NPDES Field Studies Report – Tailings Basin

Prepared for
Cliffs Erie L.L.C. and
PolyMet Mining Inc.

September 2011

BARR

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1.0 Introduction

1.1 Background

The former LTV Steel Mining Company (LTVSMC) tailings basin is located in two local watersheds and is administered by two separate NPDES Permits. The general site layout is shown on Figure 1-1. Tailings basin surface seepage to the north (toward the Embarrass River via SD001, SD002, SD004, SD005, and SD006) is covered under Minnesota Pollution Control Agency (MPCA) NPDES Permit MN0054089. The Permit is currently held by Cliffs Erie L.L.C. (CE). However, PolyMet Mining Inc (PolyMet) is collaborating with CE on the reissuance of the Permit. A key aspect of the Permit renewal process will be the implementation of corrective actions defined in the April 6, 2010 Consent Decree between MPCA and CE. The work required under the Consent Decree is designed to address selected chemical parameters that have had elevated concentrations in the surface seepage (SD002, SD004, and SD006) and in groundwater monitoring wells (GW006 and GW007). A one-year program of field study investigations (ending on June 16, 2011) was conducted at the site, following the scope of work described in the May 6, 2010 *NPDES Field Studies Plan – Tailings Basin* (approved by the MPCA on June 16, 2010). This Field Studies Report provides a summary of the results from the individual field studies that were conducted for the tailings basin under the Consent Decree.

In addition to this Field Studies Plan, the Consent Decree requires the preparation of a Short Term Mitigation Evaluation Plan for the tailings basin. The objectives of the Short Term Mitigation Evaluation Plan are to investigate existing methods and technologies to partially or completely mitigate the elevated sulfate and elevated parameters of concern in surface discharges and in groundwater at the property boundary. Sulfate concentrations are elevated at all monitoring locations (SD001, SD002, SD004, SD006, GW001, GW006, GW007 and GW008). The Short Term Mitigation Evaluation Plan is intended to address and mitigate the existing elevated concentrations of sulfate and the parameters of concern to the extent feasible and practical during the period that field studies are being conducted to determine an appropriate long-term mitigation strategy. Depending on the outcome of the field studies and the associated development of a long-term mitigation strategy that adequately addresses water quality concerns, the ongoing need for short-term mitigation/treatment may be re-evaluated in the future. In addition, the short-term mitigation/treatment may be incorporated, in whole or in part, into the long-term mitigation strategy as appropriate.

As part of Short Term Mitigation under the Consent Decree, seepage collection and pumpback systems were constructed and were placed into operation during the summer of 2011 following completion of the field studies summarized in this document. Seepage from the tailings basin that formerly flowed from SD004 and SD006 is currently being collected and pumped to the tailings basin.

Legal and technical justification for removal of surface discharges SD001 and SD002 from permit MN0054089 was presented and accepted in the Short Term Mitigation Evaluation Plan.

For the purposes of this document, 'parameters of concern' vary depending upon the monitoring location, as follows:

SD006: bicarbonates, specific conductance
SD004: bicarbonates, total boron, total hardness (Ca + Mg as CaCO3), dissolved iron, specific conductance, turbidity
GW001: dissolved manganese, total dissolved solids (TDS)
GW006/GW007: dissolved manganese, dissolved molybdenum, TDS

1.2 Overall Objectives

The purpose of the Field Studies for the tailings basin was to develop an understanding of the potential impacts of the elevated concentrations of sulfate and parameters of concern in the surface seeps and in the groundwater at the property boundary and to collect adequate data to support either the development of recommendations for long-term mitigation alternatives or the development of site-specific standards. The Field Studies collected data to assess:

- The impact of the elevated sulfate in surface discharges and groundwater on receiving waters that support the production of wild rice

- The impact of the elevated sulfate in surface discharges and groundwater on methylmercury concentrations in receiving waters

- The impact of elevated parameters of concern in surface discharges on the water quality and aquatic life (fish and macroinvertebrates) of receiving waters.

2.0 Historical Data Compilation

2.1 Objectives

The primary objective of historical data compilation was to: identify, compile, and review readily available information regarding the tailings basin site setting, water quality, hydrology, and hydrogeology. This activity was substantially completed in support of determining the detailed scope of the individual studies described in the *NPDES Field Studies Plan – Tailings Basin*. This review of available information allowed for a more complete understanding of the site prior to designing the field studies.

2.2 Scope / Sources of Information

The following general sources of information were compiled and reviewed. Specific sources of information reviewed for the individual studies were described in detail in the *NPDES Field Studies Plan – Tailings Basin*:

- Permit monitoring data (water quality and flow)
- Other relevant data from field studies at the tailings basin (seepage computations, supplemental groundwater monitoring)
- Data from completed and ongoing studies related to the environmental review for PolyMet's NorthMet Project
- Published reports and maps regarding local geology, hydrogeology, and water quality

3.0 Groundwater Investigation

3.1 Background

As described in Section 1.0, groundwater samples from monitoring wells located at the northern (GW001, GW006) and western (GW007) perimeter of the tailings basin have concentrations that exceed the Instantaneous Maximum (IM) and/or Instantaneous Maximum Intervention (IMI) Limits specified for manganese and molybdenum. These wells are located directly at or adjacent to the toe of the tailings basin and are within the property boundary. Groundwater monitoring under the existing Permit has only been conducted at a single background well (well GW002) and at wells that are located immediately adjacent to the tailings basin dams (wells GW001, GW006, GW007, and GW008). The existing Permit also includes monitoring wells GW003, GW004, and GW005, which are located within tailings basin Cell 2W. These wells were installed to monitor hornfels rock that was placed in the tailings basin. GW003 has been dry and has not been sampled since 2003. Four additional wells (GW009 through GW012) were installed in March and May 2009 as part of the environmental review for PolyMet’s NorthMet Project and are not related to the existing Permit. Samples collected from these wells provide additional information on groundwater quality in the vicinity of the property boundary. The well locations are shown on Figure 3-1.

3.2 Study Objectives

The primary objective of the Groundwater Investigation was to evaluate the impact from seepage from the tailings basin on manganese, molybdenum, sulfate, and TDS concentrations in groundwater at the property boundary north and west of the tailings basin, in order to provide a better understanding of the quality of groundwater that is flowing within the property boundary toward potential groundwater receptors. Additional data collection, along with a review of historic groundwater data, was completed to support an evaluation of the potential impacts associated with the manganese, molybdenum, sulfate, and TDS concentrations that have been detected in groundwater adjacent to the tailings basin. A secondary objective of the Groundwater Investigation was to collect supplementary data for evaluating potential mitigation technologies for these constituents in groundwater at the property boundary.

3.3 Scope / Methods

The scope of work completed for the Groundwater Investigation included the following:

- Compilation and review of historic data collected under the existing Permit and data collected as part of the environmental review for PolyMet's NorthMet Project.
- A review of available literature/regional data to develop an understanding of typical background concentrations of manganese, molybdenum, sulfate, and TDS in the region's groundwater.
- Installation of additional monitoring wells along the property boundary to the north and west of the tailings basin to supplement the previously existing monitoring well network.
- Groundwater sampling at the previously-existing monitoring wells and the newly-installed wells.

3.3.1 Compilation and Review of Available Information

The following information was compiled and reviewed:

- Groundwater quality data and groundwater elevation data collected since 2005 under the existing Permit.
- Supplemental groundwater quality data and groundwater elevation data collected as part of the environmental review for PolyMet's NorthMet Project.
- Other site-specific geologic and hydrogeologic data that has been compiled during environmental review for PolyMet's NorthMet Project.
- Available literature and data related to regional groundwater quality (focusing on manganese, molybdenum, sulfate, and TDS).

3.3.2 Monitoring Well Installation

The installation of three additional monitoring wells (GW013, GW014, and GW015) was proposed in the Groundwater Investigation Plan based on a preliminary review of available information. The well locations were selected based on an evaluation of groundwater flow directions in the surficial aquifer north and west of the tailings basin. Prior to installation of the new wells, there were no monitoring wells positioned downgradient of the western edge of the tailings basin to evaluate groundwater quality along the northwestern property boundary. In addition, a review of historic data collected at GW002 (the well that has been used to represent background conditions for the Permit monitoring) indicated that concentrations observed at that location may not be representative of geochemical conditions that prevail in the primarily wetland areas north and northwest of the tailings basin. Therefore, new well GW015 was proposed to the west of the tailings basin, in a wetland area not expected to be impacted by tailings basin seepage.

The new monitoring wells were installed in July 2010 using rotasonic drilling techniques. Well locations are shown on Figure 3-1. Soil borings were advanced to bedrock, to depths ranging from 5 to 30 feet below ground surface (ft bgs) and monitoring wells were installed at depths ranging from 15 to 22 ft bgs. The new wells were screened to intersect the most permeable lithology based on field observations. The monitoring wells were constructed using 2-inch diameter 10-slot PVC screens and PVC risers and were completed above grade with steel protective casings. Following installation, the monitoring wells were developed using pump and surge techniques. The elevation of each monitoring well riser was surveyed to the same datum as the existing tailings basin monitoring wells. Information regarding field observations, soil types encountered, and groundwater elevations are provided in Section 3.4.2 below.

3.3.3 Groundwater Monitoring

As proposed in the Groundwater Investigation Plan, groundwater samples were collected from the new monitoring wells and existing monitoring wells outside of the tailings basin (GW001, GW002, and GW006 through GW012) for analysis of selected general parameters and total and dissolved metals. Sampling events were completed in July 2010, October 2010, and April/May 2011. Monitoring well GW002 was dry during the July 2010 sampling event and well GW001 was frozen during the April/May 2011 sampling event; therefore, samples were not collected from these wells during these sampling events. Groundwater samples were submitted to Northeast Technical Services (NTS)/Pace Analytical Services in Virginia, Minnesota for analysis of the parameters shown on Table 3-1.

Groundwater sampling results are discussed in Section 3.4.3 below.

3.4 Results

3.4.1 Data Review/Compilation

The pertinent results from the data compilation are included in the specific discussions of the solutes of interest in Section 3.5.

3.4.2 Monitoring Well Installation

Boring logs for the new monitoring wells are included in Appendix 3-1. In general, soil types observed during drilling are consistent with those that have been observed at the other monitoring well locations. Glacial deposits generally consist of discontinuous lenses of silty sand to poorly graded sand with silt, to poorly graded sand with gravel.

Groundwater elevations at the new monitoring wells are consistent with the previous conceptual model of groundwater flow in the area and indicate groundwater flows to the north and northwest from the tailings basin toward the Embarrass River.

3.4.3 Groundwater Monitoring

A summary of groundwater data collected as part of the Groundwater Investigation Plan is provided in Table 3-1. Note that duplicate samples are indicated by the code “FD” in Table 3-1. Laboratory reports are not included, but are available upon request. More specific discussion of results for the solutes of interest is included in Section 3.5.

3.5 Discussion / Recommendations

This section presents a summary of available data and discussion related to each of the identified solutes of interest at the tailings basin (manganese, molybdenum, sulfate, and total dissolved solids).

3.5.1 Manganese

3.5.1.1 Site Data

A summary of manganese concentrations observed at tailings basin monitoring wells is shown on Figure 3-2. Data shown on this figure include data collected for NPDES permit sampling since 2005, data collected as part of the environmental review for PolyMet’s NorthMet Project, and data collected for the Groundwater Investigation. For reference and comparison, the NPDES permit limits (IMI = 250 µg/L and IM = 1,000 µg/L) and the most stringent health-based groundwater standard (Minnesota Department of Health (MDH) Health Risk Limit (HRL) = 100 µg/L) for manganese are also shown on Figure 3-2. It should be noted that a secondary Maximum Contaminant Level (sMCL) of 50 µg/L has been established by the U.S. Environmental Protection Agency (EPA); however, because this standard is not health-based, it is not considered further in the following discussion.

Manganese concentrations at the monitoring wells immediately adjacent to the tailings basin (upper plot on Figure 3-2) show a large degree of spatial and temporal variability, ranging from 14 µg/L at well GW008 to 3,620 µg/L at well GW001. With the exception of well GW001, which has shown a generally increasing trend since 2005, manganese concentrations have been generally stable.

Manganese concentrations are also highly variable at the property boundary wells (GW009 through GW011, GW013 through GW015) and well GW002 (lower plot on Figure 3-2), ranging from occasionally below detection limits at well GW002 to 3,730 µg/L at well GW009.

3.5.1.2 Regional Data

Manganese concentrations in soil and groundwater across Minnesota (Lively and Thorleifson, 2009) and in the groundwater of northeastern Minnesota (MPCA, 1999A; Siegel and Ericson, 1980) are highly variable. Table 3-2 (below) provides a summary of regional manganese concentration data. Data from the MPCA Ground Water Monitoring and Assessment Program indicated manganese concentrations ranging from below detection limits to 1,462 µg/L in a total of 85 samples collected from three types of Quaternary aquifers (artesian, unconfined buried, and water table) in northeastern Minnesota. The mean manganese concentrations in two of the classified aquifer types (artesian = 84 µg/L, water table = 89 µg/L) are just below the current HRL of 100 µg/L, while the mean concentration in samples from unconfined buried aquifers (282 µg/L) exceeded the current HRL (MPCA, 1999A). Siegel and Ericson observed a range of manganese concentrations from below detection limits to 26,000 µg/L in a total of 69 groundwater samples collected from surficial aquifers within the Copper-Nickel Study Area. In their study, Siegel and Ericson classified two types of surficial aquifers (till and sand and gravel) and the mean manganese concentrations in both types are well above the current HRL (1,268 µg/L for till; 2,140 µg/L for sand and gravel).

The data collected for the studies referenced above covers a large area, where a large amount of spatial variability may be expected. However, as part of the environmental review for PolyMet's NorthMet Project, groundwater samples were collected from a total of 15 residential wells located within approximately 4 miles of the tailings basin. Manganese concentrations in the seven surficial aquifer wells sampled ranged from 1.3 µg/L to 4,850 µg/L.

Table 3-2 Summary of Regional Manganese Data (concentrations in µg/L)

Aquifer Type	Study Area	# of Samples	Mean	Median	Min	Max	Data Source
Quaternary artesian	Northeastern Minnesota	52	84	89	< 0.90	1462	MPCA, 1999A
Quaternary unconfined buried	Northeastern Minnesota	12	282	157	< 0.90	1248	MPCA, 1999A
Quaternary water table	Northeastern Minnesota	21	89	90	< 0.90	1011	MPCA, 1999A
Till	Copper-Nickel Study Region	31	1268	330	10	7190	Siegel and Ericson, 1980
Sand and gravel	Copper-Nickel Study Region	38	2140	45	0	26000	Siegel and Ericson, 1980
Surficial	Residential Wells North of Tailings Basin	7	1015	272	1.3	4850	Barr, 2009

3.5.1.3 Data Interpretation

The behavior of manganese in groundwater is complex and is controlled by a number of processes, including oxidation-reduction (redox) conditions (Hem, 1975) and carbonate alkalinity (Berndt and Lapakko, 1997). Therefore, it is often difficult to isolate the specific factor or set of factors that ultimately result in the observed manganese concentration at a given location. To facilitate interpretation of the variability of manganese concentrations observed in the tailings basin monitoring wells, stability relations in the Mn-H_2O-CO_2 system were modeled using Geochemist's Workbench (Release 8.0; Bethke, 2008) at 10°C (average monitoring well water temperature), assuming equilibration of groundwater with atmospheric CO_2. The initial result is a pH-Eh (Eh is a measure of oxidation-reduction potential) diagram at a constant manganese activity of 10^{-6}, with Eh and pH data collected as part of the Groundwater Investigation shown for comparison (Figure 3-3A). With the exception of one sample from each of wells GW001, GW006, and GW012, the groundwater manganese concentrations all fell within the stability field of dissolved Mn^{2+}, suggesting that the groundwater still had the capacity to further dissolve manganese from surrounding source material. To gauge the magnitude of this capacity, phase stability was modeled as a function of Mn activity (a) and Eh, holding pH constant at 7 (Figure 3-3B). The result suggests that under these conditions, when Eh is less than approximately 5.75 volts, the manganese concentration is limited by saturation with the manganese carbonate mineral rhodochrosite. At saturation under these conditions, the groundwater would contain approximately 5,500 µg/L Mn^{2+}. The effect of increasing pH would be to expand the stability field of rhodochrosite and decrease equilibrium manganese concentration of the water.

This preliminary analysis indicates that geochemical conditions in the surficial aquifer near the tailings basin are favorable to support concentrations of manganese well in excess of the HRL. However, it is not known whether the source of the manganese is tailings basin seepage, manganese that is naturally present in minerals in the aquifer material, or some combination of the two.

3.5.1.4 Groundwater Standards/Basis for Current Permit Limits

The current HRL for manganese, originally adopted by MDH in 1993, is 100 µg/L. Since the promulgation of this standard, guidance regarding manganese has changed multiple times. In 1997, a Health Based Value (HBV) of 1,000 µg/L was adopted. This value was then superseded in 2008 by a Risk Assessment Advice (RAA) value of 300 µg/L, which was based a preliminary review of EPA guidance released at that time. MDH review of more recent studies has resulted in removal of the RAA of 300 µg/L.

The current manganese Permit limits for wells GW001, GW006, GW007, and GW008 are 250 µg/L (IMI) and 1,000 µg/L (IM). It is presumed that the IMI value was based on ¼ of the Health Based Value (HBV) of 1,000 µg/L that was recommended by MDH at the time of Permit issuance.

3.5.1.5 Recommendations

The most stringent health-based groundwater standard for manganese is the MDH HRL of100 µg/L. Manganese limits established in a reissued NPDES permit would presumably be based on this standard and applied at the property boundary wells. However, regional manganese data and the groundwater data collected from monitoring wells near the tailings basin do not support a conclusion that elevated manganese concentrations are definitively related to tailings basin seepage. Given the complexity of understanding the fate and transport of manganese in groundwater, not only in the vicinity of the tailings basin but throughout the region, along with the difficulty in establishing health-based guidance values, it is recommended that a site specific Permit Limit be developed for manganese. This recommendation is believed to be appropriate for the following reasons:

- Manganese concentrations near the tailings basin, as well as throughout the region, are highly variable spatially and span a large range of concentrations, making it difficult to establish the specific factors that control concentrations at a given location.
- Geochemical conditions in the surficial aquifer near the tailings basin (and apparently throughout the region, based on the elevated concentrations that have been observed

regionally) are favorable to support high dissolved manganese concentrations, but it is difficult to determine if the source of manganese is tailings basin seepage or naturally-occurring manganese in the aquifer matrix.

3.5.2 Molybdenum

3.5.2.1 Site Data

A summary of molybdenum concentrations observed at tailings basin monitoring wells is shown on Figure 3-4. Data shown on this figure include data collected for NPDES Permit sampling since 2005, data collected as part of the environmental review for PolyMet's NorthMet Project, and data collected for the Groundwater Investigation. For reference and comparison, the NPDES Permit limits (IMI = 7.5 µg/L and IM = 30 µg/L) are also shown on Figure 3-4. There is no current health-based or secondary guidance or limits established by MDH or EPA for molybdenum. Molybdenum concentrations at the wells immediately adjacent to the tailings basin (upper plot on Figure 3-4) range from below detection limits at well GW008 to 57 µg/L at well GW006. The highest concentrations are observed at wells GW006, GW007, and GW012, although concentrations at wells GW006 and GW007 have declined from just below 60 µg/L in 2005 to near 30 µg/L since 2008. Concentrations above the detection limit, but below the IM are observed at well GW001. Molybdenum concentrations at the property boundary wells and well GW002 (lower plot on Figure 3-4) range from below detection limits at wells GW002, GW011, and GW013 to 59 µg/L at well GW014. Concentrations at well GW014 have been highly variable, ranging from 16.2 µg/L in April 2011 to 59 µg/L in September 2010. Concentrations above the detection limit, but below the IM, are observed at wells GW009 and GW015.

3.5.2.2 Regional Data

The amount of available data regarding molybdenum concentrations in regional groundwater is relatively sparse compared with manganese; however, the available data indicates a relatively narrow range of observed values (Table 3-3). The MPCA Ground Water Monitoring and Assessment Program indicated manganese concentrations ranging from below detection limits to 18 µg/L in a total of 85 samples collected from three types of Quaternary aquifers (artesian, unconfined buried, and water table) in northeastern Minnesota. Molybdenum concentrations ranged from below detection limits to 1.3 µg/L in the seven residential wells completed in the surficial aquifer that were sampled as part of the environmental review for PolyMet's NorthMet Project (Barr, 2009).

Table 3-3 Summary of Regional Molybdenum Data (concentrations in µg/L)

Aquifer Type	Study Area	# of Samples	Mean	Median	Min	Max	Data Source

Quaternary artesian	Northeastern Minnesota	52	3.6	< 4.2	< 4.2	18	MPCA, 1999A
Quaternary unconfined buried	Northeastern Minnesota	12	2.1	< 4.2	< 4.2	12	MPCA, 1999A
Quaternary water table	Northeastern Minnesota	21	1.9	< 4.2	< 4.2	12	MPCA, 1999A
Surficial	Residential Wells North of Tailings Basin	7	0.41	0.32	< 0.2	1.3	Barr, 2009

3.5.2.3 Data Interpretation

Molybdenum is a naturally occurring element that occurs in small quantities in soil and rocks, generally in concentrations less than 10 mg/kg (MPCA, 1999B). In taconite tailings basins, molybdenum may be derived from the ore, but may also be released due to corrosion of grinding media or from dissolution of lubricating agents. Adsorption to iron oxides is a key process that controls the mobility of molybdenum and the degree of adsorption that occurs is strongly controlled by pH. At higher pH (≥ 8.5), adsorption of molybdenum is inhibited due to competition with hydroxide ion for available sorption sites. These pH conditions generally prevail in process water from taconite processing plants and molybdenum may accumulate when process water is recycled between the processing plant and the tailings basin. At neutral to somewhat lower pH conditions, which generally occur in tailings/pore fluid environments, molybdenum adsorbs more readily (Berndt et al., 1999). The groundwater samples collected for the Groundwater Investigation indicate that the groundwater pH ranges from 5.3 to 8.0, with an average of 7.1. Therefore, pH conditions in the aquifer would not be expected to hinder molybdenum adsorption.

In general, molybdenum concentrations observed in the monitoring wells suggest that attenuation is occurring with distance from the tailings basin. For example, concentrations decrease significantly between wells GW012 and GW010. The exact attenuation mechanisms are unknown, but may include adsorption to the aquifer matrix and dilution from precipitation-derived recharge. A notable exception is well GW014, which displays molybdenum concentrations of up to 59 µg/L, similar to those that have been observed at monitoring wells at the perimeter of the tailings basin. Well GW014 is located adjacent to an unnamed creek that flows northwest from the tailings basin and surface water sampling point SW003 (named PM11 for NorthMet Project) is located on the creek near well GW014. Based on the available data, chloride concentrations (assumed to act as a conservative tracer of tailings basin seepage) at well GW014 and SW003/PM11 are similar (Figure 3-5), suggesting that well GW014 may be located along a surface water flow path that is currently or was transporting tailings basin water with minimal attenuation. Therefore, it is possible that groundwater quality observed at new well GW014 may represent tailings basin seepage that has migrated to this location largely via surface water flow. Similar molybdenum concentrations have been observed at GW014 and SW003/PM11 (Figure 3-5) supporting the concept that the water at GW014 has been transported largely via surface water flow, and therefore has not undergone significant molybdenum attenuation in the groundwater system.

3.5.2.4 Groundwater Standards/Basis for Current Permit Limits

There are currently no health-based or secondary standards established by MDH or EPA for molybdenum in groundwater. As of 1999, the MDH had a HBV of 30 µg/L established (MPCA, 1999B), but it is apparently no longer in effect. It is presumed that the current permit limits are based on this HBV value, which was likely still in effect when the permit was issued (IMI is ¼ of the former HBV, IM is equal to the former HBV).

3.5.2.5 Recommendations

Due to the lack of health-based or secondary groundwater standards, it is unclear how limits for molybdenum would be established in a reissued NPDES permit. Presumably, if Permit Limits were established for molybdenum, they would be applied at the property boundary wells. With the exception of well GW014 (which is likely influenced by adjacent surface water), molybdenum concentrations at the property boundary do not exceed the current IM limit. The available data for molybdenum suggests that attenuation is likely occurring in the tailings basin area. Samples from residential wells north of the tailings basin did not exhibit elevated concentrations, suggesting that risks to potential receptors are low. Due to these factors, it is recommended that a site specific Permit Limit be developed for molybdenum, or that the molybdenum limit be removed entirely from the reissued NPDES permit.

