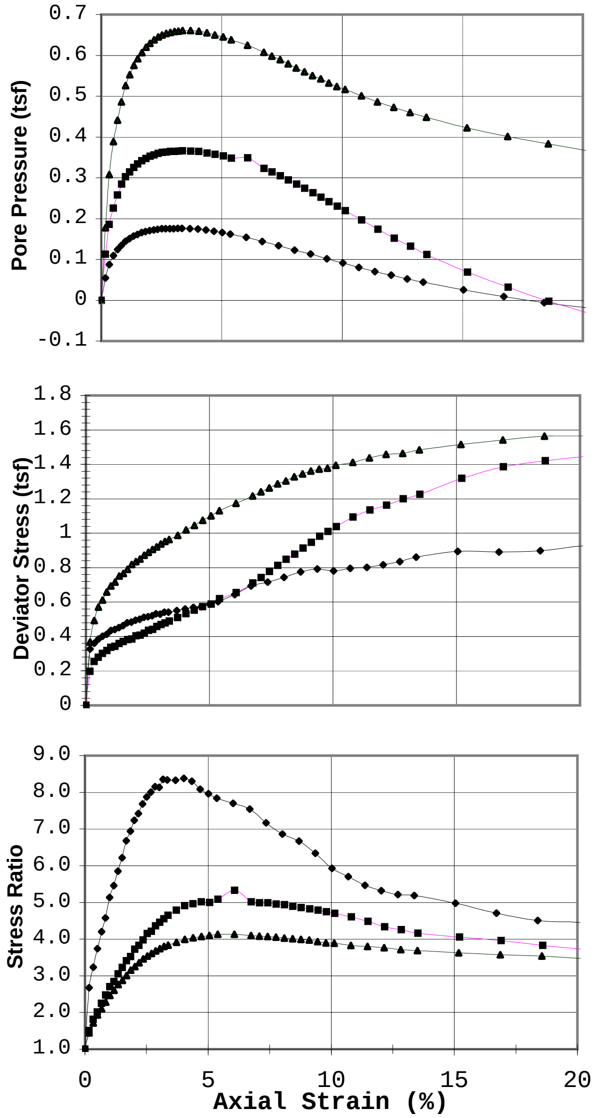
Rupture Envelope at Failure		
α = 25.7 °	a = 0.1 (tsf)	

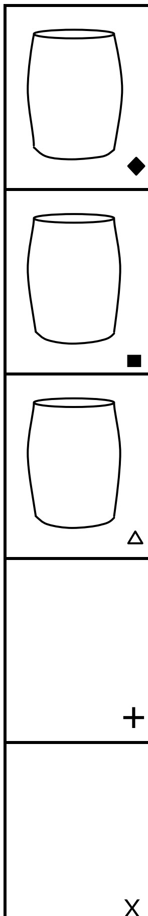
------------	Effective ϕ '	28.8 °	c '=	0.10 (tsf)
________	Total ϕ '	14.2 °	c=	0.11 (tsf)

TRIAXIAL TEST ASTM: D 4767

Job No. **6079-A**
Date: **6/7/07**

Project: **Concepts**
Boring #: **Site #3** Sample #: **1** Type: **Cylinder** Depth (ft):
Soil Type: **Lean Clay (CL)**





Failure Criterion: **Max. Deviator Stress**

Angle of internal friction, ϕ '= **28.0 °**

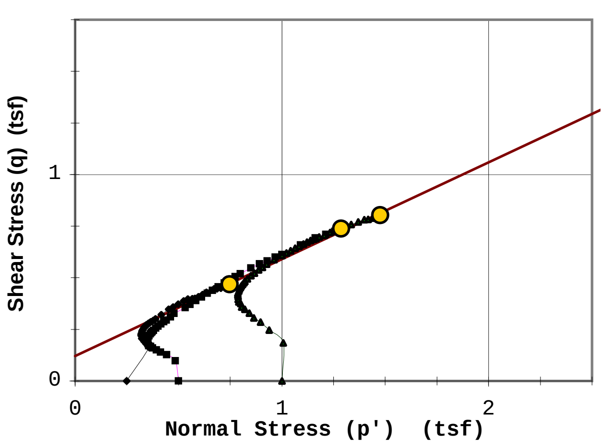
Apparent Cohesion, c '= **0.14 (tsf)**

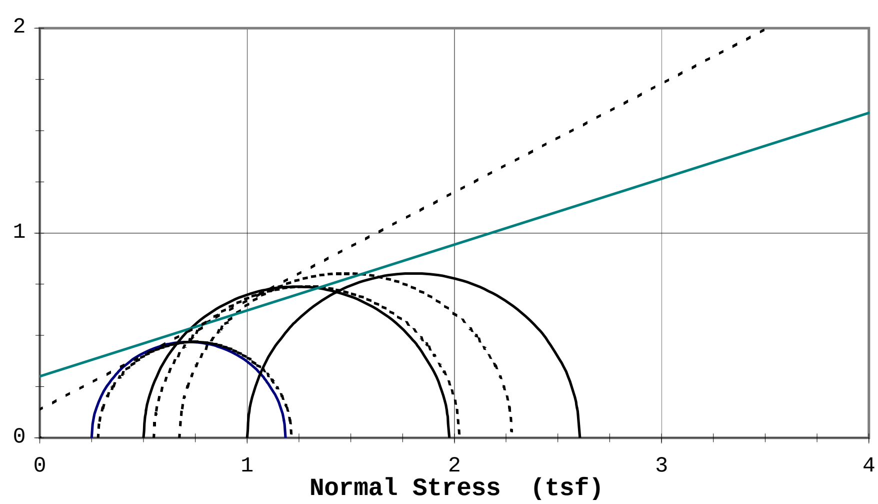
Test Date:	6/1/07	Liquid Limit:	
Test Type:	CU w/pp	Plastic Limit:	
Strain Rate (in/min):	0.003	Plasticity Index:	
Strain Rate (%/min):	0.100	Spec. Gravity (Assumed):	2.68

Before Consolidation	A	B	C	D	E
Diameter (in)	1.45	1.45	1.45		
Height (in)	2.99	2.98	3.00		
Water Content (%)	25.1	24.9	26.8		
Dry Density (pcf)	100.5	100.8	96.8		
Void Ratio	0.67	0.66	0.73		
After Consolidation					
Diameter (in)	1.44	1.43	1.42		
Height (in)	2.99	2.96	2.96		
Water Content (%)	23.9	22.6	23.7		
Dry Density (pcf)	102.0	104.2	102.3		
Void Ratio	0.64	0.61	0.64		
Back Pressure (tsf)	5.8	5.8	5.8		
Minor Principal Stress (tsf)	0.25	0.50	1.00		
Max. Deviator Stress (tsf)	0.94	1.48	1.61		
Ultimate Deviator Stress (tsf)	0.92	1.48	1.61		
Deviator Stress at Failure (tsf)	0.94	1.48	1.61		
Max. Pore Pressure Buildup (tsf)	0.18	0.37	0.66		
Pore Pressure Parameter "B"	1.0	1.0	1.0		
Pct. Axial Strain at Failure	21.7	21.3	25.1		

"These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design"

Remarks: Radial drainage strips applied to trimmed specimen; Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.