3.5.3 Sulfate

3.5.3.1 Site Data

A summary of sulfate concentrations observed at tailings basin monitoring wells is shown on Figure 3-6. Data shown on this figure include data collected for NPDES Permit sampling since 2005, data collected as part of the environmental review for PolyMet's NorthMet Project, and data collected for the Groundwater Investigation. For reference and comparison, the NPDES Permit limit (IMI = 250 mg/L) and EPA secondary MCL (250 mg/L) are shown on Figure 3-6. Sulfate concentrations at the wells immediately adjacent to the tailings basin (upper plot on Figure 3-6) range from 15.7 mg/L at well GW008 to 555 mg/L at well GW006. The highest concentrations are observed at wells GW006, GW007, and GW012. With the exception of wells GW006 and GW012, which show increasing concentration trends, sulfate concentrations at the other wells along the perimeter of the basin have been relatively stable. Wells GW006 and GW012 are the only wells that exceed the IMI and sMCL of 250 mg/L. Sulfate concentrations at the property boundary (lower plot on Figure 3-6) range from 1.9 mg/L at well GW010 to 235 mg/L at well GW009. Sulfate concentrations at the property boundary wells do not exceed the IMI/sMCL of 250 mg/L. In general, concentrations have been stable or decreasing at the property boundary wells since 2009. In particular, sulfate concentrations at GW009 have decreased from 235 mg/L in May 2009 to 59.7 mg/L in May 2011. Based on the four samples collected since well GW014 was installed, sulfate concentrations have decreased from 211 mg/L to 77.9 mg/L. The sulfate concentrations observed at well GW014 are similar (Figure 3-5) to those that have been observed at surface water monitoring station PM11, again suggesting that groundwater quality at this well may reflect transport primarily via surface water.

3.5.3.2 Regional Data

Available regional groundwater data indicate a relatively large range of observed sulfate concentrations. The MPCA Ground Water Monitoring and Assessment Program indicated sulfate concentrations ranging from below detection limits to 377 mg/L in a total of 85 samples collected from three types of Quaternary aquifers (artesian, unconfined buried, and water table) in northeastern Minnesota. In particular, samples collected from Quaternary artesian aquifers displayed a higher average sulfate concentration and a much larger maximum value than unconfined buried or water table aquifers. Siegel and Ericson (1980) observed sulfate concentrations ranging from 0.7 mg/L to 450 mg/L. As with the MPCA study, the type of aquifer appeared to exert some control on observed concentrations. Compared with sand and gravel aquifers, till aquifers exhibited a higher mean sulfate concentration and a much higher maximum concentration. Sulfate concentrations ranged from below detection limits to 10.9 mg/L in the seven residential wells completed in the surficial aquifer that were sampled as part of the environmental review for PolyMet’s NorthMet Project (Barr, 2009).

Table 3-4 Summary of Regional Sulfate Data (concentrations in mg/L)

Aquifer Type	Study Area	# of Samples	Mean	Median	Min	Max	Data Source
Quaternary artesian	Northeastern Minnesota	52	6.8	7.3	< 0.3	376.8	MPCA, 1999A
Quaternary unconfined buried	Northeastern Minnesota	12	1.9	2.7	< 0.3	14.2	MPCA, 1999A
Quaternary	Northeastern	21	7.1	10.4	< 0.3	20.5	MPCA,

water table	Minnesota						1999A
Till	Copper-Nickel Study Region	31	61	11	1.8	450	Siegel and Ericson, 1980
Sand and gravel	Copper-Nickel Study Region	38	11	6	0.7	35	Siegel and Ericson, 1980
Surficial	Residential Wells North of Tailings Basin	7	5.4	5.6	< 1.0	10.9	Barr, 2009

3.5.3.3 Data Interpretation

Sulfate is released from the taconite tailings due to the dissolution of sulfide minerals that were present in the ore during processing and that are currently present in the tailings. Sulfide is oxidized to sulfate, which is subsequently transported out of the tailings basin via surface and groundwater (Berndt et al., 1999). Sulfate in the groundwater can subsequently become reduced (to form a variety of products depending on geochemical conditions, including hydrogen sulfide gas or sulfide species, which can then react with metals to form solid sulfides), either in wetland environments or in reducing groundwater conditions in the aquifer, depending on the availability of reactive organic material and the supply of sulfate (Appelo and Postma, 2005). In general, the degree of sulfate reduction occurring in wetlands and the surficial aquifer is likely a primary control on concentrations of sulfate in groundwater downgradient from the tailings basin. Chloride and sulfate concentrations, along with coincident flow measurements, were measured along a stretch of the Embarrass River in 2010 and indicate that although there is an increasing load of chloride along the reach of the river downgradient from the tailings basin, sulfate load tends to decrease in the downstream direction (PolyMet, 2011). These data support the interpretation that sulfate reduction occurs along the groundwater flowpaths between the tailings basin and the groundwater discharge to the Embarrass River.

Data from the monitoring wells indicates that, although sulfate concentrations near the tailings basin perimeter exceed Permit limits and the sMCL, concentrations decrease substantially between the tailings basin and the property boundary. Reasons for this decrease may include sulfate reduction or dilution from precipitation-derived recharge.

3.5.3.4 Groundwater Standards/Basis for Current Permit Limits

There is no current health-based guidance or limit established by MDH or EPA for sulfate. The Permit Intervention Limit for sulfate in groundwater (250 mg/L) appears to be tied to the EPA secondary MCL for sulfate, also set at 250 mg/L.

The following language from the EPA website (at http://water.epa.gov/drink/contaminants/secondarystandards.cfm) provides some background regarding secondary maximum contaminant levels:

> *EPA has established National Secondary Drinking Water Regulations that set non-mandatory water quality standards for 15 contaminants. EPA does not enforce these "secondary maximum contaminant levels" or "SMCLs." They are established only as guidelines to assist public water systems in managing their drinking water for aesthetic considerations, such as taste, color and odor. These contaminants are not considered to present a risk to human health at the SMCL.*
>
> *There are a wide variety of problems related to secondary contaminants. These problems can be grouped into three categories: Aesthetic effects - undesirable tastes or odors; Cosmetic effects - effects which do not damage the body but are still undesirable; and Technical effects - damage to water equipment or reduced effectiveness of treatment for other contaminants.*

According to the EPA website, sulfate concentrations above the sMCL may cause aesthetic effects and cause water to have a salty taste.

3.5.3.5 Recommendations

The most stringent groundwater standard for sulfate is the EPA sMCL of 250 mg/L. Sulfate limits in a reissued NPDES permit would likely be based on this value and applied at the property boundary. Sulfate was identified in the Consent Decree for further evaluation; however, sulfate concentrations at the property boundary do not exceed current Permit limits or the sMCL. In addition, there are no health-based standards for sulfate in groundwater. Therefore, no specific additional action beyond continued groundwater monitoring is proposed for sulfate.

3.5.4 Total Dissolved Solids

3.5.4.1 Site Data

A summary of total dissolved solids concentrations observed at the tailings basin monitoring wells is shown on Figure 3-7. Data shown on this figure include data collected for NPDES Permit sampling since 2005, data collected as part of the environmental review of PolyMet’s NorthMet Project, and data collected for the Groundwater Investigation. For reference and comparison, the NPDES Permit limit (IMI = 500 mg/L) and EPA secondary MCL (500 mg/L) are shown on Figure 3-7. There is no current health-based guidance or limits established by MDH or EPA for total dissolved solids. TDS concentrations at the wells immediately adjacent to the tailings basin (upper plot on Figure 3-7) range from 151 mg/L at well GW008 to 1,660 mg/L at well GW006. TDS concentrations at wells GW006, GW007, and GW012 are consistently above the IMI/sMCL, while concentrations at well GW001 occasionally exceed the IMI/SMCL. With the possible exception of well GW012, TDS concentrations at the wells are relatively stable. TDS concentrations at the property boundary wells and well GW002 (lower plot on Figure 3-7) range from 28 mg/L at well GW013 to 653 mg/L at well GW014. With the exception of well GW014, concentrations at the property boundary do not exceed 500 mg/L. In general, TDS concentrations have been relatively stable at the property boundary wells since 2009.

3.5.4.2 Regional Data

Available regional groundwater data indicate a relatively large range of observed values for TDS (Table 3-5). The MPCA Ground Water Monitoring and Assessment Program indicated TDS concentrations ranging from 28 mg/L to 1,010 mg/L in a total of 85 samples collected from three types of Quaternary aquifers (artesian, unconfined buried, and water table) in northeastern Minnesota. Siegel and Ericson observed TDS concentrations ranging from 55 mg/L to 938 mg/L. TDS concentrations ranged from 83 mg/L to 243 mg/L in the seven residential wells completed in the surficial aquifer that were sampled as part of the environmental review for PolyMet's NorthMet Project (Barr, 2009).

Table 3-5 Summary of Regional TDS Data (concentrations in mg/L)

Aquifer Type	Study Area	# of Samples	Mean	Median	Min	Max	Data Source
Quaternary artesian	Northeastern Minnesota	52	267	240	96	1010	MPCA, 1999A
Quaternary unconfined buried	Northeastern Minnesota	12	245	223	28	482	MPCA, 1999A
Quaternary water table	Northeastern Minnesota	21	196	168	68	356	MPCA, 1999A
Till	Copper-Nickel Study Region	31	293	187	97	938	Siegel and Ericson, 1980
Sand and gravel	Copper-Nickel Study Region	38	148	130	55	284	Siegel and Ericson, 1980
Surficial	Residential Wells North of Tailings Basin	7	135	106	83	243	Barr, 2009

3.5.4.3 Data Interpretation

While TDS concentrations are generally elevated immediately adjacent to the tailings basin, concentrations are generally much lower at wells further from the basin. With the exception of well GW014, TDS concentrations do not exceed the sMCL or IMI at the property boundary. As discussed previously, available data suggest that well GW014 may be influenced by water quality in the unnamed creek that flows northwest from the tailings basin. TDS concentrations at surface water monitoring station PM11are similar to those observed at well GW014 (Figure 3-5).

3.5.4.4 Groundwater Standard/Basis for Current Permit Limit

There are no health-based standards for TDS. The Permit Intervention Limit for TDS in groundwater (500 mg/L) appears to be tied to the EPA secondary maximum contaminant level for TDS, also set at 500 mg/L. According to the EPA website referenced above, elevated TDS can be associated with aesthetic and technical effects such as hardness, deposits, colored water, staining, and salty taste.

3.5.4.5 Recommendations

The most stringent groundwater standard for TDS is the EPA sMCL of 500 mg/L. TDS limits in a reissued NPDES Permit would likely be based on this value and applied at the property boundary. TDS was identified in the Consent Decree as a parameter of concern for further evaluation; however, with the exception of well GW014 (which is likely influenced by adjacent surface water), TDS concentrations in groundwater at the property boundary do not exceed current Permit limits or the sMCL. There is no health-based standard for TDS and potential downgradient receptors (residential wells) did not exhibit elevated TDS concentrations. Therefore, it is recommended that a site specific Permit Limit be developed for TDS.

4.0 Stream Investigation

4.1 Background

A one year field study was conducted (July 2010 to June 2011) to characterize and assess the water quality and biological condition of two streams to the west and north of the Tailings Basin (Unnamed Creek and Trimble Creek) that drain wetlands that receive seepage water from the Tailings Basin.

According to Minnesota State Water Rules (Chapter 7050), Unnamed Creek (PM11) and Trimble Creek (PM19) are both unlisted waters and are designated for the protection of aquatic life (Class 2B) as well as other use protections. In general, water quality standards for the protection of aquatic life, which are based upon toxicity tests with very sensitive aquatic organisms (e.g., zooplankton), serve as a conservative means to assess whether a given discharge could possibly have an effect on aquatic life. Therefore, if a given water quality standard is met in the discharge, it can be concluded with confidence that aquatic life is protected.

Biological monitoring, consisting of both aquatic invertebrates and fish, was conducted to determine the effect of seepage water from the Tailings Basin on Unnamed Creek and Trimble Creek. Biological monitoring is important because it highlights the true in-stream effect of a discharge. Biological monitoring also separates the “chemical” effect from the “habitat” effect. For example, if the quality of a discharge is different from background or water quality standards are not met, biological monitoring will provide an indication of whether the apparent effects are expressed in the biological communities downstream of where that a discharge enters the stream. A habitat evaluation was also conducted as part of this study to quantify the difference in habitat quality between Unnamed Creek and Trimble Creek and the control site.

The goal of this stream investigation was to determine whether the biota in Unnamed Creek and Trimble Creek, which receive water from the Tailings Basin, are “ecologically” better or worse than can be reasonably expected given the available habitat and compared to control (background) streams that are not affected chemically by the seepage water.

The overall composition and evaluation of biological communities including fish and macroinvertebrates, can provide valuable information about a site and allow investigators to draw conclusions about the system even without the availability of extrinsic abiotic information. Water chemistry results should be viewed as an indicator of potential effect, while the data on macroinvertebrates provide an actual measurement.

Fish also serve as good indicators of ecological health because the taxonomy of fishes is well established; extensive information is available on distributions and life histories of most North American species. Fish populations represent a broad spectrum of community tolerances and respond predictably to changes in abiotic factors such as habitat and water quality. The general public can easily relate to statements about the condition of a particular species or the fish community on the whole. Certain key indicators of severely degraded water quality conditions include measures such as the proportion of fish sampled that have deformities (e.g. eroded fins, lesions or tumors). The species composition in a particular habitat is also indicative of overall water quality conditions. For example, a high proportion of highly tolerant species or omnivorous species, especially in comparison to a reference condition site with minimal disturbance, would suggest poor water quality conditions. By comparison, sites with good water quality conditions and high overall ecological integrity would contain top carnivorous species (e.g. northern pike, burbot) or a relatively high abundance of insectivorous fish such as perch or minnow species.

Study results provide the initial data to provide the assessment of the potential for effects from the Tailings Basin on aquatic life in Unnamed Creek and Trimble Creek.

4.2 Objectives

The objectives of the Stream Investigation were to determine whether there is an effect from the existing Tailings Basin seepage water on aquatic life (fish and macroinvertebrates) in Unnamed Creek and Trimble Creek.

4.3 Scope and Methods

The detailed scope of the Stream Investigation was defined following the review of historical data and was provided in the May 6, 2010 *NPDES Field Studies Plan – Tailings Basin,* with subsequent modification to address the MPCA’s June 16, 2011 comments. The scope of the work consisted of the following activities:

- **Literature review** on the relationship between dissolved solids/specific conductivity and aquatic life metrics. A preliminary review was completed and is summarized in Section 4.4 below.
- **Aquatic life** (fish and macroinvertebrate) monitoring Unnamed Creek and Trimble Creek and at a control site.
- **Data analysi**s to evaluate the relationship between dissolved constituents and aquatic life. The analysis also includes comparison of the number, relative abundance, and diversity of species in Unnamed Creek and Trimble Creek to the control site.
- **Summary report** that provides an evaluation of any impacts to aquatic life associated with the seepage.

4.3.1 Study Sites

A reconnaissance visit to potential stream sites was conducted during the week of April 26, 2010 to identify sites that are suitable for both fish and macroinvertebrate sampling. Following MPCA Reconnaissance Procedures (Standard Operating Procedures; http://www.pca.state.mn.us/water/biomonitoring/bio-streams-fish.html; accessed on May 4, 2010), stream reaches were chosen such that the stream substrate, morphology, and habitat have the potential to support macroinvertebrates and fish. Stream reaches included in the Stream Investigation are identified in Figure 4-1.

Figure 4.1 identifies all of the sampling sites associated with the Stream Investigations conducted for the Tailings Basin, SD026 and SD033. The three stream investigations were conducted simultaneously and in some cases (e.g., fish data) the combining of data from all three investigations provides additional perspective for assessing potential effects.

For Unnamed Creek and Trimble Creek, one suitable stream reach that can be used for both fish and macroinvertebrate sampling was identified for each of the following sites:

- Unnamed Creek (PM11): essentially at site PM11. Access to Site PM11 is as follows: from the intersection of State Highway 21 and Waisanen Road just west of the town of Embarrass, go south about 0.8 miles on Waisanen Road to a 90 degree right hand turn where Waisanen Road intersects with an ATV trail on an old railroad bed, then south about 0.9 miles on the ATV trail that follows the old railroad bed to Site PM11.
- Trimble Creek (PM19): downstream from site PM19, on the north side of County Road 615 (i.e., just downstream of where Trimble Creek intersects with County Road 615 which is also known as Salo Road).

A control stream was also identified: Bear Creek. The specific stream reach that is suitable for both macroinvertebrate and fish sampling is upstream of SW003 (also known as site PM20). The control reach is approximately 0.1 miles to the west of the intersection of County Road 969 (Forrest Road) and County Road 960 (Hayland Road); approximately 2.4 miles north of the intersection of Bear Creek with State Highway 21 (Figure 4-1).

Macroinvertebrate community sampling was conducted at two separate time periods for Bear Creek, Unnamed Creek and Trimble Creek: spring-time (early June 2011) and late summer/early fall (mid-September 2010). All three streams sampled within a day or two of each other.

The fish community was sampled at Unnamed Creek (PM11), at Trimble Creek (PM19), and at the control stream (Bear Creek) in July 2010.

Samples for water chemistry data analysis were collected at both Unnamed Creek (PM11) and Trimble Creek (PM19), as well as at the control stream, at the same time that macroinvertebrate sampling and fish sampling was conducted.

4.3.2 Physical Habitat Assessment

Each monitoring site was composed of a stream reach that was 150 meters in length. The mid-point, upstream and downstream ends of the reach were marked with surveyor tape and coordinates (NAD 83, Zone 15) were collected using a Global Positioning System (GPS) with submeter accuracy to provide consistency for future sampling efforts.

During the fish survey in July 2010, a physical habitat assessment was completed at the three monitoring sites utilizing the MPCA *Physical Habitat and Water Chemistry Assessment Protocol for Wadeable Stream Monitoring Sites* (Appendix 4-A).

During the macroinvertebrate survey in June 2011, a physical habitat evaluation was completed at the six monitoring sites to assess differences and/or similarities between sites using the *MPCA Stream Habitat Assessment Worksheet*, revised 03-07 (Appendix 4-B). Scores for the worksheet are based on a scale from -5 to 100, with higher numbers representing better quality habitat. This field worksheet provided information about the substrates, channel characteristics, riparian characteristics, and general area information.

The streambed gradient of the monitoring sites was determined by reviewing ten-foot topographic contours using the digital raster graphic (DRG) developed by the United States Geological Survey (USGS), which were overlain on the 2010 Farm Services Association (FSA) aerial imagery using ArcMap 9.3. Sinuosity was determined using the 2010 FSA imagery in ArcMap 9.3. The results were used in the MPCA's worksheets to assess the similarities and differences between the physical habitats of the sites.

Stream flow was measured during each biological sampling event at each site using a Marsh McBirney Flo-Mate 2000 flowmeter.

4.3.3 Water Chemistry

Field measurements for water chemistry parameters were collected during the fish and macroinvertebrate surveys conducted at Unnamed Creek (PM11), Trimble Creek (PM19) and Bear Creek in July 2010, September 2010 and June 2011. Additional field measurements for water chemistry parameters were collected at Bear Creek in October 2010 related to sampling conducted for Whole Effluent Toxicity (WET) testing for the SD026 and SD033 stream investigations (Bear Creek was the control stream for that testing as well as for the biological monitoring). Additional field measurements for water chemistry parameters were also collected at Unnamed Creek and Trimble Creek in October 2010 related to other sampling being conducted for the Tailings Basin.

The parameters, measured using a YSI multi-probe unit, included dissolved oxygen (DO), temperature, pH, oxidation reduction potential (ORP), specific conductance and turbidity. The protocols for the water chemistry assessment presented in the MPCA document *Physical Habitat and Water Chemistry Assessment Protocol for Wadeable Stream Monitoring Sites* (see Appendix 4-A) were used as a guide for chemical measurement and sampling.

Water samples collected in the field were also processed in the laboratory to measure a suite of physico-chemical variables as well as concentrations of 23 metals including known toxicants. All measured field and laboratory parameters are summarized in Table 4-1, including the October 2010 data for Bear Creek, Unnamed Creek and Trimble Creek (i.e., data for the fall time period).

Data analysis

All water chemistry parameters (except pH) and metal concentration values were $\log_{10}$ (Y+1) transformed to improve homogeneity of variances and normality of the data. A spearman rank correlation matrix was used to identify redundancy among the set of variables. In the case where two variables were significantly correlated, only one of the two variables was chosen for further analysis (e.g. total suspended solids and total dissolved solids; Nitrate+Nitrite and Nitrogen (total kjeldahl)).

To determine if the sites Unnamed Creek (PM11), Trimble Creek (PM19) and Bear Creek were significantly different based on water chemistry parameters, a randomized block Analysis of Variance (ANOVA) (blocking factor: season) was conducted for each of the measured parameters across sampling periods. For parameters that showed a significant difference among sites, a post-hoc test (Tukey's HSD (Honestly Significant Difference)) was conducted to determine which of the three sites were significantly different from each other.

Water chemistry parameter and concentration values from all biological sampling events were combined (July 26, 2010; September 15-17, 2010; October 26, 2010; June 2011), and the average values were compared to the Minnesota Water Quality Standards criteria for each individual parameter value or concentration (including metal concentrations).

Finally, as a further step in determining the overall surface water quality, a water quality index classification system (developed by Prati, et al. 1971) was used to categorize the sites into one of five different water quality classes, each of which corresponds to an implicit index of pollution (IIP), ranging from 1-8. The five classes correspond to conditions of ‘excellent’ (index value = 1), ‘acceptable’ (index value = 2), ‘slightly polluted’ (index value = 4), ‘polluted’ (index value = 8) and ‘heavily polluted’ (index value > 8) (terminology as prescribed by Prati, et al. 1971). The parameters evaluated were – dissolved oxygen, pH, 5-day biological oxygen demand (B.O.D.), chemical oxygen demand (C.O.D.), total suspended solids, ammonia, chlorides, iron and manganese. Parameter values were averaged across the four sampling periods. For each parameter, an explicit mathematical function was used to determine the value of each IIP and its corresponding classification.

4.3.4 Macroinvertebrates

Biological monitoring required an assessment of the status of the biota in terms of the physical, chemical and biological conditions of the water body. Biological monitoring in Bear Creek, Unnamed Creek (PM11) and Trimble Creek (PM19) assessed fish and macroinvertebrate communities. The physical components of the respective stream reaches were measured using stream geomorphology concepts and data, while parameter values and chemical concentrations were obtained from the analysis of water samples that were collected in July 2010, September 2010 and June 2011 (field analysis and laboratory analysis).

The MPCA Standard Operating Procedures (SOPs) were followed for this study.

Macroinvertebrate Sampling

Aquatic macroinvertebrates were sampled using the MPCA multi-habitat invertebrate sampling procedures (MPCA protocol EMAP-SOP4 (Appendix 4-C)). For each site, the relative proportion of available habitat was identified and the various habitats were sampled according to their relative proportion to obtain similar samples of macroinvertebrates. A total of 20 samples were collected at each site. All macroinvertebrates were collected using D-frame dip nets. The debris (large twigs, leaves, plants, rocks, etc.) were washed with stream water, visually inspected and discarded. Collected macroinvertebrates were composited in a sieve bucket, transferred into 500-ml plastic bottles, and preserved in 85 percent reagent alcohol. All containers were labeled (inside and outside) with information including site identification, habitat type and collection date.

Macroinvertebrates were sorted using the MPCA *Invertebrate Identification and Enumeration* (SOP BMIP03; Appendix 4-D) procedures as a reference. Macroinvertebrates were identified by Dr. Dean Hansen, and the MPCA procedures were provided to Dr. Hansen. Macroinvertebrates were identified to the genus level as possible for all organisms. Large macroinvertebrates were picked and identified for the entire sample.

Measures of Biological Diversity – Macroinvertebrate Community

Biological monitoring can be used to evaluate the relative condition of biological communities in streams. This monitoring is usually conducted in association with physical and chemical monitoring at the site to assess all aspects of the stream reach. Several metrics can be used to evaluate and compare the biological communities of streams.

Abundance

Abundance (n) for a site was determined as the total number of organisms collected in the sampling effort. Samples were subsampled to a minimum of 300 organisms as per MPCA’s general guidelines for aquatic invertebrate monitoring in streams (http://www.pca.state.mn.us/index.php/water/water-monitoring-and-reporting/biological-monitoring/stream-monitoring/stream-monitoring-aquatic-invertebrates.html; Date Accessed: August 29, 2011).

Richness

Richness (s) for a site was the number of species collected in the sampling effort for the fish data. For the macroinvertebrate data, the number of families and genera was used to determine richness.

Shannon-Wiener Diversity Index

The Shannon-Wiener Diversity Index (H´) was used in conjunction with abundance and richness to detect environmental disturbances that may cause a decrease in diversity. H´ is calculated as:

$$H' = - \sum_{i=1}^{s} (n_i/n)\ln_2(n_i/n),$$

where n is the total number of individuals of all taxa, n_i is the number of individuals in the i^{th} taxon, and s is the total number of taxa in the community. The values of n and s were used as previously indicated for abundance and richness.

Evenness

Evenness was calculated to determine how equally abundant the species are among the families. Evenness (E) was calculated as:

$$E = H'/\ln s$$

where H´ is the calculated Shannon-Wiener Diversity Index and ln s is the natural logarithm (ln) of the total number of taxa in a community (s). High evenness occurs when species are equal or nearly equal in abundance and it is usually equated with high diversity. The maximum diversity would be possible if all species were equally abundant. By contrast, low evenness occurs when one or more species dominate the community which indicates low diversity.

Hilsenhoff Biotic Index (HBI) for Macroinvertebrates

The 2010 and 2011 macroinvertebrate data were evaluated using the Hilsenhoff Biotic Index (HBI). The HBI provides a method to assess water quality based on taxa pollution-tolerance (Hilsenhoff 1987). The HBI was developed from research on more than 1,000 small streams in Wisconsin (Hilsenhoff, 1982 and 1987). Small streams typically have a naturally low biological diversity, which is unrelated to their water quality. Small low-gradient streams in northeast Minnesota are also generally naturally low in DO without the introduction of nutrient or organic pollutants. Other water quality indices attribute biological diversity to stream condition and water quality. However, research indicates the HBI does an excellent job of ranking small streams in this region according to their stream condition.