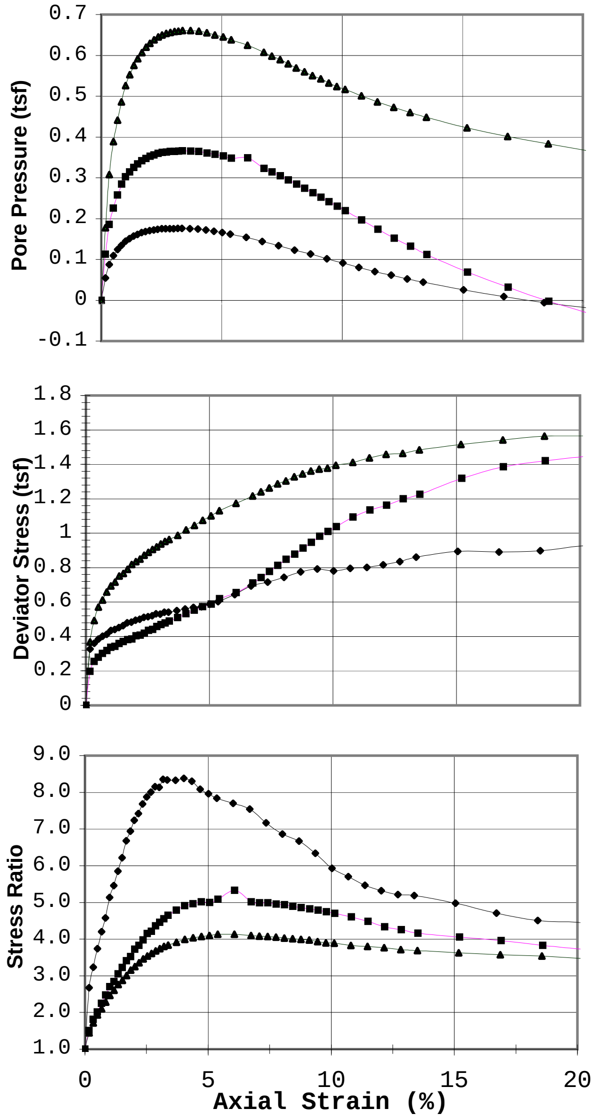
Rupture Envelope at Failure	
α = 25.1 °	a = 0.1 (tsf)

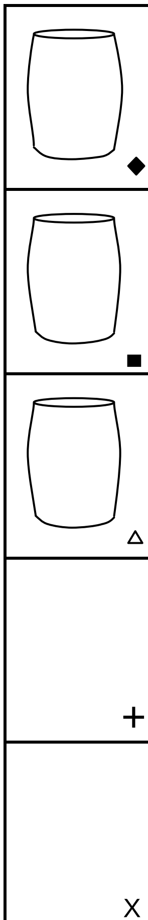
------------	Effective ϕ':	28.0 °	c'=	0.14 (tsf)
________	Total ϕ':	17.8 °	c=	0.30 (tsf)

TRIAXIAL TEST ASTM: D 4767

Job No. **6079-A**
Date: **6/7/07**

Project: **Concepts**
Boring #: **Site #3** Sample #: **1** Type: **Cylinder** Depth (ft):
Soil Type: **Lean Clay (CL)**





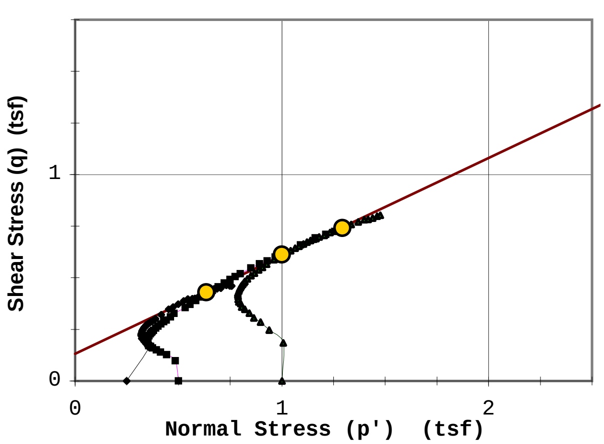
Failure Criterion:	Given Strain of: 15%
Angle of internal friction, ϕ '=	28.3 °
Apparent Cohesion, c '=	0.15 (tsf)

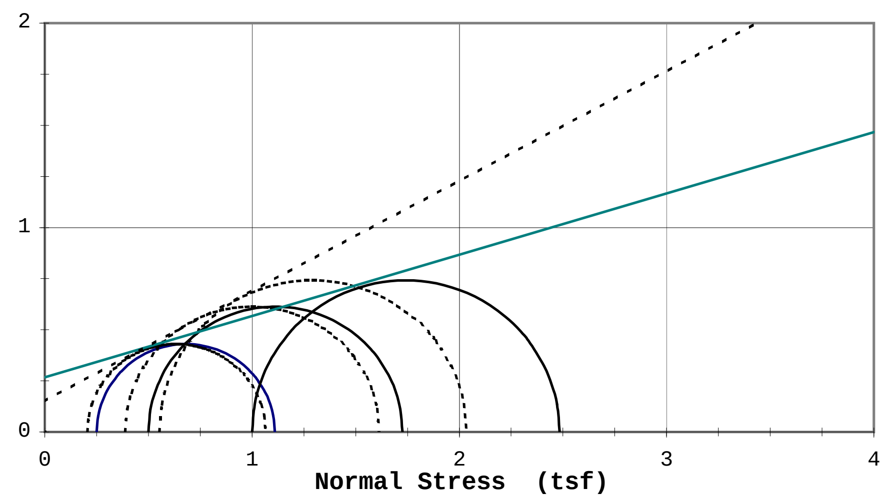
Test Date:	6/1/07	Liquid Limit:	
Test Type:	CU w/pp	Plastic Limit:	
Strain Rate (in/min):	0.003	Plasticity Index:	
Strain Rate (%/min):	0.100	Spec. Gravity (Assumed):	2.68

Before Consolidation	A	B	C	D	E
Diameter (in)	1.45	1.45	1.45		
Height (in)	2.99	2.98	3.00		
Water Content (%)	25.1	24.9	26.8		
Dry Density (pcf)	100.5	100.8	96.8		
Void Ratio	0.67	0.66	0.73		
After Consolidation					
Diameter (in)	1.44	1.43	1.42		
Height (in)	2.99	2.96	2.96		
Water Content (%)	23.9	22.6	23.7		
Dry Density (pcf)	102.0	104.2	102.3		
Void Ratio	0.64	0.61	0.64		
Back Pressure (tsf)	5.8	5.8	5.8		
Minor Principal Stress (tsf)	0.25	0.50	1.00		
Max. Deviator Stress (tsf)	0.94	1.48	1.61		
Ultimate Deviator Stress (tsf)	0.92	1.48	1.61		
Deviator Stress at Failure (tsf)	0.86	1.23	1.48		
Max. Pore Pressure Buildup (tsf)	0.18	0.37	0.66		
Pore Pressure Parameter "B"	1.0	1.0	1.0		
Pct. Axial Strain at Failure	15.0	15.0	15.0		

"These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design"

Remarks: Radial drainage strips applied to trimmed specimen; Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.





Rupture Envelope at Failure	
α = 25.4 °	a = 0.1 (tsf)

------------	Effective ϕ ': 28.3 °	c '=	0.15 (tsf)
________	Total ϕ : 16.7 °	c=	0.27 (tsf)

MEMO

6-8-07

John,

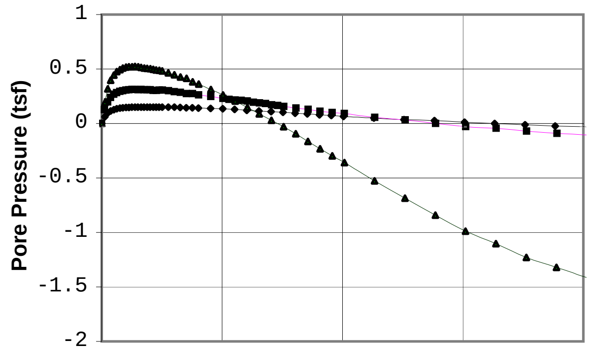
We show the maximum deviator stress and conditions at 15% strain; however because of dilation starting at about 2-3% strain the pore pressure drops dramatically resulting in a gradual increase in deviator stress, thus the high apparent strengths & friction angles at 15% & near 20% (Maximum Deviator Stress Failure Criteria).

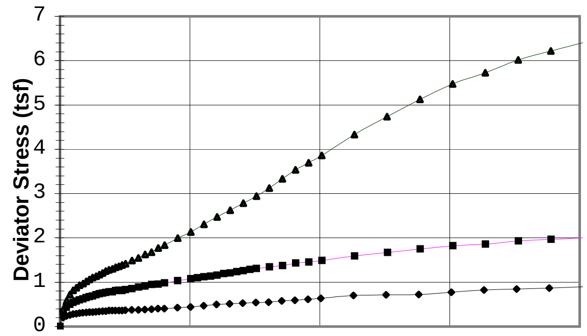
-Gordon Eischens,
Soil Engineering Testing, Inc.

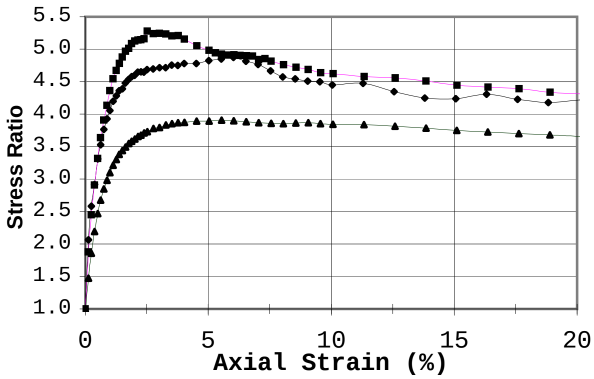
TRIAXIAL TEST ASTM: D 4767

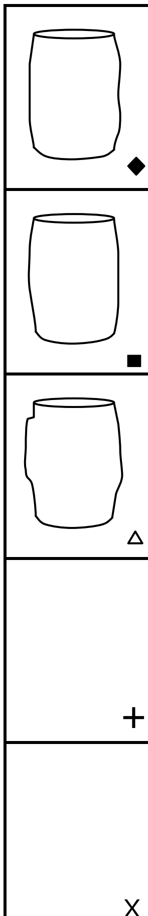
Job No. **6079-A**
Date: **6/8/07**

Project:	**Concepts**				
Boring #:	**Site 8**	Sample #:		Type: **Cylinder**	Depth (ft):
Soil Type:	**Sand, medium to fine grained (SP)**				









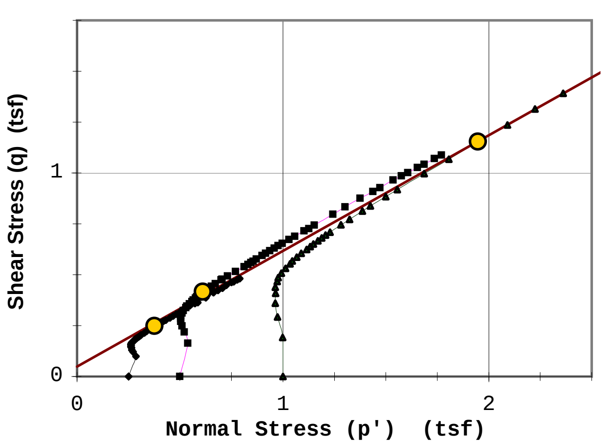
Failure Criterion:	**Max. Stress Ratio**
Angle of internal friction, ϕ' =	**34.6 °**
Apparent Cohesion, c' =	**0.06 (tsf)**

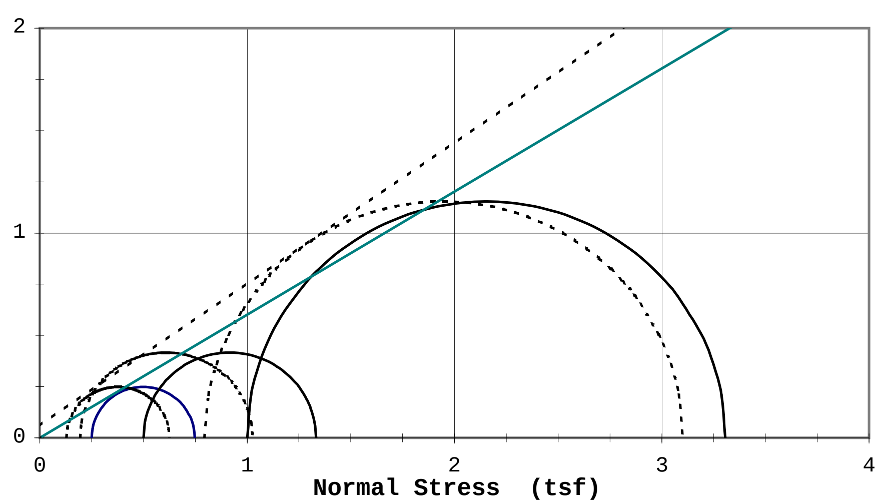
Test Date:	6/4/07	Liquid Limit:	
Test Type:	CU w/pp	Plastic Limit:	
Strain Rate (in/min):	0.004	Plasticity Index:	
Strain Rate (%/min):	0.100	Spec. Gravity (Assumed):	2.67