The HBI was developed using macroinvertebrate populations in streams with a range of organic and nutrient levels, and therefore DO levels. The HBI is typically used to measure biodiversity in streams that may be affected by nutrient or organic pollution that causes excessive plant growth which reduces the DO and may affect the growth of other aquatic biota, e.g. macroinvertebrates. In general, species resident in streams with high organic levels and low DO levels were assigned high tolerance values and those species absent from these types of streams were given lower tolerance values. Using the tolerance values developed by Hilsenhoff and the EPA (*Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers*, July 1999), every species or genus identified at the monitoring sites has been assigned an index value from 0-10, with 0 assigned to the most intolerant species and 10 assigned to the most tolerant species. Species with tolerance values that are less than or equal to 3 are considered to be sensitive (intolerant) and species with values greater than or equal to 7 are considered to be tolerant.

When evaluating water quality conditions at a site, only those taxa with assigned tolerance values are included in the analysis. The HBI is an average of tolerance values for all individuals collected from a site. The calculations result in a HBI value that is a tolerance score for the sample weighted by the number of individuals in each contributing taxon. The calculated HBI scores can range from 0 to 10.

An HBI score at the high end of the scale indicates the macroinvertebrate community is dominated by pollution-tolerant taxa and that the site has some amount of pollution or that conditions are stressing the resident populations. A score at the low end of the scale indicates the macroinvertebrate community is dominated by organisms intolerant of pollution or stressor conditions (i.e., sensitive taxa) and implies that the water quality is good.

It is noted that the stream evaluations based on the HBI may underestimate the biologic integrity of the streams discussed in this report. The HBI is generally a measure of organic or nutrient pollution which affects organisms resulting from low DO or fluctuating DO levels. The study streams may have naturally low DO levels because they generally flow through wetland complexes and may not have any relationship to "organic pollution". However, even with these limitations, the HBI values are presented as a method for comparing the streams included in this study.

Other Biotic Measures of Integrity for Macroinvertebrates

There are other metrics or measures of biological communities that are often used to provide some additional understanding of biological communities. The metrics that include composition and habitat include the percent Ephemeroptera, Plecoptera, and Tricoptera (% EPT); percent Ephemeroptera, Plecoptera, Tricoptera, and Odonata (% EPTO); and percent insecta versus percent non-insecta.

Composition metrics require identification of key genera and their associated ecological patterns. The presence of a nuisance genus, or notable lack of a preferred genus, relates to stream condition. Composition metrics also provide information on the relative contribution of the genera to the total assemblage. There is a high level of redundancy in the input values used to calculate various composition metrics when the pollution tolerant genera are dominant and there is low diversity, and estimated scores tend to be similar.

Habitat metrics explain the morphological adaptation of genera for feeding and movement in the aquatic habitat. Insects are clinger taxa and require adaptations for attachment in flowing water to maintain position. Typically, with increased pollution, the number of insect taxa decreases. These additional biotic metrics can be used to provide additional understanding of macroinvertebrate populations at each site.

The EPA Biological Indicators of Watershed Health (2007) identifies the benthic macroinvertebrate orders that indicate stream health. In a degraded stream, pollution tolerant organisms (midgeflies, worms, leeches, pouch snails) would dominate the population. Sites dominated by sensitive (stoneflies, riffle beetles, mayflies) and moderately tolerant (dragonflies, crayfish, scuds, blackflies, caddisflies) orders indicate good stream health.

4.3.5 Fish

Fish Sampling

Fish communities were sampled at Unnamed Creek (PM11), Trimble Creek (PM19) and Bear Creek on July 26, 2010 using the MPCA *Fish Community Sampling Protocol for Stream Monitoring Site* (Appendix 4-E). A Minnesota Department of Natural Resources (MDNR) collection permit (Special Permit Number 16639) was obtained prior to fish sampling. As part of the permit requirement, the electro-fishing data and site figures were submitted to the MDNR - Fisheries Research on December 3, 2010.

For each stream reach, the fish community was sampled using a Smith-Root backpack electrofisher (135-245 volts), while walking 150m in an upstream direction and weaving between habitat types. Due to variable configurations of each of the stream reaches, the overall time fished was not consistent among streams. As such, abundances of fish species at each stream site were standardized based on time fished. All habitat types were sampled in the proportion that they existed in the stream reach.

Fish less than 25 mm in total length were excluded from the sampling effort. All specimens over 25mm were identified to the species level, measured for total length (mm) and weighed (to the nearest g) before being released into the stream. Any anomalies on a specimen (e.g. parasites, lesions, popeye) were recorded in the field. Unidentifiable fish were euthanized and preserved in 10% formalin for subsequent identification in the laboratory - specimens were sent to Dr. Andrew Simons in the Department of Fisheries and Wildlife, University of Minnesota, St. Paul, for detailed examination and were later retained for deposition in the Minnesota Bell Museum of Natural History.

Fish Community Assessment

The index of biotic integrity (IBI) approach is the most commonly used technique in fish community assessment and overall habitat assessment, particularly for streams and rivers (Karr 1981, Lyons et al. 1996, Mundahl and Simon 1999). Originally formulated specifically for the evaluation of fish communities, the IBI takes into account a variety of measures or attributes in connection with the region under investigation. A metric is a calculated term or enumeration representing some aspect of biological assemblage structure, function, or other measurable characteristic that changes with increasing human disturbance, in a predictable manner (Fausch et al. 1984). In an IBI, each metric is equally weighted and contributes to an overall IBI score, which signifies the "integrity" of a fish community at a site. In theory, the IBI reflects the degree to which environment influences the fish community.

Development of an IBI requires fish community data at several reference condition (i.e. non-disturbed) sites in addition to data acquired from test sites (i.e., sites under investigation) because scoring of each metric is dependent upon variation in the metric response against some measure of anthropogenic disturbance. Due to limitations with suitable site availability for fish community sampling, only one reference condition site was benchmarked for inclusion in this study. Therefore, the IBI approach could not be used to calculate an overall index score and determine a qualitative measure of biological integrity; however, certain individual metrics within the index could still be evaluated against measure(s) of stream pollution and ultimately compared among sites to determine whether there are overall differences in the fish community between the reference condition site (i.e., Bear Creek), Unnamed Creek (PM11) and Trimble Creek (PM19). Six of the original twelve IBI metrics (Karr et al. 1981) were selected for evaluation because these metrics are the most comprehensive and informative measures of overall fish community health.

Measures of Fish Community Health

Total number of species

Total species richness is the most commonly used measure of fish community health and is defined as the total number of species sampled at the site under investigation (standardized by catch per unit effort) (Karr 1981). A decline of species richness can be indicative of degraded conditions as certain species can be intolerant to various types of stressors such as toxic metals (Lyons 1992).

Simpson's Diversity Index

Simpson's diversity index is the simplest measure of the character of a biological community that takes into account both abundance and species richness. This is calculated by determining, for each species, the proportion of individuals that it contributes to the total abundance at a site (i.e. the proportion is P_i for the ith species):

$$\text{Simpson's index, } D = \frac{1}{\sum_{i=1}^{s} P_i^2}$$

where *S* is the total number of fish species (i.e., the richness).

Proportion of individuals as tolerant species

This measure is most sensitive to changes in stream condition. A site with many tolerant species is indicative of degrading conditions (Karr 1981). As an example of species present in a degraded system, the more tolerant species in the Minnesota River Basin include white sucker, common carp, fathead minnow, Creek chub and black bullhead (Bailey et al. 1993).

Proportion of individuals as insectivores

This measure evaluates the species that restrict their diet to benthic macroinvertebrates. Karr (1981) and Karr et al. (1986) used this measure in stream quality assessments. Typically, a decline in insectivores is indicative of degraded conditions.

Proportion of individuals as omnivores

Omnivores have a diet that includes $\geq$25% animal food and 25% plant food. Because the omnivore has a flexible diet, they generally can subsist in a range of stream conditions. The dominance of omnivores tends to suggest degradation in the trophic structure of a habitat (Karr 1981). Greater relative abundance of omnivores is thus considered to be an indication of poor habitat conditions.

Proportion of individuals with DELT (diseases, eroded fins, lesions, tumors) anomalies

This measure is widely used in stream quality assessments. The presence and especially abundance of fish with DELT anomalies is a sign of severe degradation at a site (Karr 1981), typically as a result of an environmental stressor (e.g., chemicals, overcrowding, improper diet, excessive siltation, etc.). It is important to mention that DELT anomalies do not black spot because it may be a natural occurrence and is not a reflection of stream quality. Bailey et. al. (1993) found that the frequency of DELT occurrences in fish from the Minnesota River Basin was relatively low.

Each of the above fish community measures was compared among the fish sampling sites and further evaluated against a measure of pollution. When selecting a measure of pollution against which to compare a metric response, some degree of variability in the pollution measure among sites is necessary in order to assess the predicted response for a site with minimal disturbance (i.e., a background site) compared to a site with heavy disturbance. Non-essential metals such as mercury, cadmium, lead and arsenic are known to cause significant toxic effects in aquatic organisms and their respective concentration can be used as a measure of pollution. Arsenic concentration showed the most variability among all sites where water chemistry data was collected for this study, and was thus chosen as one measure of metal pollution against which each fish community metric was evaluated.

4.4 Results and Discussion

Results for the stream habitat surveys, surface water samples (chemistry), macroinvertebrate sampling and fish sampling are presented and discussed in the following sections.

4.4.1 Physical Habitat

The physical and chemical measurements that were taken in the field during the macroinvertebrate surveys are presented in Table 4.2. The water level for each stream reach was within normal levels, based on observations of vegetation along the bank. The water level was within the banks of all streams when the macroinvertebrate samples were collected.

With regard to precipitation, the following is noted:

- There was 0.24 inches of rainfall in the seven days prior to sampling on September 15 and 17, 2010, with the 0.24 inches occurring on September 11 (precipitation data from state climatologist network, Station: 210390 Babbitt 2SE, http://climate.umn.edu/HIDradius/radius.asp). In addition, during the day on September 16 there was 0.17 inches of rain.

- In the seven days prior to the June 2, 2011 sampling there was 0.73 inches of rain, occurring on May 28 (0.15 inches) , 29 (0.53 inches) and 31 (0.05 inches).

- Recent precipitation data were compared to historic data for evaluating annual and monthly deviations from normal conditions and to determine if the macroinvertebrate and water chemistry sampling was representative of “normal” conditions. Precipitation data were obtained from the Minnesota Climatology Working Group, Wetland Delineation Precipitation Data Retrieval from a Gridded Database (http://climate.umn.edu/wetland/) for St. Louis County, Township 60N, Range 13W, Section 1. Precipitation during the 2 months prior to the mid-September 2010 macroinvertebrate sampling was above normal in July and August. In

2011, the previous 2 months prior to sampling were above the normal range in April and within the normal range in May).

The precipitation data suggests that the macroinvertebrate sampling in September 2010 and June 2011 was conducted during a wet time period. However, water levels in the streams were within the banks and do not indicate sampling was conducted during high flow or flooding conditions. Therefore, the biological sampling is considered to have been completed under relatively normal precipitation conditions.

Reference Stream Habitat – Bear Creek

For the stream reach assessed, available habitat types at Bear Creek included undercut banks/overhanging vegetation, woody debris, emergent vegetation and sediment (Table 4-2). The riparian zone was characterized by reed canarygrass, alders and willows. The substrate included muck and detritus. The Qualitative Habitat Evaluation Index (QHEI) for the MPCA worksheet was 44/100. The lower Index value reflects the low diversity of habitat types, substrate and in-stream cover. Stream flow (in cubic feet per second, cfs) was higher in 2011 compared to 2010, with a maximum water depth of 1.8 feet. The stream shading was similar in 2010 and 2011 for the reach. The water temperature ranged from 10.2 ºC (2010) to 15.7 ºC (2011). Specific conductivity ranged from 105 µmhos (2010) to 62 µmhos (2011). The pH ranged from 6.9 (2010) to 6.4 (2011). Dissolved oxygen values were 6.4 ppm in 2010 and 6.8 ppm in 2011.

Tailings Basin – Unnamed Creek (PM11), Trimble Creek (PM19)

Available habitat types at Unnamed Creek (PM11) included undercut banks/overhanging vegetation, emergent vegetation, submergent vegetation, woody debris, and sediment (Table 4.2). The riparian zone was characterized by reed canarygrass, alders and willows. The substrate included muck and detritus. The QHEI for the MPCA worksheet was 59/100. The slightly higher Index value reflects the somewhat better diversity of habitat types, substrate and in-stream cover. Stream flow (cfs) was higher in 2011 compared to 2010, with a maximum water depth of 1.8 to 2.0 feet. The stream shading was similar in 2010 and 2011 for the reach. The water temperature ranged from 12.4 ºC (2010) to 15.2 ºC (2011). Specific conductivity ranged from 985 µmhos (2010) to 618 µmhos (2011). The pH ranged from 7.8 (2010) to 7.9 (2011). Dissolved oxygen values were 7.1 ppm in 2010 and 7.4 ppm in 2011.

Available habitat types at Trimble Creek (PM19) included undercut banks/overhanging vegetation, emergent vegetation, woody debris, and sediment (Table 4.2). The riparian zone was characterized by reed canarygrass with some willows. The substrate included sand and silt. The QHEI for the MPCA worksheet was 46/100. The lower Index value reflects the low diversity of habitat types, substrate and in-stream cover. Stream flow (cfs) was higher in 2011 compared to 2010, with a maximum water depth of 1.5 to 2.0 feet. The stream shading was similar in 2010 and 2011 for the reach. The water temperature ranged from 11.1 ºC (2010) to 14.2 ºC (2011). Specific conductivity ranged from 628 µmhos (2010) to 435 µmhos (2011). The pH ranged from 7.8 (2010) to 7.6 (2011). Dissolved oxygen values were 7.7 ppm in 2010 and 6.8 ppm in 2011.

4.4.2 Water Chemistry

Water chemistry data collected from July 2010, September 2010, October 2010, and June 2011 were evaluated.

General Comparison and Evaluation

Bear Creek, Unnamed Creek (PM11), and Trimble Creek (PM19) were all significantly different, based on 14 of the 41 measured water chemistry parameters (Table 4-3). The following is noted.

- Of the general chemistry parameters, alkalinity, chloride, hardness, pH, total dissolved solids, specific conductance and sulfate were significantly higher in Unnamed Creek (PM11) and Trimble Creek (PM19) compared to Bear Creek.

- Of the metal concentrations, barium, boron, calcium, magnesium, molybdenum, potassium and sodium were significantly higher in Unnamed Creek (PM11) and Trimble Creek (PM19) compared to Bear Creek.

Comparison to Surface Water Standards and Criterion

The average parameter values were compared against the Minnesota Water Quality (WQ) Standards and Aquatic Life Criteria for surface waters. Of the 18 parameters for which standard criterion values are available for comparison, Trimble Creek (PM19) met the criteria for all parameters, Unnamed Creek met the criteria for 17 of the 18 parameters, and Bear Creek met the criteria for 17 of the 18 parameters (Table 4-4). No aquatic life criteria were exceeded.

For those parameters that did not meet the relevant surface water standard, the following is noted.

- Average total hardness value of 387 mg/L for Unnamed Creek (PM11) exceeded the standard of 305 mg/L.

- Average dissolved oxygen (DO) concentration of 4.8 mg/L in Bear Creek was slightly lower than the daily minimum standard of 5.0 mg/L; however, this was not surprising because Bear Creek is a low gradient and slow moving stream that drains a wetland complex. Low dissolved oxygen is typical of these types of stream reaches in the region, particularly in summer (value of 3.8 mg/L; Table 4-4).

Water Quality Classification Index

Based on the water quality classification index (Prati, et al. 1971), results were variable and dependent upon specific parameters evaluated. The following is noted with regard to the index values calculated for Bear Creek, Unnamed Creek (PM11) and Trimble Creek (PM19):

- All 3 sites were rated as ‘excellent’ for the following parameters: biological oxygen demand, chlorides, pH and total suspended solids (Table 4-5).

- Dissolved oxygen values ranged from 3.3 mg/L to 6.7 mg/L (Table 4.1), classifying all three sites as ‘acceptable’ to ‘slightly polluted’ (Table 4-5).

- Chemical oxygen demand and iron concentration were highest at Bear Creek, classifying the water as ‘slightly polluted-polluted’ and ‘heavily polluted’ respectively. By comparison, C.O.D. and iron concentrations at Unnamed Creek (PM11) and Trimble Creek (PM19) resulted in those waters being classified as ‘acceptable-slightly polluted’ (Table 4-5).

- Based on measured manganese concentrations, Bear Creek was classified as ‘acceptable-slightly polluted’, while Unnamed Creek (PM11) and Trimble Creek (PM19) were classified as ‘excellent-acceptable’ (Table 4-5).

Overall, in comparison to the reference site (Bear Creek), Unnamed Creek (PM11) and Trimble Creek (PM19) were generally classified as ‘excellent’ or ‘acceptable’ for most of the parameters in the index.

4.4.3 Macroinvertebrate Survey Data and Assessment

The total number of macroinvertebrates sampled in each stream segment is provided in Table 4-6. The data presented in Table 4-6 was then used to prepare other tables discussed in this section and related to macroinvertebrate survey results.

Taxa

Reference Stream – Bear Creek

Taxa collected at Bear Creek in 2010 and 2011 represented 6 classes and 14 orders (Tables 4-7 and 4-8). There were 32 families collected in 2010 and 34 families collected in 2011 (Table 4-7). The **classes** and orders collected in 2010 and 2011 included: **Insecta (insects) –** Coleoptera (beetles), Diptera (true flies), Ephemeroptera (mayflies), Odonata (dragonflies), Megaloptera (alderflies and dobsonflies), Lepidoptera (moths and butterflies), Plecoptera (stoneflies) and Trichoptera (caddisflies); **Crustacea (crustaceans) –** Amphipoda (scuds) and Decapoda (crayfish); **Entoprocta (brozoans)**; **Annelida (segmented worms) –** Oligochaeta (aquatic worms), Arhynchobdellida (leeches) and Rhynchobdellida (leeches); **Gastropoda (snails)** – Basommatophora (snails); **Bivalvia (bivalve clams)** – Veneroida (clams); **Malacostraca (crustaceans) –** Isopoda (pillbugs and sowbugs); **Hydrozoa (hydrozoans) –** Hydroida (hydra)**;** and **Nematoda (roundworms)**.

Classes identified at the site in 2010 and 2011 included insects, crustaceans, segmented worms, snails, and clams. Classes only identified in 2010 and 2011 were bryozoans and hydrozoans, respectively. Dominant classes in 2010 and 2011 were insects, segmented worms and crustaceans.

Orders that were identified at the site in 2010 and 2011 included beetles, true flies, mayflies, dragonflies, moths and butterflies, caddisflies, scuds, aquatic worms, leeches, snails and clams. Orders only identified in 2010 included crayfish, bryozoans and alderflies, dobsonflies and fishflies. Orders only identified in 2011 included stoneflies and hydra. Dominant orders in 2010 were true flies, caddisflies, aquatic worms and scuds; and in 2011 were mayflies, true flies, scuds and aquatic worms.

Unnamed Creek (PM11)

Taxa collected at Unnamed Creek (PM11) in 2010 and 2011 represented 5 classes and 11 orders (Tables 4-7 and 4-8). There were 22 families collected in 2010 and 31 families collected in 2011 (Table 4-7). The **classes** and orders collected in 2010 and 2011 included: **Insecta (insects) –** Coleoptera (beetles), Diptera (true flies), Ephemeroptera (mayflies), Odonata (dragonflies), Plecoptera (stoneflies) and Trichoptera (caddisflies); **Crustacea (crustaceans) –** Amphipoda (scuds); **Annelida (segmented worms) –** Oligochaeta (aquatic worms) and Rhynchobdellida (leeches); **Gastropoda (snails)** – Basommatophora (snails); and **Bivalvia (bivalve clams)** – Veneroida (clams).

Classes identified at the site in 2010 and 2011 included insects, crustaceans, segmented worms, snails, and clams. There were no unique classes identified at the sites. Dominant classes in 2010 were insects, segmented worms and crustaceans; in 2011 were insects.

Orders that were identified at the site in 2010 and 2011 included beetles, true flies, mayflies, dragonflies, stoneflies, caddisflies, scuds, aquatic worms, leeches, snails and clams. Orders only identified in 2011 included stoneflies and leeches. Dominant orders in 2010 were true flies, caddisflies and aquatic worms; and in 2011 were true flies, caddisflies and mayflies.

Trimble Creek (PM19)

Taxa collected at Bear Creek in 2010 and 2011 represented 6 classes and 11 orders (Tables 4-7 and 4-8). There were 23 families collected in 2010 and 24 families collected in 2011 (Table 4-7). The **classes** and orders collected in 2010 and 2011 included: **Insecta (insects) –** Coleoptera (beetles), Diptera (true flies), Ephemeroptera (mayflies), Odonata (dragonflies) and Trichoptera (caddisflies); **Crustacea (crustaceans) –** Amphipoda (scuds); **Annelida (segmented worms) –** Oligochaeta (aquatic worms), Arhynchnobdellida (leeches) and Rhynchnobdellida (leeches); **Gastropoda (snails)** – Basommatophora (snails); **Bivalvia (bivalve clams)** – Veneroida (clams)**;** and **Nematoda (roundworms)**.

Classes identified at the site in 2010 and 2011 included insects, crustaceans, segmented worms, snails, clams and roundworms. Classes only identified in 2011 were roundworms. Dominant classes in 2010 and 2011 were insects and segmented worms.

Orders that were identified at the site in 2010 and 2011 included beetles, true flies, mayflies, dragonflies, caddisflies, scuds, aquatic worms, leeches, snails, clams and roundworms. Orders only identified in 2010 and 2011 included leeches (Arhynchobdellida) and roundworms, respectively. Dominant orders in 2010 were true flies, mayflies and caddisflies; and in 2011 were true flies, caddisflies, mayflies and aquatic worms.

Abundance and Richness

Reference Stream – Bear Creek

The abundance of macroinvertebrates in September 2010 and June 2011 was 2,787 and 1,113, respectively (Table 4-7). The abundance was lower in the spring sampling compared to the fall sampling. The difference in abundance reflects the seasonal emergence of adults such as caddisflies, mayflies and black flies.

Richness describes the number of families or genera present within a sampled group. In 2010, there were 32 families and 46 genera collected; in 2011, there were 34 families and 43 genera collected from the site (Tables 4-2 and 4-7).

Unnamed Creek (PM11)

The abundance of macroinvertebrates in September 2010 and June 2011 was 2,484 and 1,077, respectively (Table 4-7). As found for Bear Creek (control stream), the abundance was lower in the spring sampling compared to the fall sampling. The difference in abundance reflects the seasonal emergence of adults such as caddisflies, mayflies and black flies.

Richness describes the number of families or genera present within a sampled group. In 2010, there were 22 families and 32 genera collected; in 2011, there were 31 families and 55 genera collected from the site (Tables 4-2 and 4-7).

Trimble Creek (PM19)

The abundance of macroinvertebrates in September 2010 and June 2011 was 6,998 and 376, respectively (Table 4-7). Consistent with the findings from the control stream (Bear Creek), the abundance was lower in the spring sampling compared to the fall sampling. The difference in abundance reflects the seasonal emergence of adults such as caddisflies, mayflies and black flies.

Richness describes the number of families or genera present within a sampled group. In 2010, there were 23 families and 31 genera collected; in 2011, there were 24 families and 40 genera collected from the site (Tables 4-2 and 4-7).

Shannon-Wiener Diversity Index (H´)

The index is increased either by having additional unique species or by having a greater evenness. Typically, the value of the index ranges from 1.5 (low species richness and evenness) to 3.5 (high species richness and evenness). It is useful when comparing stream sites that have similar habitats.

Reference Stream – Bear Creek

The H´ scores were similar in 2010 (2.91) and 2011 (2.42) (Table 4.2). The evenness scores were 0.75 in 2010 and 0.64 in 2011 (Table 4-2).

Unnamed Creek (PM11)

The H´ score was 2.78 in 2010 and increased in 2011 to 3.25 (Table 4.2). The evenness scores were similar in 2010 (0.78) and 2011 (0.79) (Table 4-2). The individuals were more evenly distributed among the genera in 2010 and 2011 as indicated by the higher H´ and evenness scores.

Trimble Creek (PM19)

The H´ score was 1.75 in 2010 and decreased in 2011 to 0.95 (Table 4-2). The evenness scores were 0.50 in 2010 and 0.25 in 2011 (Table 4-2). In 2010, over 70 percent of the individuals were classified in the black fly and baetis mayfly genera. In 2011, the abundance was reduced by nearly 95 percent which reduced the H´ score. The evenness score was also reduced because the individuals were unevenly distributed across the genera.

Hilsenhoff Biotic Index

Reference Stream – Bear Creek

The HBI score for 2010 was 6.36 ("fairly poor") and the score increased to 5.94 ("fair") in 2011 (Tables 4-2 and 4-11). The HBI values are scaled to **indicate improving biotic condition with decreasing values** (Table 4-10). In 2011, the number of tolerant taxa (tolerance score ≥ 7) decreased slightly which slightly improved the HBI rating from "fairly poor" to "fair".