Before Consolidation	A	B	C	D	E
Diameter (in)	1.94	1.94	1.94		
Height (in)	3.98	3.98	3.98		
Water Content (%)	12.0	14.7	15.0		
Dry Density (pcf)	103.5	103.4	102.7		
Void Ratio	0.61	0.61	0.62		
After Consolidation					
Diameter (in)	1.94	1.94	1.94		
Height (in)	3.98	3.97	3.97		
Water Content (%)	22.7	22.5	22.9		
Dry Density (pcf)	103.8	104.1	103.5		
Void Ratio	0.61	0.60	0.61		
Back Pressure (tsf)	5.8	5.8	5.8		
Minor Principal Stress (tsf)	0.25	0.50	1.00		
Max. Deviator Stress (tsf)	0.96	2.18	6.45		
Ultimate Deviator Stress (tsf)	0.96	2.18	6.45		
Deviator Stress at Failure (tsf)	0.50	0.83	2.31		
Max. Pore Pressure Buildup (tsf)	0.15	0.31	0.52		
Pore Pressure Parameter "B"	1.0	1.0	1.0		
Pct. Axial Strain at Failure	6.0	2.5	5.5		

"These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design"

Remarks: Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.





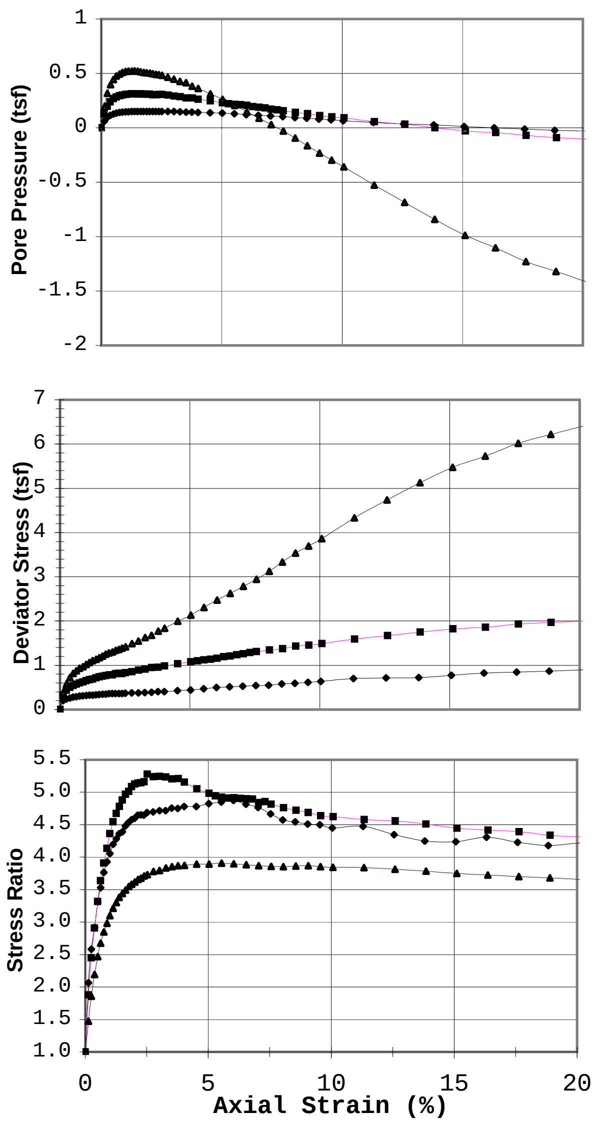
Rupture Envelope at Failure	
α = 29.6 °	a = 0.0 (tsf)

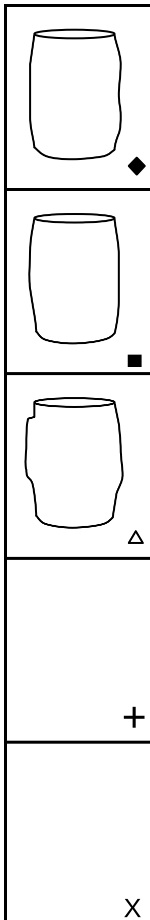
------------	Effective ϕ':	34.6 °	c'=	0.06 (tsf)
________	Total ϕ':	31.0 °	c=	0.00 (tsf)

TRIAXIAL TEST ASTM: D 4767

Job No. **6079-A**
Date: **6/8/07**

Project: **Concepts**
Boring #: **Site 8**   Sample #:   Type: **Cylinder**   Depth (ft):
Soil Type: **Sand, medium to fine grained (SP)**

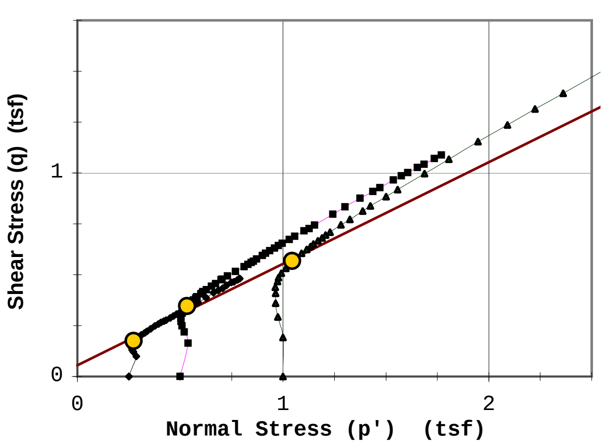


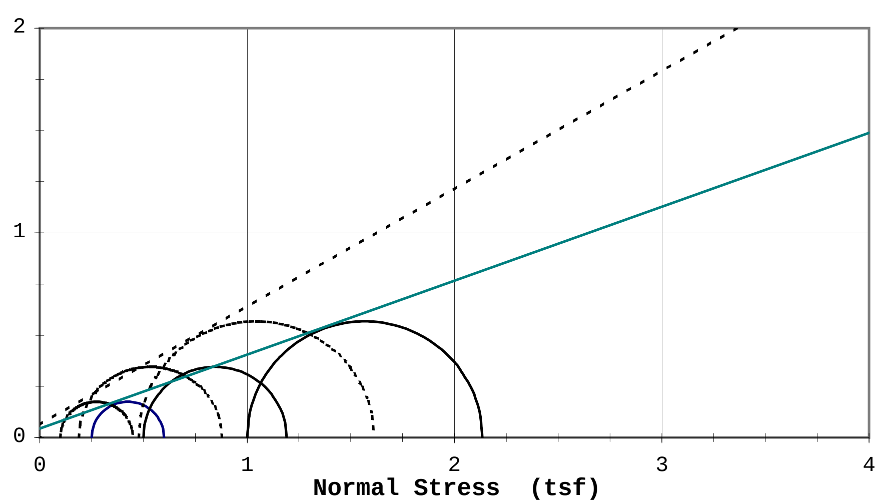


Failure Criterion:	**Max. Pore Pressure**				
Angle of internal friction, ϕ '=	**29.9 °**				
Apparent Cohesion, **c** '=	**0.06 (tsf)**				
Test Date: 6/4/07	Liquid Limit:				
Test Type: CU w/pp	Plastic Limit:				
Strain Rate (in/min): 0.004	Plasticity Index:				
Strain Rate (%/min): 0.100	Spec. Gravity (Assumed): 2.67				
Before Consolidation	**A**	**B**	**C**	**D**	**E**
Diameter (in)	1.94	1.94	1.94		
Height (in)	3.98	3.98	3.98		
Water Content (%)	12.0	14.7	15.0		
Dry Density (pcf)	103.5	103.4	102.7		
Void Ratio	0.61	0.61	0.62		
After Consolidation					
Diameter (in)	1.94	1.94	1.94		
Height (in)	3.98	3.97	3.97		
Water Content (%)	22.7	22.5	22.9		
Dry Density (pcf)	103.8	104.1	103.5		
Void Ratio	0.61	0.60	0.61		
Back Pressure (tsf)	5.8	5.8	5.8		
Minor Principal Stress (tsf)	0.25	0.50	1.00		
Max. Deviator Stress (tsf)	0.96	2.18	6.45		
Ultimate Deviator Stress (tsf)	0.96	2.18	6.45		
Deviator Stress at Failure (tsf)	0.35	0.69	1.14		
Max. Pore Pressure Buildup (tsf)	0.15	0.31	0.52		
Pore Pressure Parameter "B"	1.0	1.0	1.0		
Pct. Axial Strain at Failure	1.8	1.3	1.4		

"These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design"

Remarks: Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.





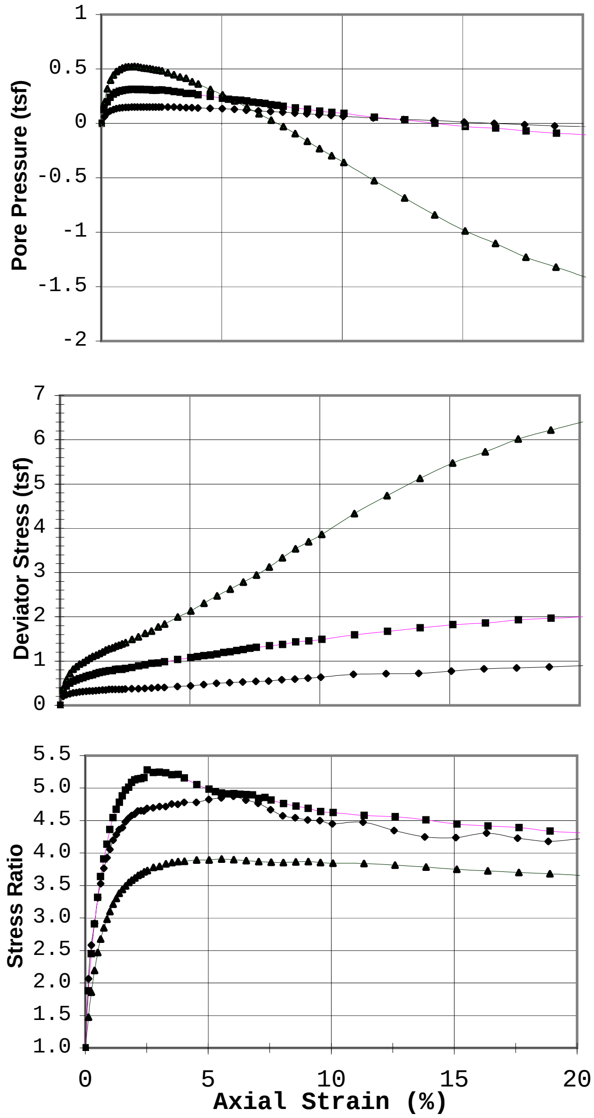
Rupture Envelope at Failure	
α = 26.5 °	a = 0.1 (tsf)

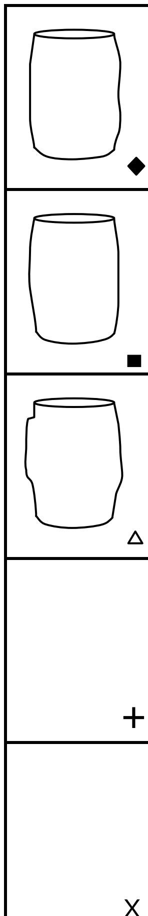
------------	Effective ϕ ':	29.9 °	c '=	0.06 (tsf)
________	Total ϕ ':	19.9 °	c=	0.04 (tsf)

TRIAXIAL TEST ASTM: D 4767

Job No. **6079-A**
Date: **6/8/07**

Project: **Concepts**
Boring #: **Site 8** Sample #: Type: **Cylinder** Depth (ft):
Soil Type: **Sand, medium to fine grained (SP)**



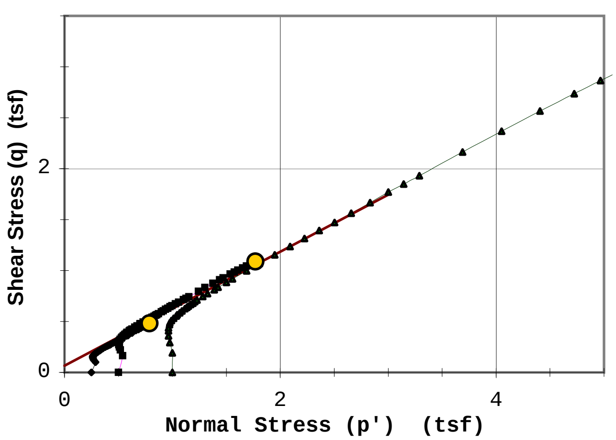


Failure Criterion:	**Max. Deviator Stress**				
Angle of internal friction, ϕ '=	**34.0 °**				
Apparent Cohesion, c '=	**0.08 (tsf)**				
Test Date: 6/4/07	Liquid Limit:				
Test Type: CU w/pp	Plastic Limit:				
Strain Rate (in/min): 0.004	Plasticity Index:				
Strain Rate (%/min): 0.100	Spec. Gravity (Assumed): 2.67				