Unnamed Creek (PM11)

The HBI score for 2010 was 6.54 ("fair") and the score increased to 5.91 ("fair") in 2011 (Tables 4-2 and 4-11). The HBI values are scaled to **indicate improving biotic condition with decreasing values** (Table 4-10). In 2011, the number of tolerant taxa (tolerance score ≥ 7) decreased over 20 percent which increased the HBI value, although the rating remained "fair".

Trimble Creek (PM19)

The HBI score for 2010 was 5.53 ("fair") and the score decreased to 5.99 ("fair") in 2011 (Tables 4-2 and 4-11). The HBI values are scaled to **indicate improving biotic condition with decreasing values** (Table 4-10). In 2011, the number of tolerant taxa (tolerance score ≥ 7) increased over 25 percent and the number of sensitive taxa (tolerance score ≤ 3) increased over 10 percent; however the HBI value decreased, although the rating remained "fair".

Other Measures of Biotic Integrity

The percentage composition of Ephemeroptera, Plecoptera and Trichoptera (% EPT) and Ephemeroptera, Plecoptera, Trichoptera and Odonata (% EPTO) are other methods used to evaluate macroinvertebrate data. These species are generally considered to be in more environmentally sensitive Orders so are better indicators of the stream quality or are more sensitive to stress. Another composition metric used to evaluate macroinvertebrate data includes percentage composition of black flies (Simulidae), non-insects (Non-Insecta), true flies (Diptera) and midges (Chironomids).

Results for these other measures of biotic integrity are summarized below.

Reference Stream – Bear Creek

In 2010, there were 14 EPT and 19 EPTO genera collected in the stream; in 2011, there were 9 EPT and 12 EPTO genera (Table 4-2). The %EPT and EPTO ranges from 24 percent to 37 percent over the two sampling events (Table 4-2). In 2010 caddisflies were one of the dominant orders, while in 2011; mayflies were a dominant order (Table 4-9). Most of the caddisfly and dragonfly species present at the site tend to be the more tolerant species that can adapt to a wide range of environmental conditions, however there are species present with tolerance values ≤ 3 (Table 4-11). No riffles were present at the site, so most of these organisms were either found on overhanging vegetation or woody debris.

The abundance of black flies (moderately sensitive) was 11 percent in 2010 and 15 percent in 2011 (Table 4-2). The percentage composition of non-insect individuals was lowest at the reference site, Bear Creek, compared to all other sites (Table 4-2). True flies comprised about one-third of the macroinvertebrates at the site, with chironomids (bloodworms) accounting for 20 to 30 percent of the true flies. The higher percentage of chironomids is typically found in slow-moving, low DO streams typically found in this area.

Unnamed Creek (PM11)

In 2010, there were 8 EPT and 10 EPTO genera collected in the stream; in 2011, there were 16 EPT and 20 EPTO genera present (Table 4-2). The % EPT and EPTO ranges from 27 percent to 35 percent over the two sampling events (Table 4-2). Most of the caddisfly and mayfly species present at the site tend to be the more tolerant species (tolerance scores 4-6) that can adapt to a wide range of environmental conditions, however there are species present with tolerance values ≤ 3 (Table 4-11). No riffles were present at the site, so most of these organisms were either found on overhanging vegetation or woody debris.

The abundance of black flies (moderately sensitive) was 9 percent in 2010 and 26 percent in 2011 (Table 4-2). The percentage composition of non-insect individuals was 35 percent at the site in 2010 and 12 percent in 2011 (Table 4-2). True flies comprised about less than 25 and 53 percent of the macroinvertebrates at the site in 2010 and 2011, respectively. Chironomids (bloodworms) accounting for over 50 percent of the true flies in 2010 and 2011.

Trimble Creek (PM19)

In 2010, there were 12 EPT and 14 EPTO genera collected in the stream; in 2011, there were 14 EPT and 16 EPTO genera present (Table 4-2). The % EPT and EPTO ranges from 42 percent to 45 percent over the two sampling events (Table 4-2). Most of the caddisfly and mayfly species present at the site tend to be the more tolerant species (tolerance scores 4-6) that can adapt to a wide range of environmental conditions, however there are species present with tolerance values ≤ 3 (Table 4-11). No riffles were present at the site, so most of these organisms were either found on overhanging vegetation or woody debris.

The abundance of black flies (moderately sensitive) was 47 percent in 2010 and 6 percent in 2011 (Table 4-2). The percentage composition of non-insect individuals was 9 percent at the site in 2010 and 22 percent in 2011 (Table 4-2). True flies comprised 49 percent of the macroinvertebrates at the site in 2010, with chironomids (bloodworms) accounting for 4 percent of the true flies. In 2011, true flies accounted for 32 percent of the individuals, with 78 percent of the true flies represented by chironomids.

4.4.4 Fish Community Assessment

At Bear Creek, 20 individuals represented by 5 species were sampled (Table 4-12). The most abundant species captured were white sucker (*Catostomus commersonii*) and Johnny darter (*Etheostoma nigrum*). At Unnamed Creek (PM11), a total of 121 individuals, represented by five species were sampled (Table 4-12). Creek chub and Northern redbelly dace were the most abundant species in the catch at Unnamed Creek (PM11). Trimble Creek (PM19) had the lowest overall abundance of fish with a total of 13 individuals represented by 5 species (Table 4-12). Overall, at least one species from each of the major trophic guilds (piscivore, insectivore and omnivore) was present at all three sites.

Measures of fish community health

Total number of species

At each of the three sites, the total number of fish species sampled was 5 (Figure 4-2a). Generally, overall species richness tends to decrease with increasing disturbance or stress. Because there was no variation in species richness among sites, this metric could not be further evaluated against any measure of stream pollution. Based on this metric, however, there was no difference between the reference condition site (Bear Creek) and the other sites, Unnamed Creek (PM11) and Trimble Creek (PM19).

Simpson's Diversity

Simpson's diversity index at Bear Creek was 3.22. By comparison, the diversity index values at Unnamed Creek (PM11) and Trimble Creek (PM19) were higher, at 3.42 and 3.93, respectively (Figure 4-2b).

When comparing all sites where fish data was collected, as expected, Simpson's diversity was negatively correlated with arsenic concentration. Bear Creek had the highest arsenic concentration and thereby, the lowest Simpson's diversity value (Figure 4-3b).

Proportion of individuals as tolerant

Tolerant individuals are generally present at a higher abundance in habitats that are degraded or indicative of poor water quality conditions. Unnamed Creek (PM11) had the lowest proportion of tolerant individuals at 0.48, followed by Bear Creek, at 0.6 (Figure 4-2c). Trimble Creek had the highest proportion of tolerant individuals at 0.85 (Figure 4-2c).

Across all sites, as expected, a positive relationship was found between proportion of individuals that were tolerant and arsenic concentration (Figure 4-3c). Bear Creek and Trimble Creek were associated with higher arsenic concentrations, while Unnamed Creek was associated with lower arsenic concentrations.

Proportion of individuals as insectivores

Bear Creek had the highest proportion of insectivores, at 0.5, followed by Trimble Creek and Unnamed Creek at 0.30 and 0.27, respectively (Figure 4-2d). Based on this metric, Bear Creek had slightly better water quality conditions for insectivores, compared to Unnamed Creek (PM11) and Trimble Creek (PM19).

Contrary to expectations, across all sites, there was a positive, albeit, weak relationship between the proportion of insectivores and arsenic concentration (Figure 4-3d). Unnamed Creek was on the lower end of the spectrum, with Bear Creek (higher arsenic concentrations) on the upper end of the spectrum.

Proportion of individuals as omnivores

Unnamed Creek (PM11) had the lowest proportion of omnivores at 0.02, followed by Trimble Creek (PM19) and Bear Creek, at 0.31 and 0.45, respectively (Figure 4-2e). The proportion of omnivores in a community is expected to increase with increasing habitat deterioration (Karr 1986). These scores suggest that the habitat in Bear Creek is more deteriorated than in either Unnamed Creek or Trimble Creek. Because Bear Creek represents background conditions, any potential habitat deterioration is related to non-mining effects and likely reflects the natural conditions of a low-gradient stream draining a wetland complex. In comparison to the reference condition site (Bear Creek), Unnamed Creek (PM11) and Trimble Creek (PM19) had a relatively low proportion of omnivorous fish and therefore, represent 'fair' conditions.

As expected, there was a strong positive relationship between the proportion of individuals as omnivores and arsenic concentration (Figure 4-3e). As found for the proportion of insectivores, Bear Creek (control stream) was at the higher end of the spectrum (higher number of omnivores and higher arsenic concentration) while Unnamed Creek was at the lower end of the spectrum. Trimble Creek was in the intermediate range.

Proportion of individuals with DELT (diseases, eroded fins, lesions, tumors) anomalies

None of the individuals sampled at Bear Creek, Unnamed Creek (PM11) and Trimble Creek (PM19) had any DELT anomalies. This metric is one of the strongest indicators of conditions of severe degradation and poor water quality conditions at a site. The absence of fish with anomalies suggests that neither Unnamed Creek (PM11) nor Trimble Creek (PM19) would be considered 'degraded'.

For comparison, Bailey et. al. (1993) found that the frequency of DELT occurrences in fish from the Minnesota River Basin was relatively low. The Minnesota River is known to have water quality issues. If fish in the Minnesota River had a low DELT occurrence, then it would be unlikely for Unnamed Creek and Trimble Creek to have DELT occurrence given the generally better water quality conditions in these two streams compared to the Minnesota River.

4.5 Conclusions

Chemistry

The chemical composition of Unnamed Creek (PM11) and Trimble Creek (PM19) is different from the surface water in Bear Creek that served as a reference site for this field investigation. Samples from Unnamed Creek (PM11) and Trimble Creek (PM19) had elevated levels of bicarbonate (measured as alkalinity), chloride, hardness, pH, total dissolved solids, boron, calcium, magnesium, potassium, molybdenum and sodium, with respect to the reference site, Bear Creek. With the possible exceptions of boron and chloride, constituents found to be elevated at Unnamed Creek (PM11) and Trimble Creek (PM19) are not traditionally viewed as “toxicants” and do not have applicable water quality criteria for aquatic life. No water quality criteria for aquatic life were exceeded at the two sites.

Macroinvertebrates

Overall, the macroinvertebrate communities in Unnamed Creek (PM11) and Trimble Creek (PM19) are comparable to the invertebrate community in the reference site (Bear Creek), and there is no evidence that the macroinvertebrate communities are being notably impacted by the seepage water from the Tailings Basin. One of the most widely used indices of community “health” is the Hilsenhoff Biotic Index (HBI). Among the three sites, Trimble Creek had the highest proportion of sensitive species and Unnamed Creek (PM11) had relatively better habitat quality (based on the QHEI) compared to Bear Creek. Due to the similarity of the macroinvertebrate communities in all three sites, and due to an overall high proportion of sensitive species, there appears to be no significant effect to the macroinvertebrate communities in Unnamed Creek (PM11) and Trimble Creek (PM19) from tailings basin water.

Fish

The fish communities at Unnamed Creek (PM11) and Trimble Creek (PM19) were compared to the fish community at the reference site, Bear Creek. While species richness was the same at all three sites, Simpson’s Diversity Index was higher at Trimble Creek (PM19) and Unnamed Creek (PM11), compared to Bear Creek. While the proportion of tolerant individuals was higher in Trimble Creek, the proportion of omnivores (a strong indicator of degraded trophic structure in a system) was lower in both Unnamed Creek (PM11) and Trimble Creek (PM19), compared to the reference site, Bear Creek. The absence of any fish with anomalies such as lesions, tumors or eroded fins, further corroborates the findings of no measurable or notable disturbance to the biological community in the streams receiving water from the Tailings Basin, Unnamed Creek (PM11) and Trimble Creek (PM19).

Summary

Overall, the results from the Stream Investigation indicate that while Unnamed Creek (PM11) and Trimble Creek (PM19) have elevated concentrations of some parameters (e.g., alkalinity, sulfate, magnesium, calcium) due to seepage to the wetlands north and west of the tailings basin, the biological monitoring data for fish and macroinvertebrates indicate no measurable or notable effects in the those streams when compared to the data from the reference stream (Bear Creek).

4.6 Recommendations for Future Work

Based on the biological monitoring data collected for the 2010-2011 Stream Investigation Study, the following is recommended.

1) No additional fish monitoring. The fish community measures indicate that the fish assemblages in Unnamed Creek and Trimble Creek are compositionally similar to those found in Bear Creek. There is no evidence of an effect to the fish community as a result of “toxicants” in the seepage from the Tailings Basin. Because this seepage water has been part of the environment for several decades and there has been no notable effect to date, there is no need to conduct additional fish monitoring.

2) No additional macroinvertebrate monitoring. The available data indicates that the macroinvertebrate community inhabiting Unnamed Creek (PM11) and Trimble Creek (PM19) is similar to the reference stream (Bear Creek). The various indices calculated from the macroinvertebrate data indicate that both Unnamed Creek (PM11) and Trimble Creek (PM19) are similar to the reference stream. The seepage from the Tailings Basin has been part of the environment for several decades and there has been no notable effect to date; therefore, there is no need to conduct additional macroinvertebrate data.

3) It is recommended that site specific standards be developed for the parameters of concern.

5.0 Methylmercury Investigation

As described in the *NPDES Field Studies Plan – Tailings Basin* (approved by the MPCA on June 16, 2010), it is unlikely that continued discharge from the tailings basin will have an effect on the sulfate and methylmercury dynamics in the Embarrass River watershed. Therefore, no additional sampling of the streams to the north/northwest of the tailings basin for methylmercury and sulfate was conducted as part of the Field Studies.

6.0 Wild Rice and Sulfate Monitoring

6.1 Background

In 2009, the MPCA requested that PolyMet and Mesabi Mining, LLC (Mesabi) provide information and data regarding wild rice stand locations, densities, and surface sulfate levels in waters potentially affected by their projects (correspondence May 28, 2009 regarding the PolyMet NorthMet and Mesabi Nugget Phase II Projects (study areas)). The request included: 1.) conducting a literature search for the presence of wild rice in downstream receiving waters, 2.) cooperating with tribes in the study areas, 3.) conducting field surveys to determine the presence of wild rice in the study areas, and 4.) determining surface sulfate levels in waters where wild rice is identified. Following the 2009 request, PolyMet and Mesabi carried out multi-phase studies in summers 2009 and 2010. PolyMet and Mesabi carried out the following activities. First, they consulted literature sources as part of determining the study areas. Second, they analyzed historic aerial photographs of the project areas and compared them to results from field surveys. Third, they determined wild rice stand density and calculated average plant height. Finally, they collected and analyzed water samples for sulfate concentrations in the study areas. The study results are documented in *2009 Wild Rice Survey and Sulfate Monitoring Prepared for Steel Dynamics, Inc. and Mesabi Mining, LLC*, October 2009, *2009 Wild Rice and Sulfate Monitoring Prepared for PolyMet Mining Inc. – NorthMet Project*, September 2009, *2010 Wild Rice Survey and Sulfate Monitoring Prepared for Mesabi Mining, LLC*, March 2011, and *2010 Wild Rice and Water Quality Monitoring Report, Prepared for PolyMet Mining Inc. – NorthMet Project*, January 2011.

6.2 Objective

The purpose of the Wild Rice Survey was to determine the presence of wild rice (*Zizania palustris* L.), an annual grass, in waterbodies potentially affected by the tailings basin seepage in the study areas. The study's purpose was also to determine sulfate levels at the locations where wild rice was found and whether sulfate affects wild rice growth and production in the study area. In particular, the objective of the Wild Rice Survey conducted under the Consent Decree was to evaluate the presence of wild rice along the stretch of the Embarrass River from the mouth of Spring Mine Creek to the Embarrass River chain of lakes. It was also to evaluate the presence of wild rice in waterbodies that were not included in the 2009 or 2010 studies conducted by PolyMet and Mesabi (Unnamed Creek (PM 11) and Trimble Creek).

6.3 Scope and Methods

Waterbodies potentially affected by the tailings basin seepage include the Embarrass River, Unnamed Creek (PM11) and Trimble Creek. As discussed in Section 6.1, the Embarrass River was surveyed for the presence of wild rice and surface water samples were analyzed for sulfate in response to the MPCA request. The results of the multi-phase studies (submitted to the MPCA in 2009 and 2011), and the findings from the MDNR’s 2008 Legislative Report on wild rice (February 2008), will form the basis for the MPCA’s determination of wild rice waterbodies potentially affected by the tailings basin seepage.

6.4 2009 Results

Wild rice was found in the upper and lower portions of the Embarrass River chain of lakes (Figure 6-1). The water bodies surveyed in 2009 included:

- Upper reach of the Embarrass River, including the confluence of Spring Mine Creek (upper Spring Mine Creek) and the Embarrass River.
- Embarrass River chain of lakes (Sabin, Wynne, Embarrass, Cedar Island, and Esquagama Lakes and unnamed stretches in between these lakes) and a 0.5 mile stretch of the Embarrass River downstream of Esquagama Lake.
- Other lakes (Hay Lake, MN lake ID 69435, to the east of the Embarrass River; Unnamed Lake, west of County Road 4).

Cedar Island Lake had qualitative estimates of wild rice density factors ranging from 1 to 4 along its perimeter (factor of 1 = low density of wild rice; factor of 5 = high density; factor of 4 indicating moderate to high density of wild rice). Wild rice was also counted by hand in 20 randomly generated – 1 m x 1 m plots within a 10 m x 10 m grid.

Sulfate concentration results are documented in *2009 Wild Rice Survey and Sulfate Monitoring Prepared for Steel Dynamics, Inc. and Mesabi Mining, LLC*, October 2009 and *2009 Wild Rice and Sulfate Monitoring Prepared for PolyMet Mining Inc. – NorthMet Project*, September 2009.

Results from historic aerial photographs have been found to be inconsistent with ground surveys. The locations of wild rice in the photographs often did not match those locations identified on the ground.

In the Upper Embarrass River, sparse stands of wild rice with density rating 1 were identified from its headwaters to the north end of Embarrass Lake. From Embarrass Lake to south of Lake Esquagama, wild rice densities ranged from 1 to 4.

Based on this information, it is not possible to determine the effects of sulfate on wild rice growth and populations.

6.5 2010 Results and Discussion

Wild rice was found in the upper and lower portions of the Embarrass River chain of lakes (Figure 6-2). The results were the same as in 2009; in the Upper Embarrass River, sparse stands of wild rice with density rating 1 were identified from its headwaters to the north end of Embarrass Lake. From Embarrass Lake to south of Esquagama, wild rice densities ranged from 1 to 4.

No wild rice was identified along Unnamed Creek (PM 11) or Trimble Creek. Portions of these streams were unnavigable by canoe or kayak and were, therefore, traversed by foot or driven by car to the extent possible. The creek beds were largely characterized by the presence of gravel, cobble, sand, loose sediments, grassy banks, and in places thick overhead canopy. A memorandum was prepared for PolyMet at the request of the MPCA and sent June 29, 2011 providing additional evidence that wild rice was not identified in Unnamed Creek (PM11).

Based on this information, it was not possible to determine the effects of sulfate on wild rice growth and populations.

6.6 Recommendations

Based on findings that sparse wild rice was identified along the upper Embarrass River and no wild rice was identified in Trimble Creek and Unnamed Creek (PM 11) in 2009 and 2010, no additional wild rice survey work is recommended for the Consent Decree Field Studies. A number of ongoing and potential future studies are being undertaken to address questions regarding sulfate and wild rice. None of these studies are related directly to the Consent Decree.

7.0 Summary

The Field Studies for the tailings basin were intended to provide a better understanding of the groundwater concentrations at the property boundary and the potential impacts of constituents that have been detected at elevated concentrations in seepage from the tailings basin on Unnamed Creek and Trimble Creek. The results from the Field Studies were also intended to be used to support either the development of recommendations for long-term mitigation alternatives or the development of site specific standards for the tailings basin surface discharges.

Briefly, the Field Studies results indicate the following:

- Manganese concentrations are highly variable in the wells surrounding the tailings basin, as well as across the region. Although a HRL of 100 µg/L has been established, manganese concentrations that exceed the HRL are observed throughout northeastern Minnesota and are not clearly related to any anthropogenic source of manganese. The mechanisms controlling manganese distribution in groundwater are complex and are highly sensitive to localized geochemical conditions in the surficial aquifer. The available data do not establish a clear link between tailings basin seepage and elevated manganese concentrations.

- With the exception of well GW014, molybdenum concentrations at the property boundary were below 30 µg/L, the former HBV and the current IM for the Permit wells. There are currently no health-based or secondary standards established by MDH or EPA for molybdenum in groundwater. Concentrations have declined in well GW014 since September 2010 and the most recent sample collected from GW014 was below 30 µg/L. Molybdenum concentrations in samples collected from residential wells north of the tailings basin are well below 30 µg/L (maximum = 1.3 µg/L), indicating that attenuation of molybdenum is occurring. In addition, there is no current health-based or secondary guidance for molybdenum.

- Sulfate concentrations did not exceed the secondary MCL at any of the property boundary wells. Sulfate concentrations decline rapidly between the tailings basin and the property boundary. This decrease is likely from some combination of dilution from precipitation-derived recharge and sulfate reduction in the wetlands and/or surficial aquifer. A separate study of sulfate loading to the Embarrass River also indicated that significant decreases in sulfate concentrations are occurring between the tailings basin and the Embarrass River.

- The secondary MCL for TDS was exceeded at only a single property boundary monitoring well (GW014). However, the elevated concentrations at this well are believed to be related to surface water discharge from the tailings basin. TDS concentrations in residential wells north of the tailings basin were below the secondary MCL, indicating that attenuation is occurring and the risk to potential receptors is minimal.

- Overall, the results from the Stream Investigation indicate that while Unnamed Creek (PM11) and Trimble Creek (PM19) have elevated concentrations of some parameters (e.g., alkalinity, sulfate, magnesium, calcium) due to seepage to the wetlands north and west of the tailings basin, the biological monitoring data for fish and macroinvertebrates indicate no measurable or notable effects in the those streams when compared to the data from the reference stream (Bear Creek).

- In the Upper Embarrass River, sparse stands of wild rice with density rating 1 were identified from its headwaters to the north end of Embarrass Lake. No wild rice was identified along Unnamed Creek (PM 11) or Trimble Creek.

8.0 Recommendations

The following recommendations are based on the results of the Field Studies for the tailings basin:

- At the present time, flow from SD004 and SD006 has been eliminated. Field Studies indicate that the aquatic life in Unnamed Creek and Trimble Creek downstream of SD004 and SD006 has not been adversely impacted by the discharge at SD004 and SD006. Therefore, no additional fish monitoring or macroinvertebrate monitoring is recommended.

- Development of site specific Permit limits for manganese, molybdenum, and TDS in groundwater is recommended.

- It is recommended that site specific standards be developed for the parameters of concern at SD004 and SD006.

- Wild rice is found in Embarrass Lake. There are sulfate sources other than the Tailings Basin upstream of the rice (SD033). A potential compliance point for SD033 and the Tailings Basin should be downstream of SD033 and the Tailings Basin and upstream of the rice and any other sulfate sources. Compliance to wild rice standard is emerging and at the present time, source mitigation has not been developed for sulfate sources to SD033. Options for passive treatment that could be applied at SD006 and SD004 are being developed. Recent water quality study activities performed for the NorthMet Project in the Embarrass River watershed have indicated that sulfate reduction is occurring in the surface waterbodies downstream from SD033 (i.e., sulfate load tends to decrease in the downstream direction). In order to better understand ramifications of this reduction related to potential long-term mitigation at the Tailings Basin (related to sulfate), it is recommended that additional study be conducted into the fate of sulfate that is discharged at SD006 and SD004. The scope of such a study has not been developed at this time. A detailed work plan would be developed prior to conducting the study into the fate of sulfate in the SD006 and SD004 discharges.

9.0 References

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Tables

Table 3-1
Groundwater Quality Data Summary - Tailings Basin Field Study
PolyMet Mining Inc./Cliffs Erie L.L.C.