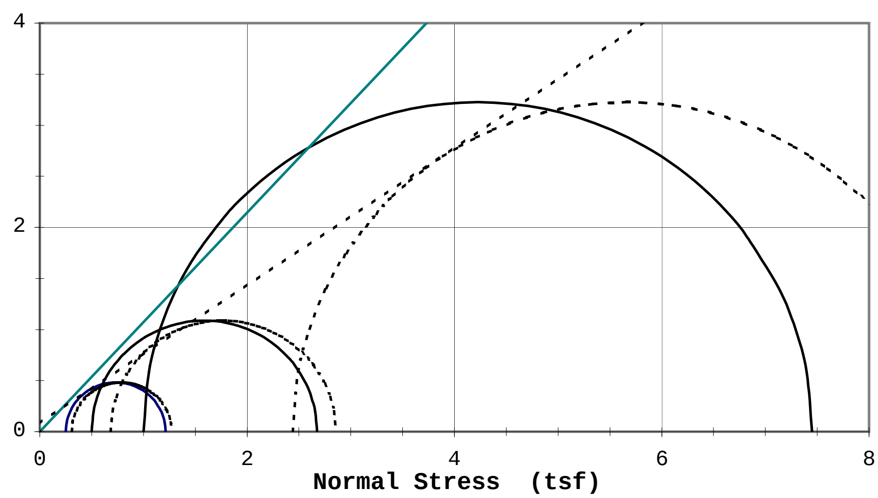
Before Consolidation	A	B	C	D	E
Diameter (in)	1.94	1.94	1.94		
Height (in)	3.98	3.98	3.98		
Water Content (%)	12.0	14.7	15.0		
Dry Density (pcf)	103.5	103.4	102.7		
Void Ratio	0.61	0.61	0.62		
After Consolidation					
Diameter (in)	1.94	1.94	1.94		
Height (in)	3.98	3.97	3.97		
Water Content (%)	22.7	22.5	22.9		
Dry Density (pcf)	103.8	104.1	103.5		
Void Ratio	0.61	0.60	0.61		
Back Pressure (tsf)	5.8	5.8	5.8		
Minor Principal Stress (tsf)	0.25	0.50	1.00		
Max. Deviator Stress (tsf)	0.96	2.18	6.45		
Ultimate Deviator Stress (tsf)	0.96	2.18	6.45		
Deviator Stress at Failure (tsf)	0.96	2.18	6.45		
Max. Pore Pressure Buildup (tsf)	0.15	0.31	0.52		
Pore Pressure Parameter "B"	1.0	1.0	1.0		
Pct. Axial Strain at Failure	25.1	25.0	20.5		

"These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design"

Remarks: Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.



Rupture Envelope at Failure	
α = 29.2 °	a = 0.1 (tsf)

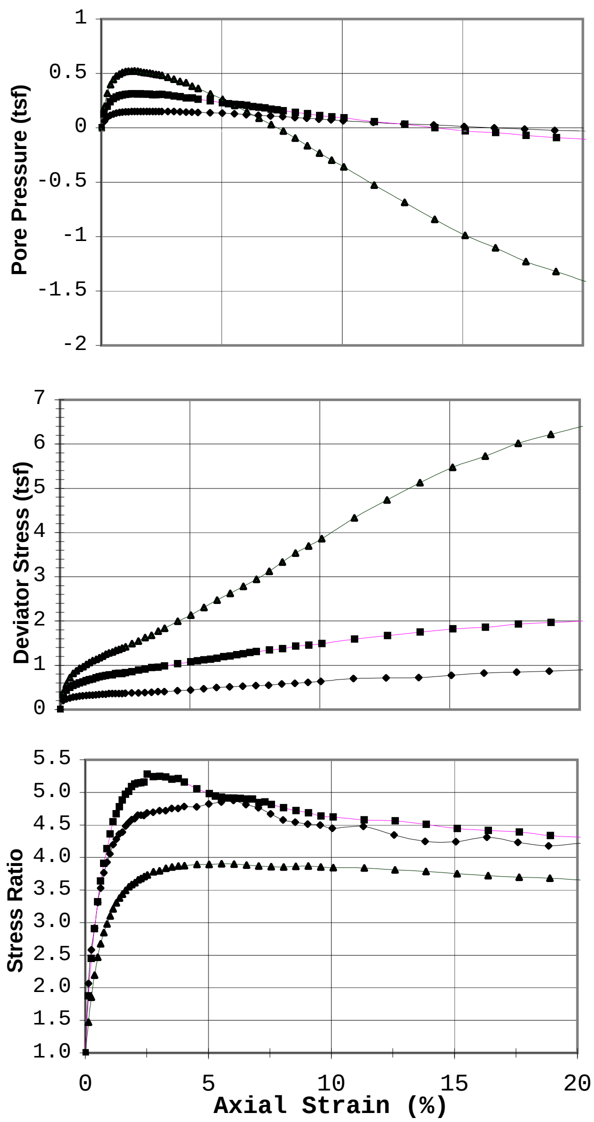


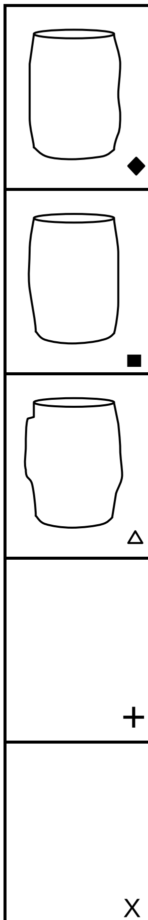
------------	Effective ϕ '=	34.0 °	c '=	0.08 (tsf)
________	Total ϕ '=	47.0 °	c=	0.00 (tsf)

TRIAXIAL TEST ASTM: D 4767

Job No. **6079-A**
Date: **6/8/07**

Project: **Concepts**
Boring #: **Site 8** Sample #: Type: **Cylinder** Depth (ft):
Soil Type: **Sand, medium to fine grained (SP)**

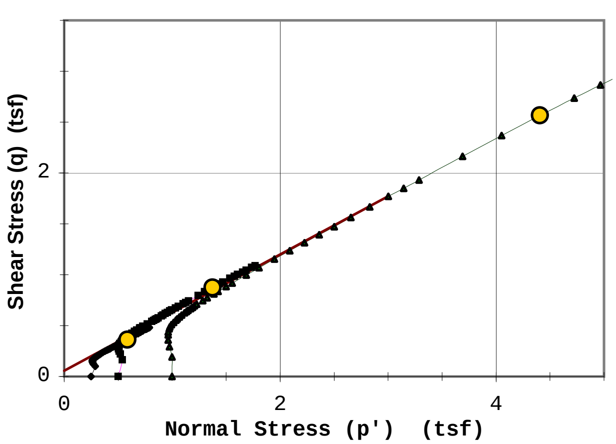


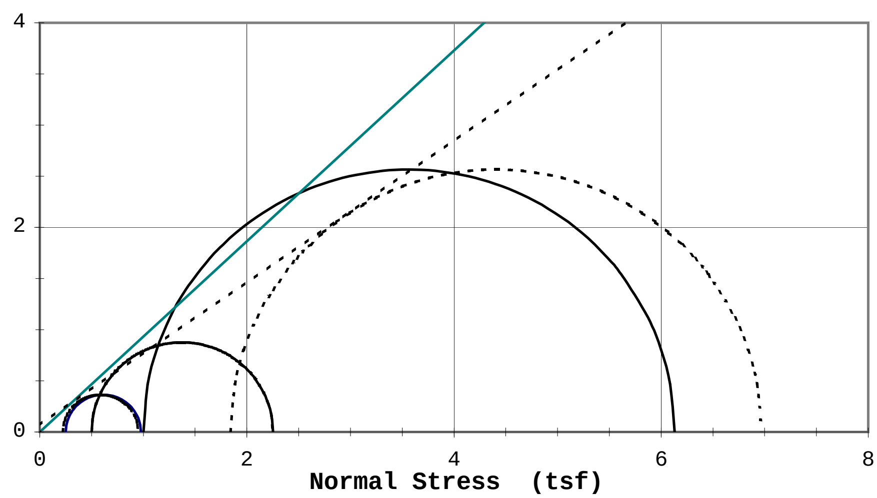


Failure Criterion:		Given Strain of: 15%			
Angle of internal friction, ϕ '=		34.8 °			
Apparent Cohesion, c '=		0.07 (tsf)			
Test Date: 6/4/07		Liquid Limit:			
Test Type: CU w/pp		Plastic Limit:			
Strain Rate (in/min): 0.004		Plasticity Index:			
Strain Rate (%/min): 0.100		Spec. Gravity (Assumed): 2.67			
Before Consolidation	A	B	C	D	E
Diameter (in)	1.94	1.94	1.94		
Height (in)	3.98	3.98	3.98		
Water Content (%)	12.0	14.7	15.0		
Dry Density (pcf)	103.5	103.4	102.7		
Void Ratio	0.61	0.61	0.62		
After Consolidation					
Diameter (in)	1.94	1.94	1.94		
Height (in)	3.98	3.97	3.97		
Water Content (%)	22.7	22.5	22.9		
Dry Density (pcf)	103.8	104.1	103.5		
Void Ratio	0.61	0.60	0.61		
Back Pressure (tsf)	5.8	5.8	5.8		
Minor Principal Stress (tsf)	0.25	0.50	1.00		
Max. Deviator Stress (tsf)	0.96	2.18	6.45		
Ultimate Deviator Stress (tsf)	0.96	2.18	6.45		
Deviator Stress at Failure (tsf)	0.73	1.75	5.13		
Max. Pore Pressure Buildup (tsf)	0.15	0.31	0.52		
Pore Pressure Parameter "B"	1.0	1.0	1.0		
Pct. Axial Strain at Failure	15.0	15.0	15.0		

"These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design"

Remarks: Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.





Rupture Envelope at Failure	
α = 29.7 °	a = 0.1 (tsf)

------------	Effective ϕ': 34.8 °	c '=	0.07 (tsf)
________	Total ϕ': 43.0 °	c=	0.00 (tsf)

SET Job#: 6079-A

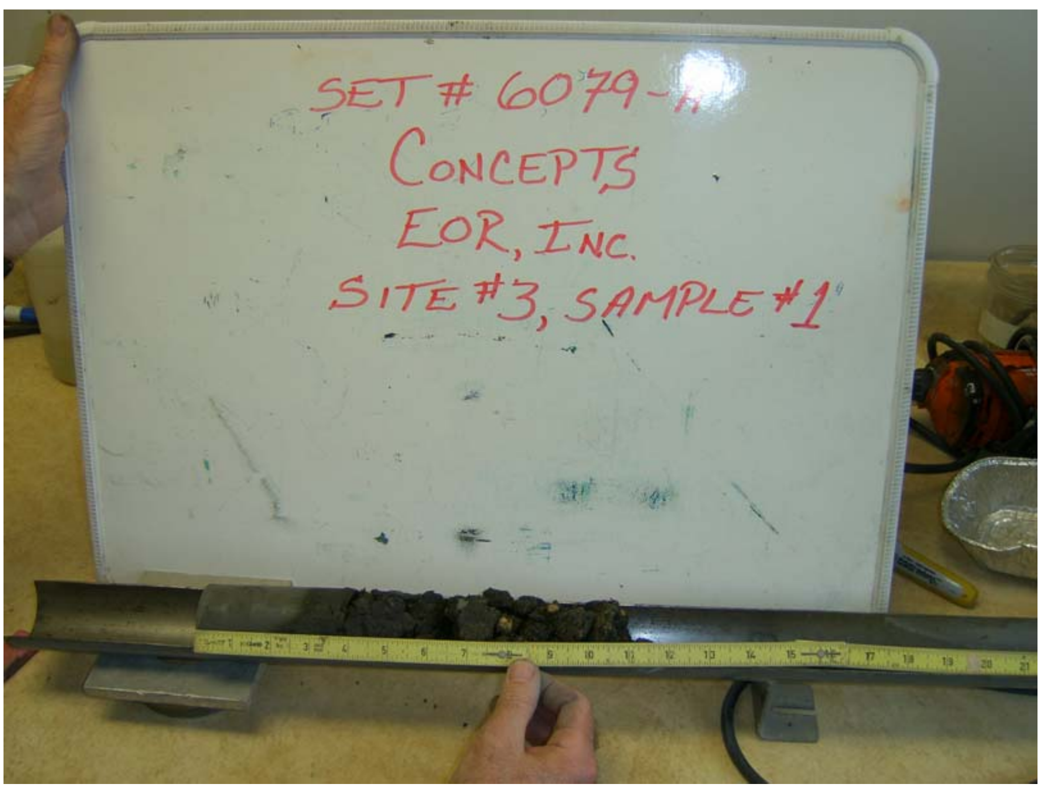
Extrusion Log

Date: 5-29-07

Project/Client: CONCEPTS

Boring #	Sample#	Depth(ft)	Recovery (in)		Soil Description
SITE #3	1		BE:	≈5	TOP ≈ 1" SILTY SAND W/A LITTLE GRAVEL, DARK BROWNISH GRAY AND GRAYISH BROWN AND A LITTLE BLACK, MOIST, W/A LITTLE ORGANIC MATERIAL, (SM)
			AE:	≈5	MID. ≈ 1½" ORGANIC CLAY W/A TRACE OF GRAVEL, A FEW ROOTS AND ROOTLETS, DARK GRAY AND BLACK W/A FEW LAMINATIONS OF SAND W/SILT AND SILTY SAND (OH)
					BOT. ≈ 2½" LEAN CLAY, LIGHT GRAY, W/A FEW LAMINATIONS OF SILT AND SILTY CLAY, (CL/CL-ML)

Soil Testing Sample Photos



9. References

Chang, HH. 1998. Fluvial process in river engineering. Krieger Publishing, Malabar, FL.