		Sys Loc Code	GW-001	GW-001	GW-002	GW-002	GW-006	GW-006	GW-006		GW-007		GW-007		GW-007	GW-008	GW-008	GW-008
		Sample Date	7/26/2010	10/5/2010	10/6/2010	4/21/2011	7/26/2010	10/4/2010	4/22/2011		7/26/2010		10/4/2010		4/22/2011	7/27/2010	10/4/2010	4/22/2011
		Sample Type Code	N	N	N	N	N	N	N	FD	N	FD	N	FD	N	N	N	N
Chemical Name	Total or Dissolved	Analysis Location																
General Parameters																		
Alkalinity, bicarbonate as CaCO3	NA	Lab	339 mg/l	375 mg/l	32.7 mg/l	26.6 mg/l	654 mg/l	654 mg/l	605 mg/l	614 mg/l	285 mg/l	274 mg/l	281 mg/l	283 mg/l	304 mg/l	118 mg/l	121 mg/l	115 mg/l
Alkalinity, carbonate as CaCO3	NA	Lab	< 10 mg/l	< 20 mg/l	< 10 mg/l	< 10 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 10 mg/l	< 20 mg/l	< 10 mg/l	< 10 mg/l	< 20 mg/l	< 10 mg/l	< 10 mg/l	< 20 mg/l
Biochemical Oxygen Demand (5-day)	NA	Lab	< 3 mg/l	< 3 mg/l	< 2.4 mg/l	< 4 mg/l	< 3 mg/l	< 3 mg/l	< 2.4 mg/l	< 2.4 mg/l	< 2.4 mg/l	< 2.4 mg/l	< 2.4 mg/l	< 2.4 h mg/l	< 2.4 mg/l	< 3 mg/l	< 2.4 mg/l	< 2.4 mg/l
Carbon, dissolved organic	NA	Lab	8.9 mg/l	9.2 mg/l	2.7 mg/l	7.1 mg/l	3.2 mg/l	3.5 mg/l	2.9 mg/l	2.8 mg/l	1.9 mg/l	1.7 mg/l	2.3 mg/l	1.8 mg/l	2.2 mg/l	1.4 mg/l	1.9 mg/l	2.3 mg/l
Carbon, total organic	NA	Lab	8.5 mg/l	8.7 mg/l	1.5 mg/l	5.6 mg/l	3.1 mg/l	3.2 mg/l	2.1 mg/l	2.0 mg/l	2.1 mg/l	1.6 mg/l	1.6 mg/l	1.8 mg/l	1.4 mg/l	1.5 mg/l	1.7 mg/l	1 mg/l
Chemical Oxygen Demand	NA	Lab	32.1 mg/l	35.2 mg/l	16.5 mg/l	16.8 mg/l	12.8 mg/l	12.4 mg/l	13 mg/l	< 10 mg/l	11.5 mg/l	10.8 mg/l	10 mg/l	10.9 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l
Chloride	NA	Lab	26.4 mg/l	27.1 mg/l	< 0.5 mg/l	1.2 mg/l	18.6 mg/l	18.9 mg/l	17.7 mg/l	17.6 mg/l	29.5 mg/l	29.5 mg/l	29.5 mg/l	29.7 mg/l	27.7 mg/l	0.96 mg/l	0.61 mg/l	0.8 mg/l
Nitrate + Nitrite	NA	Lab	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	0.33 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l
Solids, total dissolved	NA	Lab	455 mg/l	509 mg/l	90 mg/l	95 mg/l	1280 mg/l	1310 mg/l	1220 mg/l	1240 mg/l	557 mg/l	517 mg/l	536 mg/l	567 mg/l	592 mg/l	151 mg/l	194 mg/l	163 mg/l
Sulfate	NA	Lab	33.4 mg/l	33.3 mg/l	6.56 mg/l	6.27 mg/l	525 mg/l	519 mg/l	455 mg/l	455 mg/l	178 mg/l	173 mg/l	165 mg/l	166 mg/l	173 mg/l	17.8 mg/l	18.2 mg/l	15.7 mg/l
pH, standard units	NA	Lab	7.7 pH units	7.4 pH units	7.0 pH units	--	7.8 pH units	7.3 pH units	--	--	7.7 pH units	7.9 pH units	7.6 pH units	7.6 pH units	--	7.0 pH units	6.8 pH units	--
pH, standard units	NA	Field	6.74 pH units	8.00 pH units	5.3 pH units	7.59 pH units	7.92 pH units	6.7 pH units	7.2 pH units	--	7.51 pH units	--	7.1 pH units	--	7.46 pH units	7.00 pH units	6.3 pH units	6.67 pH units
Water Elevation	NA	Field	--	1486.15 ft./MSL	1783.67 ft./MSL	--	1486.77 ft./MSL	1487.12 ft./MSL	1487.88 ft./MSL	--	1506.41 ft./MSL	--	1505.64 ft./MSL	--	1505.56 ft./MSL	1556.54 ft./MSL	1557.72 ft./MSL	1559.22 ft./MSL
Dissolved oxygen	NA	Field	4.62 mg/l	3.0 mg/l	8.2 mg/l	9.52 mg/l	0.96 mg/l	0.6 mg/l	1.3 mg/l	--	0.57 mg/l	--	1.4 mg/l	--	1.21 mg/l	2.03 mg/l	2.6 mg/l	2.88 mg/l
Redox (oxidation potential)	NA	Field	562 mV	560 mV	632 mV	337 mV	371 mV	326 mV	452 mV	--	391 mV	--	397 mV	--	475 mV	433 mV	419 mV	537 mV
Specific Conductance umhos@ 25oC	NA	Field	902 umhos/cm	753 umhos/cm	225 umhos/cm	37.9 umhos/cm	559 umhos/cm	1941 umhos/cm	1758 umhos/cm	--	531 umhos/cm	--	916 umhos/cm	--	931.3 umhos/cm	268 umhos/cm	274 umhos/cm	232.3 umhos/cm
Temperature, degrees C	NA	Field	7.9 deg C	8.6 deg C	13.6 deg C	12.21 deg C	12.62 deg C	12.5 deg C	6.44 deg C	--	12.5 deg C	--	11.6 deg C	--	5.9 deg C	11.2 deg C	11.1 deg C	5.21 deg C
Turbidity	NA	Field	146 NTU	2.1 NTU	16 NTU	178.1 NTU	0 NTU	1 NTU	0 NTU	--	13.7 NTU	--	< 1 NTU	--	0 NTU	2.5 NTU	1 NTU	0 NTU
Metals																		
Arsenic	Dissolved	Lab	< 1 ug/l	< 1 ug/l	< 1 ug/l	< 0.5 ug/l	3.47 ug/l	6.5 ug/l	0.94 ug/l	0.69 ug/l	< 1 ug/l	2.51 ug/l	1.64 ug/l	1.71 ug/l	0.86 ug/l	< 1 ug/l	< 1 ug/l	< 0.5 ug/l
Arsenic	Total	Lab	< 1 ug/l	< 1 ug/l	< 1 ug/l	0.96 ug/l	5.75 ug/l	6.62 ug/l	0.8 ug/l	0.66 ug/l	1.33 ug/l	3.32 ug/l	1.58 ug/l	1.58 ug/l	0.84 ug/l	< 1 ug/l	< 1 ug/l	< 0.5 ug/l
Calcium	Total	Lab	61800 ug/l	77500 ug/l	9740 ug/l	9800 ug/l	104000 ug/l	109000 ug/l	96800 ug/l	97200 ug/l	51800 ug/l	50600 ug/l	52100 ug/l	52200 ug/l	52500 ug/l	23400 ug/l	24400 ug/l	21800 ug/l
Iron	Dissolved	Lab	7850 ug/l	9430 ug/l	< 50 ug/l	288 ug/l	4200 ug/l	4810 ug/l	144 ug/l	126 ug/l	< 50 * ug/l	132 * ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l
Iron	Total	Lab	8690 ug/l	10800 ug/l	2320 ug/l	6810 ug/l	5770 ug/l	4700 ug/l	148 ug/l	148 ug/l	401 ug/l	536 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	1040 ug/l	< 50 ug/l	< 50 ug/l
Magnesium	Total	Lab	42100 ug/l	46400 ug/l	3460 ug/l	3500 ug/l	202000 ug/l	215000 ug/l	198000 ug/l	195000 ug/l	68900 ug/l	69300 ug/l	69800 ug/l	70200 ug/l	73600 ug/l	19600 ug/l	20400 ug/l	18300 ug/l
Manganese	Dissolved	Lab	3620 ug/l	3160 ug/l	1.88 ug/l	5.75 ug/l	1150 ug/l	1260 ug/l	524 ug/l	495 ug/l	1380 ug/l	1300 ug/l	1280 ug/l	1340 ug/l	1270 ug/l	60.8 ug/l	19.7 ug/l	18.3 ug/l
Manganese	Total	Lab	2940 ug/l	3440 ug/l	39.4 ug/l	128 ug/l	1220 ug/l	1160 ug/l	541 ug/l	548 ug/l	2380 * ug/l	1450 * ug/l	1260 ug/l	1250 ug/l	1300 ug/l	58.4 ug/l	18.9 ug/l	24.4 ug/l
Molybdenum	Dissolved	Lab	10.2 ug/l	9.64 ug/l	< 0.2 ug/l	< 0.2 ug/l	27.9 ug/l	27.5 ug/l	27.3 ug/l	25.6 ug/l	32.2 ug/l	34.2 ug/l	30.7 ug/l	31.2 ug/l	29.5 ug/l	0.29 ug/l	0.24 ug/l	0.2 ug/l
Molybdenum	Total	Lab	9.95 ug/l	10.1 ug/l	0.22 ug/l	< 5 ug/l	27.4 ug/l	28.8 ug/l	27.8 ug/l	27.5 ug/l	28.8 ug/l	32.2 ug/l	31.7 ug/l	33.6 ug/l	29.7 ug/l	0.23 ug/l	0.21 ug/l	< 5 ug/l
Potassium	Total	Lab	3460 ug/l	3260 ug/l	930 ug/l	1180 ug/l	13600 ug/l	13600 ug/l	6840 ug/l	6840 ug/l	9600 ug/l	8830 ug/l	9380 ug/l	9280 ug/l	7630 ug/l	1800 ug/l	1810 ug/l	1360 ug/l
Sodium	Total	Lab	51300 ug/l	53300 ug/l	3330 ug/l	2490 ug/l	60100 ug/l	63100 ug/l	54200 ug/l	53600 ug/l	47000 ug/l	47200 ug/l	48800 ug/l	48600 ug/l	50100 ug/l	5670 ug/l	5620 ug/l	5070 ug/l

Table 3-1
Groundwater Quality Data Summary - Tailings Basin Field Study
PolyMet Mining Inc./Cliffs Erie L.L.C.

Sys Loc Code			GW-009	GW-009	GW-009	GW-010	GW-010		GW-010		GW-011		GW-011	GW-011	GW-012	GW-012	
Sample Date			**7/28/2010**	**10/8/2010**	**5/2/2011**	**7/28/2010**	**10/8/2010**		**5/2/2011**		**7/28/2010**		**10/8/2010**	**4/28/2011**	**7/26/2010**	**10/5/2010**	
Sample Type Code			**N**	**N**	**N**	**N**	**N**	**FD**	**N**	**FD**	**N**	**FD**	**N**	**N**	**N**	**N**	**FD**
Chemical Name	Total or Dissolved	Analysis Location															
General Parameters																	
Alkalinity, bicarbonate as CaCO3	NA	Lab	**215 mg/l**	**239 mg/l**	**212 mg/l**	**294 mg/l**	**289 mg/l**	**288 mg/l**	**278 mg/l**	**277 mg/l**	**46.3 mg/l**	**47.5 mg/l**	**46 mg/l**	**47 mg/l**	**521 mg/l**	**572 mg/l**	**554 mg/l**
Alkalinity, carbonate as CaCO3	NA	Lab	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l
Biochemical Oxygen Demand (5-day)	NA	Lab	< 3 mg/l	< 2.4 mg/l	< 4 mg/l	< 3 mg/l	< 3 mg/l	< 3 mg/l	< 3 mg/l	< 3 mg/l	< 3 mg/l	< 3 mg/l	< 2.4 mg/l	< 2.4 mg/l	< 3 mg/l	< 2.4 mg/l	< 2.4 mg/l
Carbon, dissolved organic	NA	Lab	**21.3 mg/l**	**20.2 mg/l**	**15.9 mg/l**	**10.1 mg/l**	**10.2 mg/l**	**9.8 mg/l**	**12.4 mg/l**	**12.5 mg/l**	**1.8 mg/l**	**1.3 mg/l**	**2.5 mg/l**	**1.6 mg/l**	**5.3 mg/l**	**5.2 mg/l**	**5.5 mg/l**
Carbon, total organic	NA	Lab	**25.5 mg/l**	**21.0 mg/l**	**15.9 mg/l**	**10.4 mg/l**	**10.1 mg/l**	**9.8 mg/l**	**11.9 mg/l**	**11.9 mg/l**	**1.7 mg/l**	**1.6 mg/l**	**1.1 mg/l**	**1.1 mg/l**	**4.2 mg/l**	**4.8 mg/l**	**4.9 mg/l**
Chemical Oxygen Demand	NA	Lab	**60.1 mg/l**	**72 mg/l**	**47.4 mg/l**	**26.6 mg/l**	**36.8 mg/l**	**35.8 mg/l**	**39.3 mg/l**	**36.7 mg/l**	< 10 mg/l	< 10 mg/l	**15.6 mg/l**	< 10 mg/l	**13.2 mg/l**	**18.1 mg/l**	**16.7 mg/l**
Chloride	NA	Lab	**2.6 mg/l**	**2.08 mg/l**	**3.16 mg/l**	**16.8 mg/l**	**17.2 mg/l**	**17.2 mg/l**	**16.9 mg/l**	**16.8 mg/l**	**1.01 mg/l**	**0.99 mg/l**	**0.81 mg/l**	**1.42 mg/l**	**20.7 mg/l**	**22 mg/l**	**21.9 mg/l**
Nitrate + Nitrite	NA	Lab	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l	**0.19 mg/l**	**0.19 mg/l**	**0.19 mg/l**	**0.31 mg/l**	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l
Solids, total dissolved	NA	Lab	**396 mg/l**	**396 mg/l**	**358 mg/l**	**313 mg/l**	**340 mg/l**	**321 mg/l**	**337 mg/l**	**343 mg/l**	**65 mg/l**	**78 mg/l**	**100 mg/l**	**94 mg/l**	**979 mg/l**	**1090 mg/l**	**1110 mg/l**
Sulfate	NA	Lab	**92.2 mg/l**	**64.4 mg/l**	**59.7 mg/l**	**2.98 mg/l**	**3.65 mg/l**	**3.66 mg/l**	**1.87 mg/l**	**1.81 mg/l**	**5.68 mg/l**	**5.77 mg/l**	**5.54 mg/l**	**6.17 mg/l**	**332 mg/l**	**372 mg/l**	**373 mg/l**
pH, standard units	NA	Lab	**7.0 pH units**	**7.0 pH units**	--	**7.0 pH units**	**7.2 pH units**	**7.0 pH units**	--	--	**6.7 pH units**	**6.7 pH units**	**6.8 pH units**	--	**7.7 pH units**	**7.6 pH units**	**7.7 pH units**
pH, standard units	NA	Field	**7.49 pH units**	**6.79 pH units**	**6.61 pH units**	**7.13 pH units**	**6.49 pH units**	--	**6.72 pH units**	--	**7.16 pH units**	--	**5.5 pH units**	**6.41 pH units**	**7.26 pH units**	**7.5 pH units**	--
Water Elevation	NA	Field	**1469.63 ft./MSL**	**1469.96 ft./MSL**	**1469.89 ft./MSL**	**1473.38 ft./MSL**	**1473.45 ft./MSL**	--	--	--	**1468.77 ft./MSL**	--	**1468.11 ft./MSL**	**1468.53 ft./MSL**	**1489.91 ft./MSL**	**1490.04 ft./MSL**	--
Dissolved oxygen	NA	Field	**0.42 mg/l**	**3.66 mg/l**	**3.57 mg/l**	**0.28 mg/l**	**0.64 mg/l**	--	**1.41 mg/l**	--	**11.84 mg/l**	--	**7.1 mg/l**	**7.05 mg/l**	**1.49 mg/l**	**0.4 mg/l**	--
Redox (oxidation potential)	NA	Field	**381 mV**	**194 mV**	**651 mV**	**370 mV**	**144 mV**	--	**597 mV**	--	**406 mV**	--	**466 mV**	**358 mV**	**388 mV**	**581 mV**	--
Specific Conductance umhos@ 25oC	NA	Field	**608 umhos/cm**	**589 umhos/cm**	**538.7 umhos/cm**	**535 umhos/cm**	**573 umhos/cm**	--	**574.1 umhos/cm**	--	**102 umhos/cm**	--	**182 umhos/cm**	**72.6 umhos/cm**	**573 umhos/cm**	**1445 umhos/cm**	--
Temperature, degrees C	NA	Field	**11.97 deg C**	**13.9 deg C**	**3.9 deg C**	**8.2 deg C**	**7.2 deg C**	--	**6.9 deg C**	--	**11.97 deg C**	--	**14.7 deg C**	**10.54 deg C**	**13.2 deg C**	**12.7 deg C**	--
Turbidity	NA	Field	**369 NTU**	**175 NTU**	**2543 NTU**	**14.1 NTU**	**1 NTU**	--	**4.8 NTU**	--	**254 NTU**	--	**920 NTU**	**61.5 NTU**	**28.5 NTU**	**0 NTU**	--
Metals																	
Arsenic	Dissolved	Lab	< 1 ug/l	< 1 ug/l	**0.77 ug/l**	**1.18 ug/l**	**1.41 ug/l**	**1.46 ug/l**	**2.41 ug/l**	**2.37 ug/l**	< 1 ug/l	< 1 ug/l	< 1 ug/l	< 0.5 ug/l	< 1 ug/l	< 1 ug/l	< 1 ug/l
Arsenic	Total	Lab	**1.56 ug/l**	**2.27 ug/l**	**4.28 ug/l**	**1.25 ug/l**	**1.62 ug/l**	**1.61 ug/l**	**1.84 ug/l**	**1.98 ug/l**	**1.29 * ug/l**	**2.25 * ug/l**	**4.51 ug/l**	**0.78 ug/l**	**1.02 ug/l**	< 1 ug/l	< 1 ug/l
Calcium	Total	Lab	**38000 ug/l**	**44000 ug/l**	**51100 ug/l**	**54200 ug/l**	**56500 ug/l**	**56400 ug/l**	**48600 ug/l**	**48400 ug/l**	**13600 ug/l**	**14800 ug/l**	**17600 ug/l**	**13700 ug/l**	**142000 ug/l**	**148000 ug/l**	**144000 ug/l**
Iron	Dissolved	Lab	**7390 ug/l**	**1140 ug/l**	**6520 ug/l**	**8540 ug/l**	**5960 ug/l**	**5900 ug/l**	**9080 ug/l**	**9040 ug/l**	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	**88.9 ug/l**	**90.4 ug/l**
Iron	Total	Lab	**18300 ug/l**	**20300 ug/l**	**83900 ug/l**	**8930 ug/l**	**6730 ug/l**	**6800 ug/l**	**9780 ug/l**	**9830 ug/l**	**10600 * ug/l**	**16000 * ug/l**	**18600 ug/l**	**4560 ug/l**	**8270 ug/l**	**166 ug/l**	**165 ug/l**
Magnesium	Total	Lab	**22900 ug/l**	**27600 ug/l**	**37700 ug/l**	**30600 ug/l**	**31300 ug/l**	**31100 ug/l**	**27100 ug/l**	**27100 ug/l**	**8950 ug/l**	**10600 ug/l**	**12400 ug/l**	**7410 ug/l**	**87300 ug/l**	**98100 ug/l**	**97900 ug/l**
Manganese	Dissolved	Lab	**17.3 ug/l**	**3050 ug/l**	**3520 ug/l**	**254 ug/l**	**490 ug/l**	**520 ug/l**	**383 ug/l**	**381 ug/l**	**17 ug/l**	**15.9 ug/l**	**2.43 ug/l**	**1.89 ug/l**	**171 ug/l**	**411 ug/l**	**402 ug/l**
Manganese	Total	Lab	**2940 ug/l**	**3350 ug/l**	**4220 ug/l**	**272 ug/l**	**462 ug/l**	**454 ug/l**	**365 ug/l**	**363 ug/l**	**195 ug/l**	**274 ug/l**	**582 ug/l**	**148 ug/l**	**286 ug/l**	**399 ug/l**	**410 ug/l**
Molybdenum	Dissolved	Lab	**0.26 ug/l**	**7.82 ug/l**	**4.23 ug/l**	**0.24 ug/l**	**0.27 ug/l**	**0.27 ug/l**	**0.42 ug/l**	**0.38 ug/l**	**0.23 ug/l**	**0.24 ug/l**	< 0.2 ug/l	**0.28 ug/l**	**35.7 ug/l**	**33.3 ug/l**	**33.3 ug/l**
Molybdenum	Total	Lab	**10.1 ug/l**	**8.76 ug/l**	**6.25 ug/l**	**0.22 ug/l**	**0.26 ug/l**	**0.27 ug/l**	**0.34 ug/l**	**0.33 ug/l**	**0.49 ug/l**	**0.56 ug/l**	**0.83 ug/l**	**0.33 ug/l**	**36.3 ug/l**	**34.2 ug/l**	**32.2 ug/l**
Potassium	Total	Lab	**3680 ug/l**	**4640 ug/l**	**7140 ug/l**	**2450 ug/l**	**2520 ug/l**	**2540 ug/l**	**1990 ug/l**	**1930 ug/l**	**2400 ug/l**	**2930 ug/l**	**3140 ug/l**	**1720 ug/l**	**4820 ug/l**	**4240 ug/l**	**4420 ug/l**
Sodium	Total	Lab	**77600 ug/l**	**59800 ug/l**	**46700 ug/l**	**33700 ug/l**	**34300 ug/l**	**34400 ug/l**	**34500 ug/l**	**34400 ug/l**	**4030 ug/l**	**4490 ug/l**	**4520 ug/l**	**4210 ug/l**	**106000 ug/l**	**116000 ug/l**	**114000 ug/l**

Table 3-1
Groundwater Quality Data Summary - Tailings Basin Field Study
PolyMet Mining Inc./Cliffs Erie L.L.C.