Hanson, G.J. and A. Simon. 2001. Erodibility of cohesive streambeds in the loess area of the Midwestern USA. *Hydrological Processes* 15:23-38.

Langendoen, E.J. 2000. CONCEPTS – Conservation channel evolution and pollutant transport system. Research Report No. 16, US Department of Agriculture, Agricultural Research Service. National Sedimentation Laboratory, Oxford, MS.

Rice Creek Watershed District. 2004. Washington County Judicial Ditch #2 Repair Report.

Runkel, R.L., Crawford, C.G., and Cohn, T.A., 2004, Load Estimator (LOADEST): A FORTRAN Program for Estimating Constituent Loads in Streams and Rivers: U.S. Geological Survey Techniques and Methods Book 4, Chapter A5, 69 p.

Torri, D., M. Sfalanga, and G. Chisci. 1987. Threshold conditions for incipient rilling. In: R.B. Bryan (ed.): Rill erosion – Processes and Significance; Catena Supplement 8, Catena Verlag, Cremlingen-Destedt, 97-105.

Appendix D. Ditch Maintenance BMPs

Outline for Ditch Maintenance BMP section of Hardwood Creek TMDL Plan

Background/Description of Public Drainage System within the Hardwood Creek watershed

The Public Drainage System within the Hardwood Creek watershed is comprised of 3 judicial ditches which include Anoka/Washington Judicial Ditch 2 (AWJD2) and Washington Judicial Ditches 5 & 7 (WJD5 & WJD7). AWJD2 is an open ditch and generally follows the original course of Hardwood Creek as it flows north out of Rice Lake to approximately 165th Street North where the ditch ends and turns back into a natural watercourse terminating at Peltier Lake. From its origin at 165th St North to its terminus south of Rice Lake the ditch is approximately 9.6 miles in length. AWJD2 has two branches, south of Rice Lake that are approximately 2 miles in length. WJD5 and WJD7 are tile systems that outlet to AWJD2 and are approximately 6.1 miles in length. The Rice Creek Watershed District is the legal drainage authority of the systems under Minnesota Statutes 103E. As a metropolitan watershed district it also uses its authority under Minnesota Statues 103 B and 103D to operate and maintain the drainage system. In this particular situation the Rice Creek Watershed District has an agreement with the City of Hugo to inspect and perform maintenance of AWJD2 and its branches,

The drainage system flows through a number of soil associations as shown in Exhibit 1. The soil associations range from floodplain alluvium in the un-ditched portions of Hardwood Creek to loamy tills and organic deposits for the remainder of the ditched and tiled portions of the public drainage system in the Hardwood Creek watershed. There are a few small areas of mixed till and sandy till in the far northern reaches of the system. The gradient of the drainage system ranges from very flat (almost no grade) in the organic soil to having moderate grades in the glacial till soils. This range of soils, and accompanying ditch grades, supports the tiered approach to selection of BMPs for drainages system maintenance projects within this system as follows.

Base BMPs (to be incorporated into SWPPs for all maintenance operations)

- Pre-construction
  - Acquire all necessary WCA determinations
  - Construction entrance protection
- Spoil Placement
  - Excavated material (spoil) will be placed so there is a minimum of a 5 to 10 foot separation between the top edge of the ditch side slope and spoil. If rotational slumping due to placement of spoil pile occurs, the spoil pile must be flattened or moved further from the top edge of the ditch side slope.
- Soil Stockpile Protection
  - Install silt fence around stockpiled material. Use temporary stabilization measures, as appropriate, if the stockpile is to remain in place for more than 7 days.
- Inspection & maintenance
  - Daily inspection of work site, including marking of new disturbed ditch segments, and segments that have been stabilized
  - Weekly meeting with contractor, City & Watershed District

  - Defined process for communication with, and response by, contractor when BMP implementation is not in compliance with plans and specs, or found to be inadequate.
- Stabilization of disturbed areas
  - Ditch segments (each 2000 foot stretch of ditch) will be stabilized with temporary or permanent measures within 3 days of completion of ditch maintenance in that segment. Installation of erosion control blanket and seed on ditch side slopes must be completed within 14 days of completion of the entire ditch maintenance project.
  - Ditch side-slopes that are disturbed from maintenance activities will be stabilized with Category 2 blanket starting at the normal water level and extending up to top of slope and toed in (trenched and backfilled to anchor blanket) Category 4 (coconut fiber) blanket with bionet will be used where small radius outside bends are encountered.
  - Any seed mix used needs to include ryes or other quick growing cover crop type of erosion control vegetation. Note: BWSR W2 mix (dormant) does not contain a cover crop.
- Staging
  - To the extent practical, plan ditch maintenance operations to minimize the area of disturbed and unstabilized soil during maintenance operations.
  - A maximum of 3000 lineal feet of ditch can be disturbed at one time without temporary or permanent cover on the segments where maintenance operations are complete.

Additional BMPs based on soils and channel vegetation conditions

- In-ditch
  - Floating silt fence placed in a herringbone arrangement upstream of all culvert locations in the project area. (this is included as a BMP to pilot, but not commit to using at every road crossing until it is demonstrated to be practical and effective in the Hardwood Creek conditions.)
  - Temporary in-line sediment basins, where appropriate for the soil conditions, planned construction time period and erosion potential during maintenance operations. The temporary pond will be restored to its original condition once the areas upstream are stabilized.

- Seasonal Timing
  - When feasible, all maintenance will occur during fall and winter to coincide with probable lowest flow conditions.

Additional BMPs based on observed exceedences. (These will be selected and utilized on a case by case basis)

- Water by-pass or diversion (full or partial) using pumps and conduits during ditch maintenance and stabilization operations, with energy dissipation at the outlet of the conduit.

- Use Rain-for-rent or similar sand filtration unit downstream of area being worked to filter turbid water and discharge clear water back into creek

EXHIBIT 1