		Sys Loc Code	**GW-012**		**GW-013**		**GW-013**		**GW-013**		**GW-014**	**GW-014**	**GW-014**	**GW-015**	**GW-015**	**GW-015**
		Sample Date	**4/27/2011**		**7/30/2010**		**10/8/2010**		**4/28/2011**		**7/30/2010**	**10/8/2010**	**4/27/2011**	**7/30/2010**	**10/8/2010**	**5/2/2011**
		Sample Type Code	**N**	**FD**	**N**	**FD**	**N**	**FD**	**N**	**FD**	**N**	**N**	**N**	**N**	**N**	**N**
Chemical Name	Total or Dissolved	Analysis Location														
General Parameters																
Alkalinity, bicarbonate as CaCO3	NA	Lab	**654 mg/l**	**641 mg/l**	**17.6 mg/l**	**17 mg/l**	**16 mg/l**	**16.1 mg/l**	**12.7 mg/l**	**14.5 mg/l**	**317 mg/l**	**507 mg/l**	**443 mg/l**	**118 mg/l**	**109 mg/l**	**107 mg/l**
Alkalinity, carbonate as CaCO3	NA	Lab	< 20 mg/l	< 20 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 20 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l
Biochemical Oxygen Demand (5-day)	NA	Lab	< 2.4 mg/l	< 2.4 mg/l	< 2.4 mg/l	< 2.4 mg/l	< 2.4 mg/l	< 2.4 mg/l	< 2.4 mg/l	< 2.4 mg/l	**9.7 mg/l**	**3.8 mg/l**	< 4 mg/l	< 2.4 mg/l	< 3 mg/l	< 2.4 mg/l
Carbon, dissolved organic	NA	Lab	**5.6 mg/l**	**5.5 mg/l**	**3.5 mg/l**	**3.3 mg/l**	**2.6 mg/l**	**2.7 mg/l**	**5.2 mg/l**	**5.1 mg/l**	**12.4 mg/l**	**14.9 mg/l**	**12.3 mg/l**	**3.6 mg/l**	**3.1 mg/l**	**3.5 mg/l**
Carbon, total organic	NA	Lab	**5.3 mg/l**	**5.1 mg/l**	**3.5 mg/l**	**3.4 mg/l**	**2.5 mg/l**	**2.6 mg/l**	**4.6 mg/l**	**4.5 mg/l**	**11.9 mg/l**	**13.8 mg/l**	**12.0 mg/l**	**3.7 mg/l**	**2.7 mg/l**	**2.8 mg/l**
Chemical Oxygen Demand	NA	Lab	**16.4 mg/l**	**13.8 mg/l**	< 10 mg/l	< 10 mg/l	**11.5 mg/l**	**12 mg/l**	**17.4 mg/l**	**20.4 mg/l**	**39.3 mg/l**	**53.5 mg/l**	**31.8 mg/l**	< 10 mg/l	**16.2 mg/l**	< 10 mg/l
Chloride	NA	Lab	**17.4 mg/l**	**17.5 mg/l**	**0.7 j mg/l**	**0.7 j mg/l**	< 0.5 mg/l	< 0.5 mg/l	< 0.5 mg/l	< 0.5 mg/l	**20.4 mg/l**	**19.5 mg/l**	**16.9 mg/l**	**4.8 mg/l**	**1.01 mg/l**	**0.58 mg/l**
Nitrate + Nitrite	NA	Lab	< 0.1 mg/l	< 0.1 mg/l	**0.16 mg/l**	**0.14 mg/l**	**0.18 mg/l**	**0.18 mg/l**	**0.12 mg/l**	**0.11 mg/l**	**0.51 mg/l**	< 0.1 mg/l	**0.11 mg/l**	< 0.1 mg/l	< 0.1 mg/l	< 0.1 mg/l
Solids, total dissolved	NA	Lab	**1250 mg/l**	**1270 mg/l**	**85 mg/l**	**79 mg/l**	**39 mg/l**	**38 mg/l**	**57 mg/l**	**59 mg/l**	**651 mg/l**	**653 mg/l**	**617 mg/l**	**212 mg/l**	**143 mg/l**	**151 mg/l**
Sulfate	NA	Lab	**433 mg/l**	**435 mg/l**	**4.1 mg/l**	**4 mg/l**	**2.64 mg/l**	**2.59 mg/l**	**3.23 mg/l**	**3.31 mg/l**	**211 mg/l**	**75.2 mg/l**	**77.9 mg/l**	**38.6 mg/l**	**12.5 mg/l**	**7.13 mg/l**
pH, standard units	NA	Lab	--	--	**6.9 pH units**	**6.7 pH units**	**6.4 pH units**	**6.5 pH units**	--	--	**7.7 pH units**	**7.3 pH units**	--	**7.9 pH units**	**7.6 pH units**	--
pH, standard units	NA	Field	**7.05 pH units**	--	**6.59 pH units**	--	**5.6 pH units**	--	**5.45 pH units**	--	**7.01 pH units**	**6.9 pH units**	**6.94 pH units**	**7.60 pH units**	**7.43 pH units**	**7.41 pH units**
Water Elevation	NA	Field	**1490.39 ft./MSL**		**1461.51 ft./MSL**	--	**1461.87 ft./MSL**	--	--	--	**1445.20 ft./MSL**	**1447.30 ft./MSL**	**1447.74 ft./MSL**	**1415.87 ft./MSL**	**1417.23 ft./MSL**	--
Dissolved oxygen	NA	Field	**3.55 mg/l**	--	**8.62 mg/l**	--	**5.8 mg/l**	--	**9.57 mg/l**	--	**3.58 mg/l**	**2.4 mg/l**	**1.19 mg/l**	**0 mg/l**	**0.75 mg/l**	**1.54 mg/l**
Redox (oxidation potential)	NA	Field	**353 mV**	--	**397 mV**	--	**583 mV**	--	**364 mV**	--	**143 mV**	**127 mV**	**208 mV**	**35 mV**	**228 mV**	**472 mV**
Specific Conductance umhos@ 25oC	NA	Field	**1841 umhos/cm**	--	**34.4 umhos/cm**	--	**35 umhos/cm**	--	**0 umhos/cm**	--	**505 umhos/cm**	**1022 umhos/cm**	**1001 umhos/cm**	**312 umhos/cm**	**227 umhos/cm**	**199.1 umhos/cm**
Temperature, degrees C	NA	Field	**5.57 deg C**	--	**7.87 deg C**	--	**9.6 deg C**	--	**9.57 deg C**	--	**11.03 deg C**	**14.9 deg C**	**3.61 deg C**	**8.69 deg C**	**7.2 deg C**	**6.1 deg C**
Turbidity	NA	Field	**6.8 NTU**	--	**45.5 NTU**	--	**5.6 NTU**	--	**5 NTU**	--	**530 NTU**	**64 NTU**	**223 NTU**	**66 NTU**	**303 NTU**	**161.7 NTU**
Metals																
Arsenic	Dissolved	Lab	**0.66 ug/l**	**0.69 ug/l**	< 1 ug/l	< 1 ug/l	< 1 ug/l	< 1 ug/l	< 0.5 ug/l	< 0.5 ug/l	< 1 ug/l	**1.14 ug/l**	**1.08 ug/l**	< 1 ug/l	< 1 ug/l	**1 ug/l**
Arsenic	Total	Lab	< 0.5 ug/l	< 0.5 ug/l	< 1 ug/l	< 1 ug/l	< 1 ug/l	< 1 ug/l	< 0.5 ug/l	< 0.5 ug/l	**4.66 ug/l**	**1.52 ug/l**	**1.28 ug/l**	< 1 ug/l	**1.29 ug/l**	< 1 ug/l
Calcium	Total	Lab	**179000 ug/l**	**176000 ug/l**	**4250 ug/l**	**4390 ug/l**	**4050 ug/l**	**4010 ug/l**	**3120 ug/l**	**3430 ug/l**	**129000 ug/l**	**99100 ug/l**	**100000 ug/l**	**38700 ug/l**	**30300 ug/l**	**27200 ug/l**
Iron	Dissolved	Lab	< 50 ug/l	< 50 ug/l	**103 ug/l**	**100 ug/l**	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	**2150 ug/l**	**4770 ug/l**	**10800 ug/l**	**89.6 ug/l**	< 50 ug/l	**62.1 ug/l**
Iron	Total	Lab	**255 ug/l**	**286 ug/l**	**1830 ug/l**	**2090 ug/l**	**113 ug/l**	**115 ug/l**	**364 ug/l**	**340 ug/l**	**87300 ug/l**	**8200 ug/l**	**19000 ug/l**	**3230 ug/l**	**1420 ug/l**	**5800 ug/l**
Magnesium	Total	Lab	**118000 ug/l**	**118000 ug/l**	**2030 ug/l**	**2140 ug/l**	**1610 ug/l**	**1600 ug/l**	**1330 ug/l**	**1510 ug/l**	**75100 ug/l**	**65000 ug/l**	**60800 ug/l**	**16000 ug/l**	**12300 ug/l**	**12300 ug/l**
Manganese	Dissolved	Lab	**390 ug/l**	**397 ug/l**	**29 ug/l**	**28.1 ug/l**	**2.82 ug/l**	**3.02 ug/l**	**1.28 ug/l**	**1.36 ug/l**	**1750 ug/l**	**1920 ug/l**	**1810 ug/l**	**294 ug/l**	**491 ug/l**	**541 ug/l**
Manganese	Total	Lab	**404 ug/l**	**405 ug/l**	**36.4 ug/l**	**39.7 ug/l**	**4.36 ug/l**	**4.37 ug/l**	**5.44 ug/l**	**5.39 ug/l**	**2600 ug/l**	**1980 ug/l**	**2050 ug/l**	**730 ug/l**	**575 ug/l**	**602 ug/l**
Molybdenum	Dissolved	Lab	**31.8 ug/l**	**31.9 ug/l**	**0.23 ug/l**	**0.23 ug/l**	< 0.2 ug/l	< 0.2 ug/l	< 0.2 ug/l	< 0.2 ug/l	**35.8 ug/l**	**40.8 ug/l**	**16.2 ug/l**	**3.28 ug/l**	**16.6 ug/l**	**5.76 ug/l**
Molybdenum	Total	Lab	**31.6 ug/l**	**31.6 ug/l**	**0.3 ug/l**	**0.3 ug/l**	< 0.2 ug/l	< 0.2 ug/l	< 0.2 ug/l	< 0.2 ug/l	**45.2 ug/l**	**41.6 ug/l**	**15.8 ug/l**	**8.4 ug/l**	**17.1 ug/l**	**5.9 ug/l**
Potassium	Total	Lab	**2960 ug/l**	**2920 ug/l**	**580 ug/l**	**640 ug/l**	**340 ug/l**	**340 ug/l**	**260 ug/l**	**360 ug/l**	**11000 ug/l**	**5610 ug/l**	**4400 ug/l**	**2430 ug/l**	**1860 ug/l**	**2410 ug/l**
Sodium	Total	Lab	**131000 ug/l**	**130000 ug/l**	< 2000 ug/l	< 2000 ug/l	< 2000 ug/l	< 2000 ug/l	< 2000 ug/l	< 2000 ug/l	**56800 ug/l**	**60700 ug/l**	**60100 ug/l**	**9760 ug/l**	**6420 ug/l**	**6030 ug/l**

Data Qualifiers/Footnotes

Qualifier	Definition
--	Not analyzed/not available.
a	Estimated value, calculated using some or all values that are estimates.
b	Potential false positive value based on blank data validation procedures.
c	Coeluting compound.
e	Estimated value, exceeded the instrument calibration range.
h	EPA recommended sample preservation, extraction or analysis holding time was exceeded.
I	Indeterminate value based on failure of blind duplicate data to meet quality assurance criteria.
j	Reported value is less than the stated laboratory quantitation limit and is considered an estimated value.
p	Relative percent difference is >40% (25% CLP pesticides) between primary and confirmation GC columns.
pp	Small peak in chromatogram below method detection limit.
r	The presence of the compound is suspect based on the ID criteria of the retention time and relative retention time obtained from the examination of the chromatograms.
s	Potential false positive value based on statistical analysis of blank sample data.
*	Estimated value, QA/QC criteria not met.
**	Unusable value, QA/QC criteria not met.
N	Sample Type: Normal
FD	Sample Type: Field Duplicate
AT	Sample chromatogram is noted to be atypical of a petroleum product.
DLND	Not detected, detection limit not determined.
DF	Did not flash
EMPC	Estimated maximum possible concentration.
NA – (Not applicable)	NA indicates that a fractional portion of the sample is not part of the analytical testing or field collection procedures.
ND	Not detected.
TIC	Tentatively identified compound
BQA	Barr-applied project specific qualifier: extraction and/or analyses conducted using an alternative method and/or procedure.
BQC	Barr-applied project specific qualifier: plant shut down.
BQD	Barr-applied project specific qualifier: equipment malfunction.
BQE	Barr-applied project specific qualifier: equipment adjustment.
BQM	Barr-applied project specific qualifier: manual measurement.
BQN	Barr-applied project specific qualifier: unable to be sampled or measured due to various reasons.
BQP	Barr-applied project specific qualifier: atypical chromatographic pattern.
BQQ	Barr-applied project specific qualifier: some aspect of QA/QC was not met.
BQR	Barr-applied project specific qualifier: location was re-sampled.
BQS	Barr-applied project specific qualifier: data is considered suspect.
BQT	Barr-applied project specific qualifier: summed value not displayed due to insufficient field length.
BQU	Barr-applied project specific qualifier: historical qualifier - definition unknown.
BQV	Barr-applied project specific qualifier: estimated value.
BQX	Barr-applied project specific qualifier: see notes for qualifier definition.
BQZ	Barr-applied project specific qualifier: data is considered unusable.

Table 4-1 Summary of water chemistry parameters, including metal concentrations.

Field and laboratory data for Bear Creek, Unnamed Creek (PM11) and Trimble Creek (PM19) for Summer (July 26, 2010), Fall (mean of Sept 14, 2010 and Oct 26, 2010), and Spring (June 2, 2011).

Site	**Bear Creek**			**Unnamed Creek (PM11)**			**Trimble Creek (PM19)**		
Sampling date	**Summer ‘10**	**Fall ‘10**	**Spring ‘11**	**Summer ‘10**	**Fall ‘10**	**Spring ‘11**	**Summer ‘10**	**Fall ‘10**	**Spring ‘11**
General Parameters (mg/L unless noted)									
Total Alkalinity	39.3	43.75	35.7	340	343	222	286	296	197
Biochemical Oxygen Demand (5-day)	2	1.75	1.5	1.5	1.5	1.5	1.5	1.5	1.2
Dissolved Organic Carbon	35.4	16.7	17	14.3	11.9	12.6	24.5	16.6	16.6
Total Organic Carbon	35.3	20.6	17.4	14.5	10.3	12.9	24.5	25.2	17.2
Chemical Oxygen Demand	92.7	58.1	56.9	36.8	35.8	38.8	65.5	42.4	52.1
Chloride	1.26	0.745	0.25	13.2	19.5	10.6	9.98	12.9	11.3
Dissolved oxygen	3.8	5.13	5.49	3.28	6.7	6.67	3.7	5.7	8.93
Total Hardness, as CaCO3	51.4	54.35	39.9	417	441	302	249	262	191
Nitrate + Nitrite	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Total Nitrogen (kjeldahl)	2.21	2.35	0.25	1.17	1.11	1.28	1.42	1.37	1.27
Total Nitrogen (N2)	2.21	2.45	0.25	1.17	1.21	1.28	1.42	1.47	1.27
pH	6.59	6.61	6.96	7.66	7.79	7.99	7.5	7.59	7.64
Total Phosphorus	0.056	0.0355	0.021	0.046	0.014	0.018	0.034	0.02	0.023
Total Dissolved Solids	94	81.5	77	565	564	403	361	353	284
Total Suspended Solids	2.5	20.15	1.6	4	2.5	3.6	3.2	3.2	2
Specific Conductance umhos@ 25°C	90	95.55	55	912	919.1	638	600	619.6	440
Sulfate	0.5	1.18	0.5	122	143	92.5	4.31	10.5	22
Temperature (°C)	20.82	10.71	12.77	21.9	12.23	14.12	20.36	12.44	11.78
Turbidity (NTU)	5.1	3.2	0	0	2.1	0	0	2.8	0

Site	**Bear Creek**			**Unnamed Creek (PM11)**			**Trimble Creek (PM19)**		
Sampling date	**Summer ‘10**	**Fall ‘10**	**Spring ‘11**	**Summer ‘10**	**Fall ‘10**	**Spring ‘11**	**Summer ‘10**	**Fall ‘10**	**Spring ‘11**
Metals (µg/L unless noted)									
Antimony			0.25			0.25			
Arsenic	1.96	0.82	0.25	0.50	0.50	0.25	1.50	1.15	0.25
Barium	35.6	35.7	22.7	41.6	30.4	24.9	78.7	62.6	52.0
Beryllium	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Boron	25	25	25	270	251	198	149	143	138
Cadmium	0.10	0.02	0.10	0.10	0.03	0.10	0.10	0.01	0.10
Calcium (mg/L)	15.20	17.15	12.80	46.80	47.00	38.50	42.20	43.00	31.70
Chromium	0.50	2.09	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Cobalt	0.53	0.68	0.10	0.10	0.10	0.10	0.27	0.10	0.10
Copper	0.82	1.12	0.35	0.82	0.86	0.35	0.74	0.77	0.35
Iron	6490	2940	1110	309	243	251	1650	596	350
Lead	0.25	0.36	0.25	0.25	0.06	0.25	0.25	0.05	0.25
Magnesium (mg/L)	3.26	2.80	1.93	73.00	78.60	50.00	34.80	37.50	27.20
Manganese	218.0	284.0	140.0	138.0	65.1	49.5	199.0	80.6	24.2
Molybdenum	0.41	0.15	0.10	11.50	13.00	9.56	1.49	1.44	1.60
Nickel	2.12	1.86	0.67	1.52	1.33	1.06	1.42	1.20	0.90
Potassium	0.55	1.14	0.92	6.23	8.22	5.32	2.96	3.01	2.78
Selenium	0.50	0.20	0.06	0.50	0.61	0.06	0.50	0.59	0.06
Silver	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Sodium (mg/L)	1.0	1.0	1.0	50.0	52.0	31.2	42.4	46.4	32.2
Thallium	0.26	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Tin	0.25	0.25		0.25	0.25		0.25	0.25	
Zinc	3.00	4.70	3.00	3.00	3.00	3.00	3.00	3.00	3.00

Table 4-2 Habitat characteristics and macroinvertebrate data summary for stream sampling sites.

Parameter	**Bear Creek (reference)**		**Unnamed Creek (PM11)**		**Trimble Creek (PM19)**	
Date Sampled	**9/16/2010**	**6/2/2011**	**9/16/2010**	**6/2/2011**	**9/16/2010**	**6/2/2011**
Watershed	Embarrass River	Embarrass River	Embarrass River	Embarrass River	Embarrass River	Embarrass River
UTM coordinate (NAD 83, Zone 15) Upstream End of Reach	5285620, 560384	5285620, 560384	5276145, 561069	5276145, 561069	5279492, 563999	5279492, 563999
UTM coordinate (NAD 83, Zone 15) Downstream End of Reach	5285518, 560364	5285518, 560364	5276067, 561031	5276067, 561031	5279451, 564125	5279451, 564125
Stream width at cross-section (ft)	13.0	9.5	9.0	7.0	9.0	7.5
Maximum depth at cross-section (ft)	1.8	1.8	1.8	2.0	2.0	1.5
Stream Flow (cfs)	7.06	8.62	2.53	3.45	2.64	3.77
Water temperature (°C)	10.2	15.7	12.4	15.2	11.1	14.2
pH	6.9	6.4	7.8	7.9	7.8	7.6
Specific Conductivity (µmhos)	105	62	985	618	628	435
Dissolved oxygen (ppm)	6.4	6.8	7.1	7.4	7.7	6.8
Habitat types (in-stream cover)	undercut bank/overhanging vegetation	undercut bank/overhanging vegetation	undercut bank/overhanging vegetation	undercut bank/overhanging vegetation	undercut bank/overhanging vegetation	undercut bank/overhanging vegetation
	woody debris	woody debris	emergent vegetation	woody debris	emergent vegetation	submergent vegetation
	emergent vegetation	submerged vegetation	sediment	submerged vegetation	woody debris	sediment
	sediment	sediment	woody debris	sediment	sediment	woody debris
Substrate	muck	muck	muck	muck	sand	sand
	detritus	detritus	detritus	detritus	silt	silt
Riparian zone vegetation	herbaceous/shrub	herbaceous/shrub	herbaceous/shrub	herbaceous/shrub	herbaceous	herbaceous
Qualitative Habitat Evaluation Index (QHEI)[3]	---	44	---	59	---	46

Parameter	**Bear Creek (reference)**		**Unnamed Creek (PM11)**		**Trimble Creek (PM19)**	
Date Sampled	**9/16/2010**	**6/2/2011**	**9/16/2010**	**6/2/2011**	**9/16/2010**	**6/2/2011**
Watershed	Embarrass River	Embarrass River	Embarrass River	Embarrass River	Embarrass River	Embarrass River
Shannon-Wiener Diversity Index (H')	2.91	2.42	2.78	3.25	1.75	0.95
Evenness	0.75	0.64	0.78	0.79	0.50	0.25
Hilsenhoff Biotic Index (HBI)[2]	6.36	5.94	6.54	5.91	5.53	5.99
	Fairly Poor	Fair	Fair	Fair	Fair	Fair
Richness (Family)	32	34	22	31	23	24
Richnes (Genera)	46	43	32	55	31	40
# of Insect Genera	38	33	28	46	24	34
% Insects of total individuals present at site	63%	61%	65%	88%	91%	78%
# Ephemeroptera, Plecoptera and Trichoptera (EPT) Genera	14	9	8	16	12	14
# Ephemeroptera, Plecoptera and Trichoptera (EPTO) Genera	19	12	10	20	14	16
% EPT of total individuals present at site	24%	37%	31%	27%	42%	42%
% EPTO of total individuals present at site	28%	38%	35%	27%	42%	45%
% Diptera (true flies) of total individuals present at site	30%	23%	25%	53%	49%	32%
% Chironomids (bloodworms) of Diptera	53%	31%	53%	50%	4%	78%
% Simulidae of total individuals present at site	11%	15%	9%	26%	47%	6%

Table 4-3 Results of Analysis of Variance (F-values and p-values).

Showing variables that were significantly different ($p < 0.0015$) among the sites, Unnamed Creek (PM11), Trimble Creek (PM19) and Bear Creek (control stream).

Parameter	**F-value**	**p-value**	**Tukey's HSD test**		
			Unnamed Creek	**Trimble Creek**	**Bear Creek**
Alkalinity	439.33	< 0.0001	A	A	B
Chloride	91.92	0.0005	A	A	B
Hardness, total as $CaCO_3$	6567.94	<0.0001	A	B	C
pH	146.33	0.0002	A	A	B
Total Dissolved Solids	513.99	<0.0001	A	B	C
Specific Conductance	1314.79	<0.0001	A	B	C
Sulfate	59.21	0.0011	A	B	C
Barium	60.17	0.001	B	A	B
Boron	559.80	<0.0001	A	B	C
Calcium	565.09	<0.0001	A	B	C
Magnesium	1546.81	<0.0001	A	B	C
Molybdenum	317.97	<0.0001	A	B	C
Potassium	100.05	0.0004	A	B	C
Sodium	463.14	<0.0001	A	A	B

[1] For the Tukey's HSD tests, letters earlier in the alphabet indicate higher values for the respective parameter, and sites with the same uppercase letter were not significantly different. (E.g. for alkalinity, Unnamed Creek was not significantly different from Trimble Creek; however, both Unnamed Creek and Trimble Creek were significantly different from Bear Creek).

Table 4-4 Comparison of average water chemistry parameter values with applicable Minnesota Water Quality (WQ) criteria.

Bear Creek, Unnamed Creek (PM11) and Trimble Creek (PM19)

Site	**Bear Creek**	**Unnamed Creek**	**Trimble Creek**	**WQ Criterion**
General Parameters (mg/L)				
Chloride	0.75	14.43	11.39	230
Dissolved oxygen	4.81	5.55	6.11	5.0
Total Hardness, as CaCO3	48.55	386.67	234	305
pH	6.72	7.81	7.57	6.5-8.5
Total Dissolved Solids	84.17	510.67	332.67	700
Specific Conductance µmhos@ 25°C	80.18	823.03	553.2	1000
Metals (µg/L, unless noted)				
Arsenic	1.01	0.42	0.97	53
Boron	25.00	239.67	143.33	500
Cadmium [1]	0.07	0.076	0.07	0.32-3.4
Chromium [1]	1.03	0.5	0.5	55.4-644
Cobalt	0.44	0.1	0.16	5
Copper [1]	0.76	0.67	0.62	3.6-23
Lead [1]	0.29	0.18	0.18	0.41-19
Nickel [1]	1.55	1.30	1.17	40.4-509
Selenium	0.25	0.39	0.38	5
Silver	0.10	0.1	0.1	1
Thallium	0.15	0.1	0.1	0.56
Zinc [1]	3.57	3	3	27.1-343

[1] For the metals, cadmium, chromium, copper, lead, nickel and zinc, the criteria (listed as a range) are dependent upon hardness. Values marked in red were higher than the WQ criterion.

Table 4-5 Water Quality Classification Index[1].

Bear Creek (control stream), Unnamed Creek (PM11) and Trimble Creek (PM19)

	Bear Creek index value	Bear Creek Classification	Unnamed Creek index value	Unnamed Creek Classification	Trimble Creek index value	Trimble Creek Classification
Biochemical Oxygen Demand (5-day)	1.16	Excellent-Acceptable	1.00	Excellent	0.93	Excellent
Chemical Oxygen Demand	6.92	Slightly Polluted-Polluted	3.71	Acceptable-Slightly Polluted	5.33	Slightly Polluted-Polluted
Chlorides	0.02	Excellent	0.50	Excellent	0.39	Excellent
Dissolved oxygen	4.8	Slightly Polluted-Polluted	3.2	Acceptable-Slightly Polluted	2.6	Acceptable-Slightly Polluted
pH	0.56	Excellent	0.66	Excellent	0.32	Excellent
Total suspended solids	<1	Excellent	<1	Excellent	<1	Excellent
Iron	9.49	Heavily Polluted	1.86	Excellent-Acceptable	3.91	Acceptable-Slightly Polluted
Manganese	2.34	Acceptable-Slightly Polluted	1.34	Excellent-Acceptable	1.49	Excellent-Acceptable

[1] Water Quality Classification Index based on Prati et al. (1971)

Table 4-6 Total macroinvertebrates sampled in stream sites related to Unnamed Creek (PM11) and Trimble Creek (PM19).

Taxa				HBI Value	Bear Creek (reference)		Unnamed Creek (PM11)		Trimble Creek (PM19)	
Class	Order	Family	*Genus species*	(10-0)	2010	2011	2010	2011	2010	2011
Insecta	Coleoptera	Curculionidae	undetermined	5						
		Dystiscidae	*Agabus* adults	5				4		
			Hydroporus adults	5						
			Dytiscus larvae			1		1		1
			Nebrioporus							
		Elmidae	*Dubiraphia* larvae	6			80	26	8	2
			Dubiraphia adults					4		
			Macronychus		16					
			Macronychus adults	5			8			
			Optioservus	4	8	2				
			Stenelmis larvae	5	16		8	20		
			Stenelmis adult	5			16	24		
			undetermined	4						
		Gyrinidae	*Gyrinus* adults		48					
		Hydrophilidae	*Tropisternus* adults							
	Diptera		undetermined Diperta larva					4	4	
			undetermined Diptera pupae							
		Chironomidae	undetermined	5				20		
			Chironomus	10						
			Cladopelma							2
			Cryptochironomus	8			16	4		16
			Dicrotendipes							6
			Endochironomus	10	8					
			Labrundinia	7						
			Microtendipes	6	64		64	4	4	2
			Paratendipes					56		
			Polypedilum	6	32	6		52		4
			Stenochironomus		136	4	24	26		
			Xenochironomus					2		
		Chironominae	*Pseudochironomus*					2		
			Microsectra			10		34		
			Paratanyytarsus							8
			Rheotanytarsus	6	60					4
			Tanytarsus	6		20	16	6		6
		Diamesinae	*Diamesa*	5						
		Orthocladiinae	*Undetermined*					4		
			Acricotopus	7						
			Brillia							
			Chaetocladius							
			Cricotopus	7				8	16	
			Cricotopus (C.) bicinctus group					2		
			Eukiefferiella	4						
			Heterotrissocladius	4						
			Orthocladius	6		4	72	34		4
			Parametriocnemus	5			16			
			Psectrocladius							4
			Pseudorthocladius	0						
			Rheocricotopus	6		4				
			Symposiocladius							1
			Thienemanniella	6		2	8	10	8	
			Tvetenia	5				4		
			Xylotopus	5	32					
		Prodiamesinae	*Prodiamesa*	8						
		Tanypodinae	*Ablabesmyia*	6		16				
			Larsia	6						6
			Nilotanypus	6						
			Paramerina	6				2		
			Thienemannimyia group	6	4		72	4	68	12
			Conchapelopia	6	64	4	24	12	8	14
			Procladius	9	52	4	16		24	6
			Zavrelimyia			4				
		Ceratopogonidae	*Bezzia/Palpomyia*	6	64		16			
			Ceratopogon	6	16					
			Culicoides							
			Probezzia	6						
			undetermined			6		6		**4**
		Dixidae	*Dixa*	1						
			Dixella			4				
		Empididae	undetermined Empidid larvae	6			32		4	
		Simuliidae	*Simulium*	6	308	162	224	272	3,116	22
			Simulium pupae					6	160	1
		Tabanidae	*undetermined Tabanid*	5	8					
		Tipulidae	*Antocha*	3						
			Dicronota	3						
			Limnophila	3						
			Lipsothrix				8			
			Tipula	6		2			8	
			undetermined Tipulidae				8			
		Ptychopteridae	*Ptycoptera*			1				
	Ephemeroptera	Ameletidae	*Ameletus*			4				
		Arthropleidae	*Arphroplea*			4				
		Baetidae	*Baetis brunneicolor*	4	12	264		46	1,840	12
			Baetis flavistriga	4				4		
			Baetis intercalaris	6						
			Baetis tricaudatus	6						
			undetermined *Baetis*			4		10		8
			Acentrella	4		68		16		4
			Labiobaetis	na	12					
			Acerpenna macdunnoughi	5	4				36	
			Callibaetis	7					8	
		Caenidae	*Caenis*	7			40	24	56	34
		Ephemerellidae	*Attenella*	3						
		Heptageniidae	*Stenacron*	7	8		24	9	4	
			Maccaffertium		2		144	5	40	1
		Leptophlebiidae	*Leptophlebia*		6				72	
		Siphlonuridae	*Siphlonurus*	4		2				
		Metretopodidae	*undetermined Genus*		16					
	Hemiptera	Corixidae	*Sigara*							
	Odonata	Aeshnidae	*Aeshna*	5	10	8	2		30	2
			Anax	8						
			Boyeria		12					
		Calopterygidae	*Calopteryx*	5	54		96	3		
		Coenagrionidae	undetermined Immatures						8	
		Gomphidae	*Gomphus*	6		1		1		
			immature Gomphus nymph		4					
		Cordulegasteridae	*Cordulegaster*	3						
		Corduliidae	*Somatochlora*		32	10		1		8
		Libellulidae	undetermined (immature)					2		

Taxa				HBI Value (10-0)	Bear Creek (reference)		Unnamed Creek (PM11)		Trimble Creek (PM19)	
Class	Order	Family	*Genus species*		2010	2011	2010	2011	2010	2011
	Megaloptera	Sialidae	*Sialis*	4	13					
	Lepidoptera	Pyralidae	*Acentria*	5						
			Paraponyx	5	8	1				
	Plecoptera	Perlidae	*Paragnetina*	1				1		
			Perlesta	5		22		45		
			immature Perlidae					10		
		Isoperliidae	*Isoperla*	2						
		Nemouridae	*Amphinemora*							
			Nemoura	1						
		Taeniopterugidae	undetermined earlyi nstar nymph							
	Trichoptera	Arctopsychidae	*Parapsyche*	0						
		Goeridae	*Goera*	3						
		Helicopsychidae	*Helicopsyche*	3				1		
		Hydropsychidae	*Hydropsyche slossonae*	4			40			
			Hydropsyche alhydra	4			16			
			Hydropsyche betteni	6	128	1	96	25	404	13
			Hydropsyche betteni pupae					16		
			undetermined *Hydropsyche*	4			56			
			Cheumatopsyche	5	144	4	312	9	304	7
		Hydroptilidae	*Hydroptila*	6				8		4
			Undet. Pupae							
		Lepidostomatidae	*Lepidostoma*	1		4		2		1
		Leptoceridae	*Ceraclea*							1
			Oecetis	8				2		
			Triaenodes	6						
			undetermined pupae							
		Limnephilidae	*Anabolia*	5		17		38		14
			Hydatophylax	2	8		2		12	
			Limnephilus	3	4			3	4	41
			Platycentropus					1		7
			Pycnopsyche	4				10		1
			very immature larva				16		48	
			undetermined pupae						8	9
		Molannidae	*Molanna*	6						
		Philopotamidae	*Chimarra*	4						
		Phryganeidae	*Banksiola*							1
			Ptilostomis	5	14		8		92	
			very immature larva				16			
		Polycentropodidae	*Nyctiophylax*	5			8			
			Polycentropus	6	208	13		1		
		Psychomiidae	*Lype*	2	112					
		undetermined pupae	undetermined pupae			1				
Crustacea	Amphipoda	Talitridae	*Hyalella*	8	356	218	320	32	4	3
		Gammaridae	*Gammarus*	6						
	Decapoda	Astacidae	*Orconectes*	6	2					
Malacostraca	Isopoda	undetermined	*undetermined*							
Entoprocta	Urnatellida	Urnatellidae	*Urnatella gracilis*		16					
Annelida	Oligochaeta		undetermined	8	588	160	512	26	464	58
	Arhynchnobdellida	Erpobdellidae	*Erpobdella punctata*		2	4			8	
	Rhynchnobdellida	Glossiphoniidae	*Helobdella stagnalis*	6					8	
			undetermined Leech			1		1		1
Gastropoda	Basommatophora	Ancylidae	*Ferrisia*	7	32	4	16	14		
		Lymnaeidae	*Pseudosuccinea*	6						
			Fossaria	6				16	4	
			Stagnicola			1				
		Planorbidae	*Gyraulus*					12		
		Actinommidae	*Helisoma*	6		2	16	1		3
		Physidae	*Physa*	7	22	3			24	
	undetermined slug	undetermined slug	undetermined slug							
Bivalvia/Pelecypoda	Veneroida	Pisidiidae(clams)	*Musculium*	6						
			Pisidium	6		32		24	20	16
			Sphaerium	6	6			5		
			very immature Sphaeriidae	6	16		16		72	
Hydrozoa	Hydroida	Clavidae	*Cordylophora*			4				
Nematoda (phylum)	undetermined	undetermined	undetermined							2
Total					**2,787**	**1,113**	**2,484**	**1,077**	**6,998**	**376**

Table 4-7 Classes, orders, families and abundance of macroinvertebrates.

	Bear Creek (reference)		Unnamed Creek (PM11)		Trimble Creek (PM19)	
Taxa	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Class	6	6	5	5	5	6
Order	14	14	9	11	11	11
Family	32	34	22	31	23	24
Genera	46	43	32	55	31	40
Total Organisms	2,787	1,113	2,484	1,077	6,998	376

Table 4-8 Percentage of macroinvertebrate classes collected at each site.

(**bold** font in cells represent dominant classes)

	Bear Creek (reference)		Unnamed Creek (PM11)		Trimble Creek (PM19)	
Class	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Insecta	**62.7%**	**61.5%**	**64.6%**	**87.8%**	**91.4%**	**77.9%**
Crustacea	**12.8%**	**19.6%**	**12.9%**	3.0%	0.1%	0.8%
Malacostraca	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Entoprocta (Phylum)	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%
Annelida	**21.2%**	**14.8%**	**20.6%**	2.5%	**6.9%**	**15.7%**
Gastropoda	1.9%	0.9%	1.3%	4.0%	0.4%	0.8%
Bivalvia	0.8%	2.9%	0.6%	2.7%	1.3%	4.3%
Hydrozoa	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%
Nematoda	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%

Table 4-9 Percentage of macroinvertebrate orders collected at each site.

(**bold font** in cells represent dominant orders)

Order	Bear Creek (reference)		Unnamed Creek (PM11)		Trimble Creek (PM19)	
	2010	**2011**	**2010**	**2011**	**2010**	**2011**
Coleoptera	3.2%	0.3%	4.5%	7.3%	0.1%	0.8%
Diptera	**30.4%**	**22.7%**	**24.8%**	**53.3%**	**48.9%**	**32.4%**
Ephemeroptera	2.2%	**31.1%**	8.4%	**10.6%**	**29.4%**	**15.7%**
Hemiptera	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Odonata	4.0%	1.7%	3.9%	0.6%	0.5%	2.7%
Megaloptera	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%
Lepidoptera	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%
Plecoptera	0.0%	2.0%	0.0%	5.2%	0.0%	0.0%
Trichoptera	**22.2%**	3.6%	**22.9%**	**10.8%**	**12.5%**	**26.3%**
Amphipoda	**12.8%**	**19.6%**	12.9%	3.0%	0.1%	0.8%
Decapoda	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Urnatellida	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%
Oligochaeta	**21.1%**	**14.4%**	**20.6%**	2.4%	6.6%	**15.4%**
Arhynchobdellida	0.1%	0.4%	0.0%	0.0%	0.1%	0.0%
Rhynchobdellida	0.0%	0.1%	0.0%	0.1%	0.1%	0.3%
Basommatophora	1.9%	0.9%	1.3%	4.0%	0.4%	0.8%
Veneroida	0.8%	2.9%	0.6%	2.7%	1.3%	4.3%
Isopoda	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hydroida	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%
Nematoda-unknown	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%

Table 4-10 Hilsenhoff Biotic Index (HBI) values for streams; general characterization.

HBI Value	Water Quality	Degree of Organic Pollution
0.0 - 3.50	Excellent	No apparent organic pollution
3.51 - 4.50	Very Good	Possible slight organic pollution
4.51 - 5.50	Good	Some organic pollution
5.51 - 6.50	Fair	Fairly significant organic pollution
6.51 - 7.50	Fairly Poor	Significant organic pollution
7.51 - 8.50	Poor	Very significant organic pollution
8.51 - 10.00	Very Poor	Severe organic pollution

Table 4-11 Hilsenhoff Biotic Index (HBI) calculations for each stream sampling site.

Taxa					Bear Creek (reference) 2010			Bear Creek (reference) 2011			Unnamed Creek (PM11) 2010			Unnamed Creek (PM11) 2011			Trimble Creek (PM19) 2010			Trimble Creek (PM19) 2011		
Class	Order	Family	*Genus species*	Tolerance Value (10-0)	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum
Insecta	Coleoptera	Curculionidae	undetermined	5																		
		Dysticae	*Agabus* adults	5										4	4	20						
			Hydroporus adults	5																		
			Dytiscus larvae	na				1						1						1		
			Nebrioporus	na																		
		Elmidae	*Dubiraphia* larvae	6							80	80	480	26	26	156	8	8	48	2	2	12
			Dubiraphia adults	6										4	4	24						
			Macronychus	5	16	16	80															
			Macronychus adults	5							8	8	40									
			Optioservus	4	8	8	32	2	2	8												
			Stenelmis larvae	5	16	16	80				8	8	40	20	20	100						
			Stenelmis adult	5							16	16	80	24	24	120						
			undetermined	4																		
		Gyrinidae	*Gyrinus* adults	na	48																	
		Hydrophilidae	*Tropisternus* adults	na																		
	Diptera		undetermined Diperta larva	na										4			4					
			undetermined Diptera pupae	na																		
		Chironomidae	undetermined	5										20	20	100						
			Chironomus	10																		
			Cladopelma	9																2	2	18
			Cryptochironomus	8							16	16	128	4	4	32				16	16	128
			Dicrotendipes	na																6		
			Endochironomus	10	8	8	80															
			Labrundinia	7																		
			Microtendipes	6	64	64	384				64	64	384	4	4	24	4	4	24	2	2	12
			Paratendipes	8										56	56	448						
			Polypedilum	6	32	32	192	6	6	36				52	52	312				4	4	24
			Stenochironomus	5	136	136	680	4	4	20	24	24	120	26	26	130						
			Xenochironomus	na										2								
		Chironominae	*Pseudochironomus*	5										2	2	10						
			Microsectra	na				10						34								
			Paratanytarsus	6																8	8	48
		(Tanytarsini)	*Rheotanytarsus*	6	60	60	360													4	4	24
		(Tanytarsini)	*Tanytarsus*	6				20	20	120	16	16	96	6	6	36				6	6	36
		Diamesinae	*Diamesa*	5																		
		Orthocladiinae	undetermined	na										4								
			Acricotopus	na																		
			Brillia	5																		
			Chaetocladius	na																		
			Cricotopus (Cricotopus)	7										8	8	56	16	16	112			
			Cricotopus (C.) bicinctus	na										2								
			Eukiefferiella	4																		
			Heterotrissocladius	4																		
			Orthocladius	6				4	4	24	72	72	432	34	34	204				4	4	24
			Parametriocnemus	5							16	16	80									
			Psectrocladius	8																4	4	32
			Pseudorthocladius	0																		
			Rheocricotopus	6				4	4	24												
			Symposiocladius	na																1		
			Thienemanniella	6				2	2	12	8	8	48	10	10	60	8	8	48			
			Tvetenia	5										4	4	20						
			Xylotopus	5	32	32	160															
		Prodiamesinae	*Prodiamesa*	8																		
		Tanypodinae	*Ablabesmyia*	na				16														
			Conchapelopia	6	64	64	384	4	4	24	24	24	144	12	12	72	8	8	48	14	14	84
			Larsia	6																6	6	36
			Nilotanypus	6																		
			Paramerina	na										2								

Taxa					Bear Creek (reference) 2010			Bear Creek (reference) 2011			Unnamed Creek (PM11) 2010			Unnamed Creek (PM11) 2011			Trimble Creek (PM19) 2010			Trimble Creek (PM19) 2011		
Class	Order	Family	*Genus species*	Tolerance Value (10-0)	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum
			Procladius	9	52	52	468	4	4	36	16	16	144				24	24	216	6	6	54
			Thienemannimya Group	6	4	4	24	0			72	72	432	4	4	24	68	68	408	12	12	72
			Zavrelimyia	8				4	4	32												
		Ceratopogonidae	*Bezzia/Palpomyia*	6	64	64	384				16	16	96							0		
			Ceratopogon	6	16	16	96															
			Probezzia	6																		
			undetermined	na				6						6						4		
		Dixidae	*Dixa*	1																		
			Dixella	na				4														
		Empididae	*undetermined Empidid* larvae	6							32	32	192				4	4	24			
		Simuliidae	*Simulium*	6	308	308	1,848	162	162	972	224	224	1,344	272	272	1,632	3,116	3,116	18,696	22	22	132
			Simulium pupae	6										6	6	36	160	160	960	1	1	6
		Tabanidae	*undetermined Tabanid*	5	8	8	40															
		Tipulidae	*Antocha*	3																		
			Dicronota	3																		
			Limnophila	3																		
			Lipsothrix	na							8											
			Tipula	6				2	2	12							8	8	48			
			undetermined Tipulidae	na							8											
		Ptychopteridae	*Ptycoptera*	na				1														
	Ephemeroptera	Ameletidae	*Ameletus*	na				4														
		Arthropleidae	*Arphroplea*	na				4														
		Baetidae	*Baetis brunneicolor*	4	12	12	48	264	264	1,056				46	46	184	1,840	1,840	7,360	12	12	48
			Baetis flavistriga	4										4	4	16						
			Baetis intercalaris	6																		
			Baetis tricaudatus	6																		
			undetermined *Baetis*	na				4						10						8		
			Acentrella	4				68	68	272				16	16	64				4	4	16
			Labiobaetis	na	12																	
			Acerpenna macdunnoughi	5	4	4	20										36	36	180			
			Callibaetis	7													8	8	56			
		Caenidae	*Caenis*	7							40	40	280	24	24	168	56	56	392	34	34	238
		Ephemerellidae	*Attenella*	3																		
		Heptageniidae	*Stenacron*	7	8	8	56				24	24	168	9	9	63	4	4	28			
			Maccaffertium	na	2						144			5			40			1		
		Leptophlebiidae	*Leptophlebia*	4	6	6	24										72	72	288			
		Siphlonuridae	*Siphlonurus*	4				2	2	8												
		Metretopodidae	undetermined genus	na	16																	
	Hemiptera	Corixidae	*Sigara*	na	0																	
	Odonata	Aeshnidae	*Aeshna*	5	10	10	50	8	8	40	2	2	10				30	30	150	2	2	10
			Anax	8																		
			Boyeria	na	12																	
		Calopterygidae	*Calopteryx*	5	54	54	270				96	96	480	3	3	15						
		Coenagrionidae	undetermined immatures	na													8					
		Gomphidae	*Gomphus*	6				1	1	6				1	1	6						
			immature Gomphus nymph	6	4	4	24															
		Cordulegasteridae	*Cordulegaster*	3																		
		Corduliidae	*Somatochlora*	1	32	32	32	10	10	10				1	1	1				8	8	8
		Libellulidae	undetermined (immature)	na										2								
	Megaloptera	Sialidae	*Sialis*	4	13	13	52															
	Lepidoptera	Pyralidae	*Acentria*	5																		
			Paraponyx	5	8	8	40	1	1	5												
	Plecoptera	Perlidae	*Paragnetina*	1										1	1	1						
			Perlesta	5				22	22	110				45	45	225						
			immature Perlidae	na										10								
		Isoperliidae	*Isoperla*	2																		
		Nemouridae	*Amphinemora*	na																		
			Nemoura	1																		
		Taeniopterugidae	undetermined early instar nymph	na																		

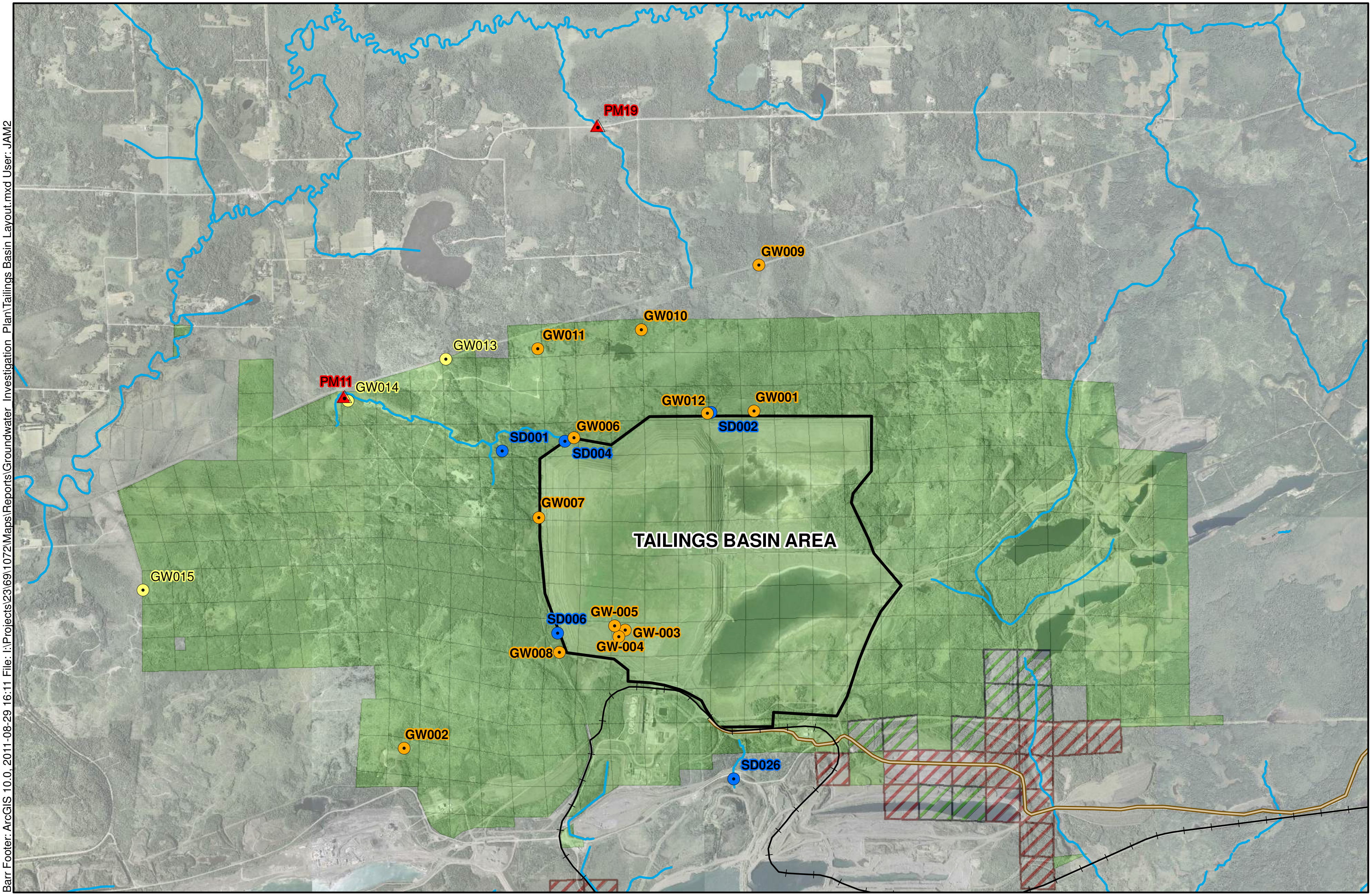
Taxa					Bear Creek (reference) 2010			Bear Creek (reference) 2011			Unnamed Creek (PM11) 2010			Unnamed Creek (PM11) 2011			Trimble Creek (PM19) 2010			Trimble Creek (PM19) 2011		
Class	Order	Family	*Genus species*	Tolerance Value (10-0)	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum	Total	Total with tolerance values	HBI Sum
	Trichoptera	Arctopsychidae	*Parapsyche*	0																		
		Goeridae	*Goera*	3																		
		Helicopsychidae	*Helicopsyche*	3										1	1	3						
		Hydropsychidae	*Hydropsyche slossonae*	4							40	40	160									
			Hydropsyche alhydra	4							16	16	64									
			Hydropsyche betteni	6	128	128	768	1	1	6	96	96	576	25	25	150	404	404	2,424	13	13	78
			Hydropsyche betteni pupae	6										16	16	96						
			undetermined *Hydropsyche*	na							56											
			Cheumatopsyche	5	144	144	720	4	4	20	312	312	1,560	9	9	45	304	304	1,520	7	7	35
		Hydroptilidae	*Hydroptila*	6										8	8	48				4	4	24
			undetermined pupae	na																		
		Lepidostomatidae	*Lepidostoma*	1				4	4	4				2	2	2				1	1	1
		Leptoceridae	*Ceraclea*	na																1		
			Oecetis	8										2	2	16						
			Triaenodes	6																		
			undetermined pupae	na																		
		Limnephilidae	*Anabolia*	5				17	17	85				38	38	190				14	14	70
			Hydatophylax	2	8	8	16				2	2	4				12	12	24			
			Limnephilus	3	4	4	12							3	3	9	4	4	12	41	41	123
			Platycentropus	na										1						7		
			Pycnopsyche	4										10	10	40				1	1	4
			very immature larva	na							16						48					
			undetermined pupae	na													8			9		
		Molannidae	*Molanna*	6																		
		Philopotamidae	*Chimarra*	4																		
		Phryganeidae	*Banksiola*	na																1		
		Phryganeidae	*Ptilostomis*	5	14	14	70				8	8	40				92	92	460			
			very immature larva	na							16											
		Polycentropodidae	*Nyctiophylax*	5							8	8	40									
			Polycentropus	6	208	208	1,248	13	13	78				1	1	6						
		Psychomiidae	*Lype*	2	112	112	224															
		undetermined pupae	*undetermined pupae*	na				1														
Crustacea	Amphipoda	Talitridae	*Hyalella*	8	356	356	2,848	218	218	1,744	320	320	2,560	32	32	256	4	4	32	3	3	24
		Gammaridae	*Gammarus*	6																		
	Decapoda	Astacidae	*Orconectes*	6	2	2	12															
Malacostraca	Isopoda	undetermined	undetermined	na																		
Entoprocta	Urnatellida	Urnatellidae	*Urnatella gracilis*	na	16																	
Annelida	Oligochaeta		undetermined	8	588	588	4,704	160	160	1,280	512	512	4,096	26	26	208	464	464	3,712	58	58	464
	Arhynchnobdellida	Erpobdellidae	*Erpobdella punctata*	na	2			4									8					
	Rhynchnobdellida	Glossiphoniidae	*Helobdella stagnalis*	6													8	8	48			
			undetermined Leech	na				1						1						1		
Gastropoda	Basommatophora	Ancylidae	*Ferrisia*	7	32	32	224	4	4	28	16	16	112	14	14	98						
		Lymnaeidae	*Pseudosuccinea*	6																		
			Fossaria	6										16	16	96	4	4	24			
			Stagnicola	na				1														
		Planorbidae	*Gyraulus*	na										12								
		Actinommidae	*Helisoma*	6				2	2	12	16	16	96	1	1	6				3	3	18
		Physidae	*Physa*	7	22	22	154	3	3	21							24	24	168			
	undetermined slug	undetermined slug	undetermined slug	na																		
Bivalvia/Pelecypoda	Veneroida	Pisidiidae(clams)	*Musculium*	6																		
			Pisidium	6				32	32	192				24	24	144	20	20	120	16	16	96
			Sphaerium	6	6	6	36							5	5	30						
			very immature Sphaeriidae	na	16						16						72					
Hydrozoa	Hydroida	Clavidae	*Cordylophora*	na				4														
Nematoda (phylum)	undetermined	undetermined	undetermined	na																2		
TOTAL					**2,787**	2,663	16,944	**1,113**	1,052	6,297	**2,484**	2,220	14,526	**1,077**	981	5,802	**6,998**	6,810	37,630	**376**	334	1,999
HBI Value							6.36			5.99			6.54			5.91			5.53			5.99
Water Quality Rating (see Table 4-10)							Fairly Poor			Fair			Fair			Fair			Fair			Fair

Table 4-12 Total abundances (total #), total length (TL) ranges (mm) and tolerance and trophic guilds of all fish species sampled at Bear Creek, Unnamed Creek (PM11) and Trimble Creek (PM19) on July 26, 2010.

Common name, Scientific name	**Bear Creek**		**Unnamed Creek**		**Trimble Creek**		**Trophic guild**	**Tolerance**
	Total #	TL (mm)	Total #	TL (mm)	Total #	TL (mm)		
Brook stickleback *Culaea inconstans*	-		23	45-55	-		Insectivore	Moderate
Burbot *Lota lota*	-		-		1	180	Piscivore	Moderate
Central mudminnow *Umbra limi*	3	35-76	10	55-75	3	46-50	Insectivore	Tolerant
Creek chub *Semotilus atromaculatus*	-		46	37-90	4	110-180	Generalist	Tolerant
Golden shiner *Notemigonus crysoleucas*	1	25	-		-		Omnivore	Tolerant
Johnny darter *Etheostoma nigrum*	7	25-74	-		1	55	Insectivore	Moderate
Northern pike *Esox Lucius*	1	145	-		-		Piscivore	Moderate
Northern redbelly dace *Phoxinus eos*	-		39	71	-		Herbivore	Moderate
White sucker *Catostomus commersonii*	8	40-210	3	74-145	4	155-190	Omnivore	Tolerant

mm = millimeters

Figures



- ○ New Well - July 2010
- ● Previous Groundwater Well
- ▲ Baseline Monitoring Location for Water Chemistry
- ● Surface Discharge Location
- — Streams

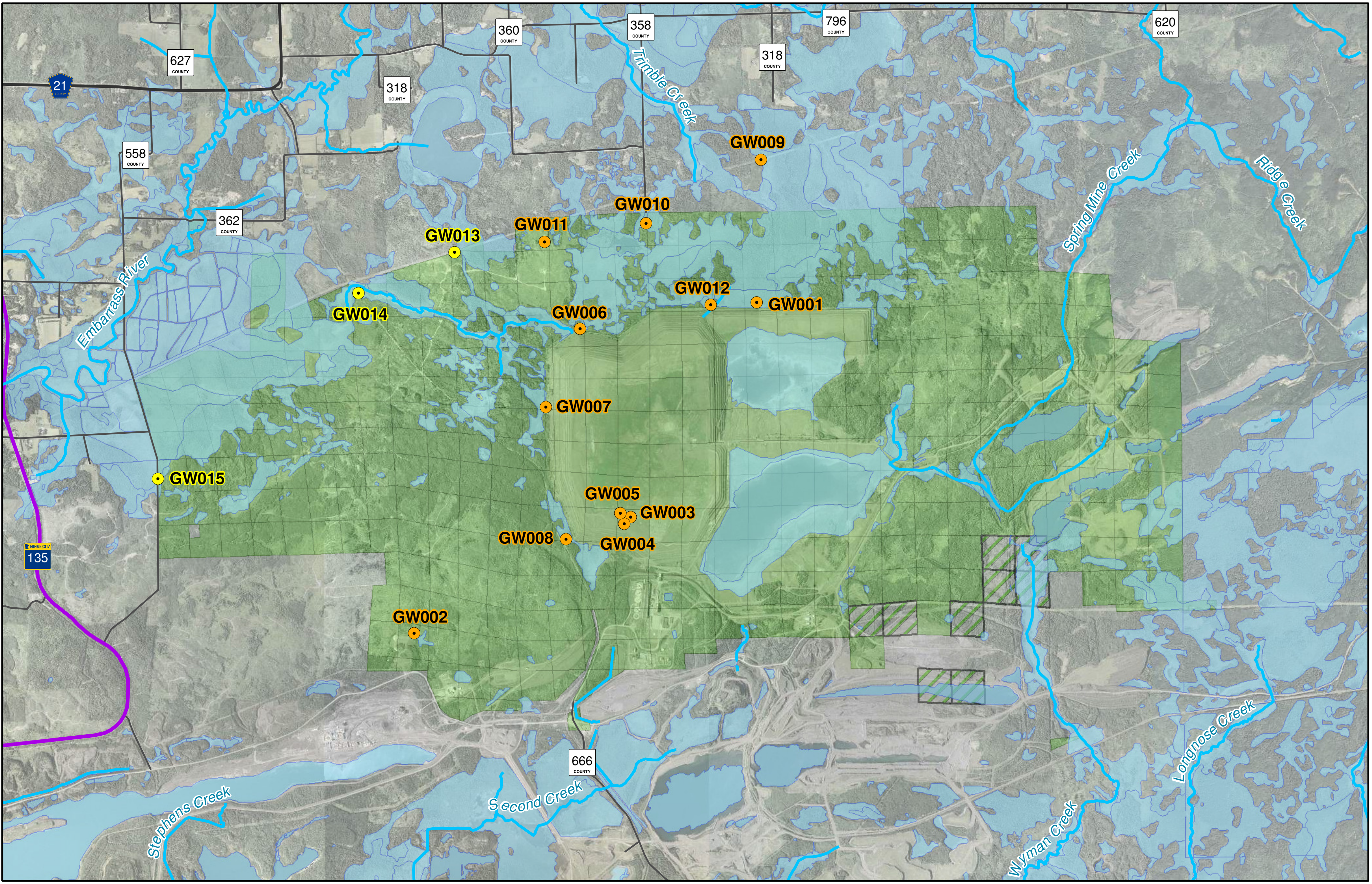
Surface Ownership

- ▨ Cliffs Erie Lease
- 🟩 Polymet
- ▨ Polymet Leased Area

N

4,000 0 4,000
Feet

Figure 1-1
TAILINGS BASIN LAYOUT
PolyMet Mining Inc.
Cliffs Erie L.L.C
Hoyt Lakes, MN



Barr Footer: ArcGIS 10.0, 2011-08-25 11:00 File: I:\Projects\23\69\1072\Maps\Reports\Tailings_Basin_Field_Study\Figure 3-1 Monitoring Well Locations.mxd User: JAM2

● New Well - July 2010

● Previous Groundwater Well

Rivers/Streams

Wetlands

Surface Ownership

🟩 PolyMet

▨ PolyMet Leased Area

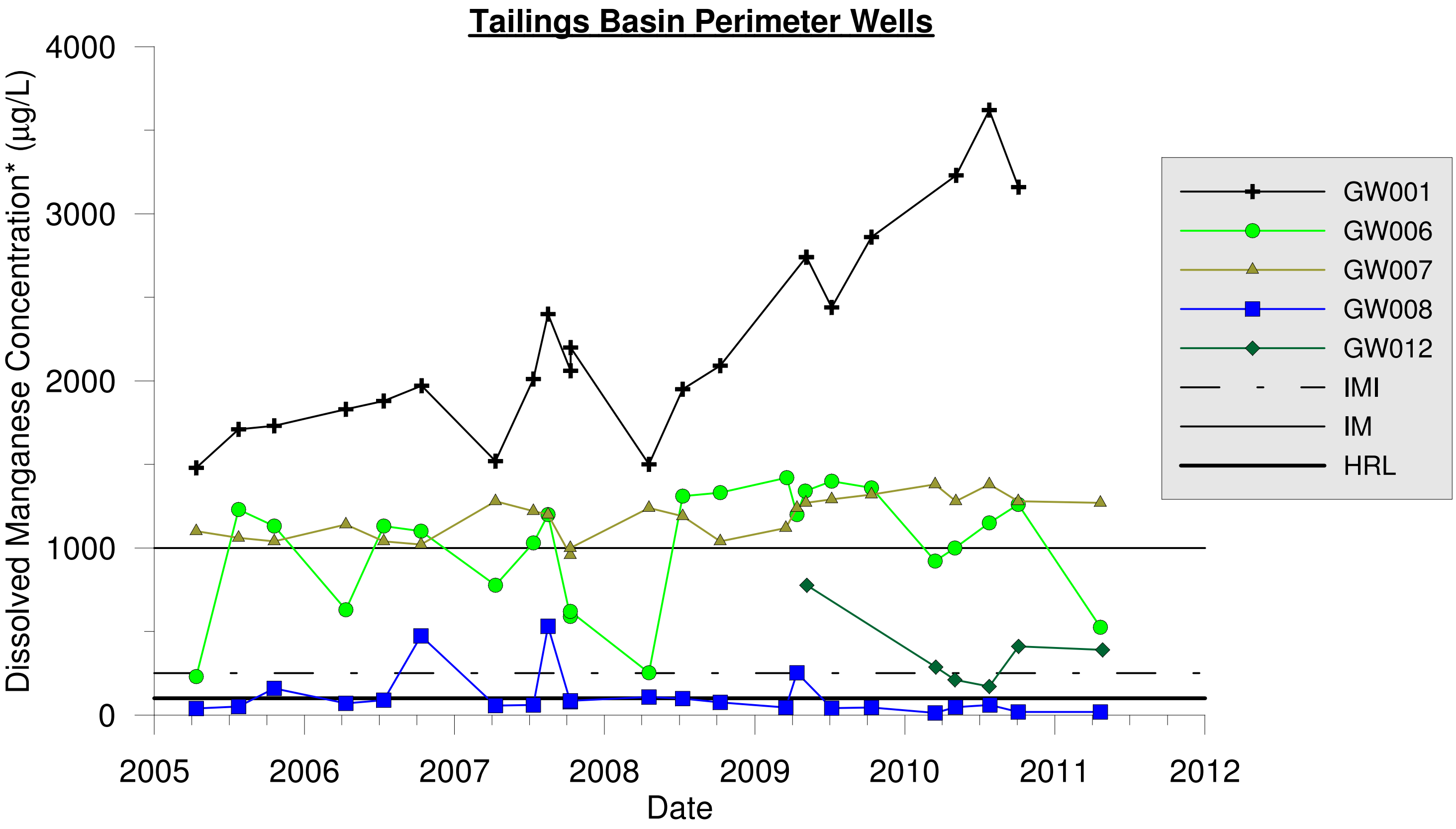
1 0.5 0 1

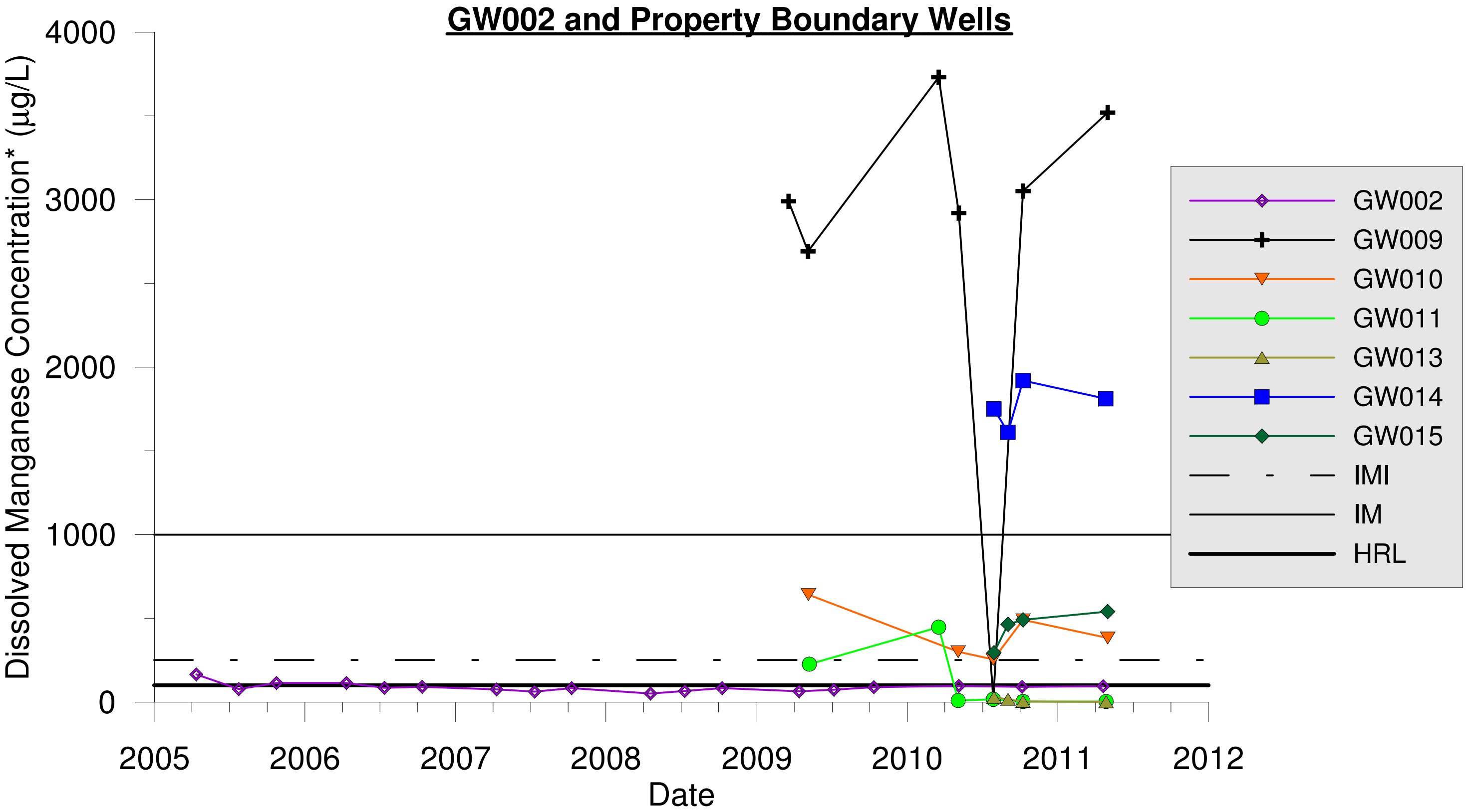
Miles

Figure 3-1

TAILINGS BASIN MONITORING
WELL LOCATIONS
PolyMet Mining Inc./Cliffs Erie L.L.C.
Hoyt Lakes, MN

Figure 3-2 - Summary of Manganese Groundwater Data
Tailings Basin Monitoring Wells
PolyMet Mining Inc./Cliffs Erie L.L.C.





* Total manganese concentrations shown for sampling dates where no dissolved concentration is available.
Non-detect concentrations shown as 1/2 the detection limit.

P:\Mpls\23 MN\69\23691072 NPDES Reissuance Area 5-Tailings Basin\WorkFiles\Field_Studies\Tailings_Basin\Groundwater_Investigation\Well_data_for_Grapher\TB_wells_Mn.grf

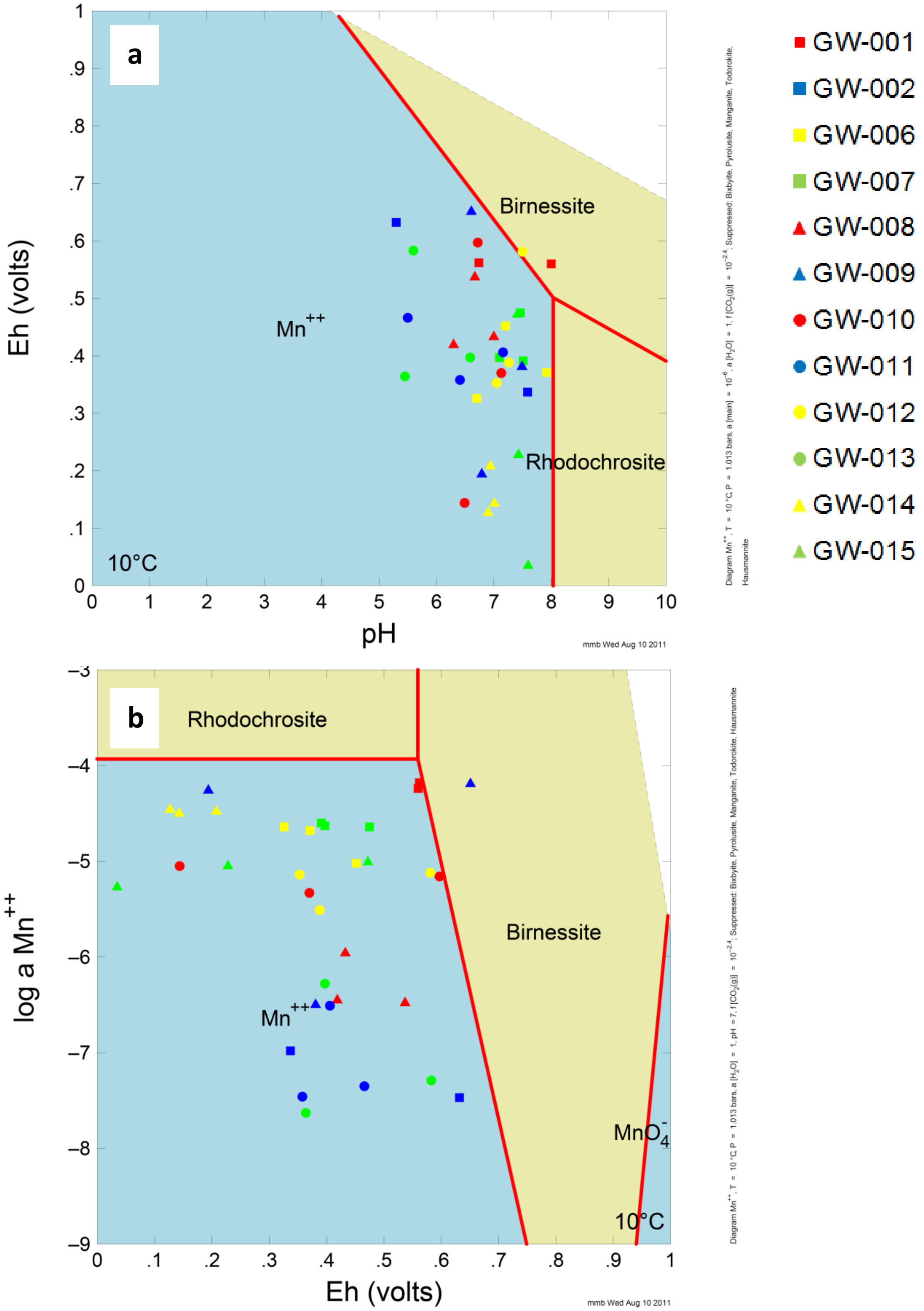
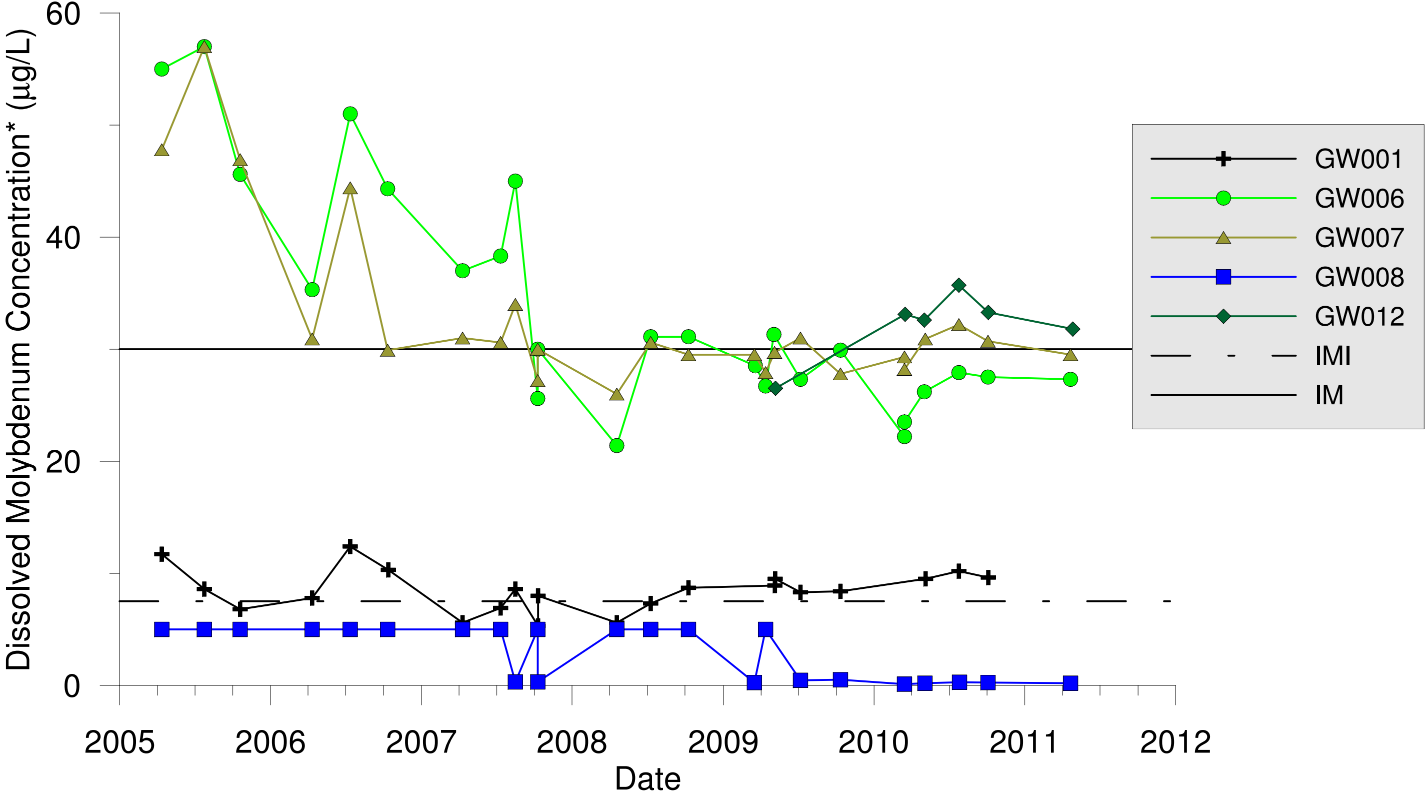


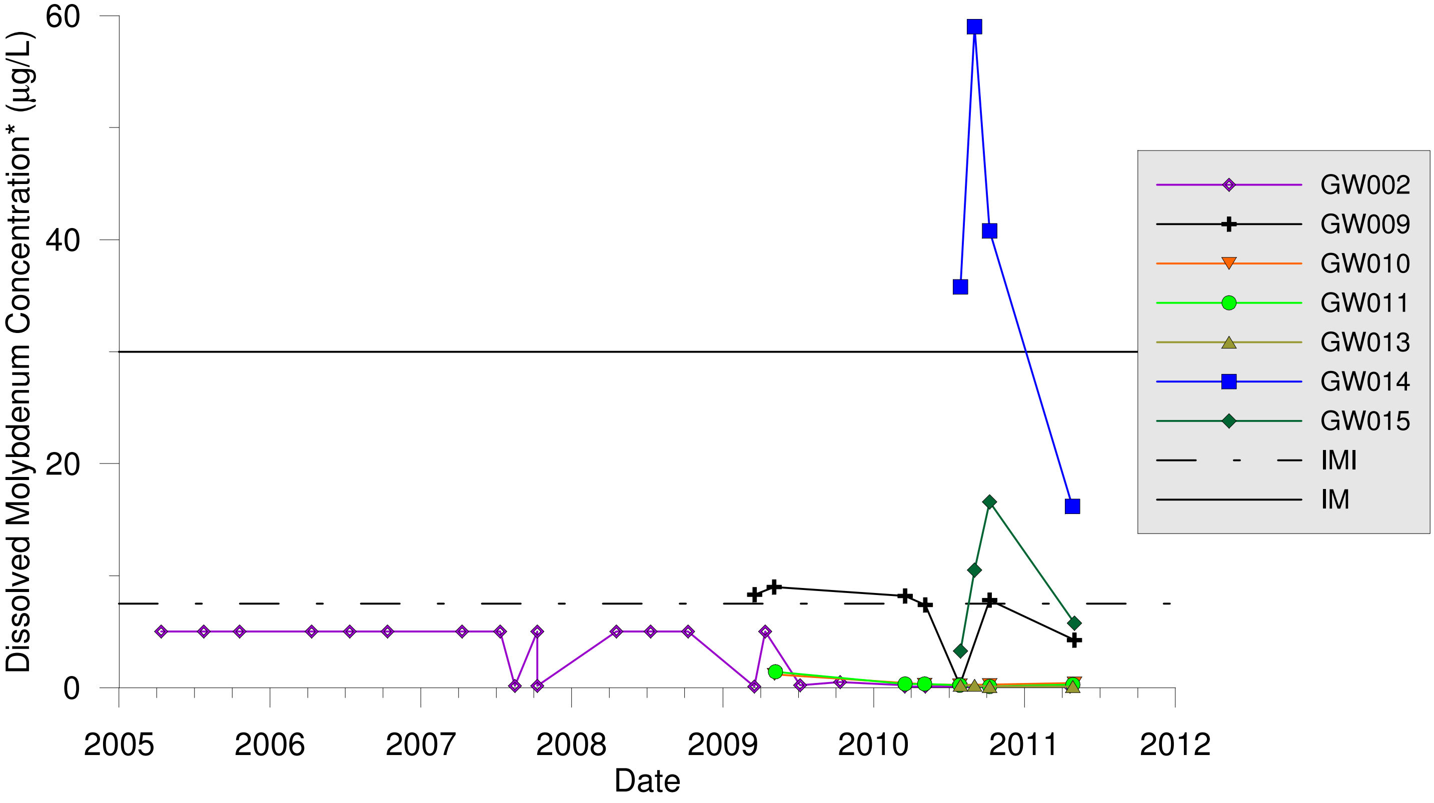
Figure 3-3. Plots showing phase stability within Mn-H_2O-CO_2 system at 10°C with Mn activity at 10^{-6} (**a**) or pH constant at 7 (**b**). Both models indicate that groundwater samples are undersaturated in Mn^{2+}.

Figure 3-4 - Summary of Molybdenum Groundwater Data
Tailings Basin Monitoring Wells
PolyMet Mining Inc./Cliffs Erie L.L.C.

Tailings Basin Perimeter Wells

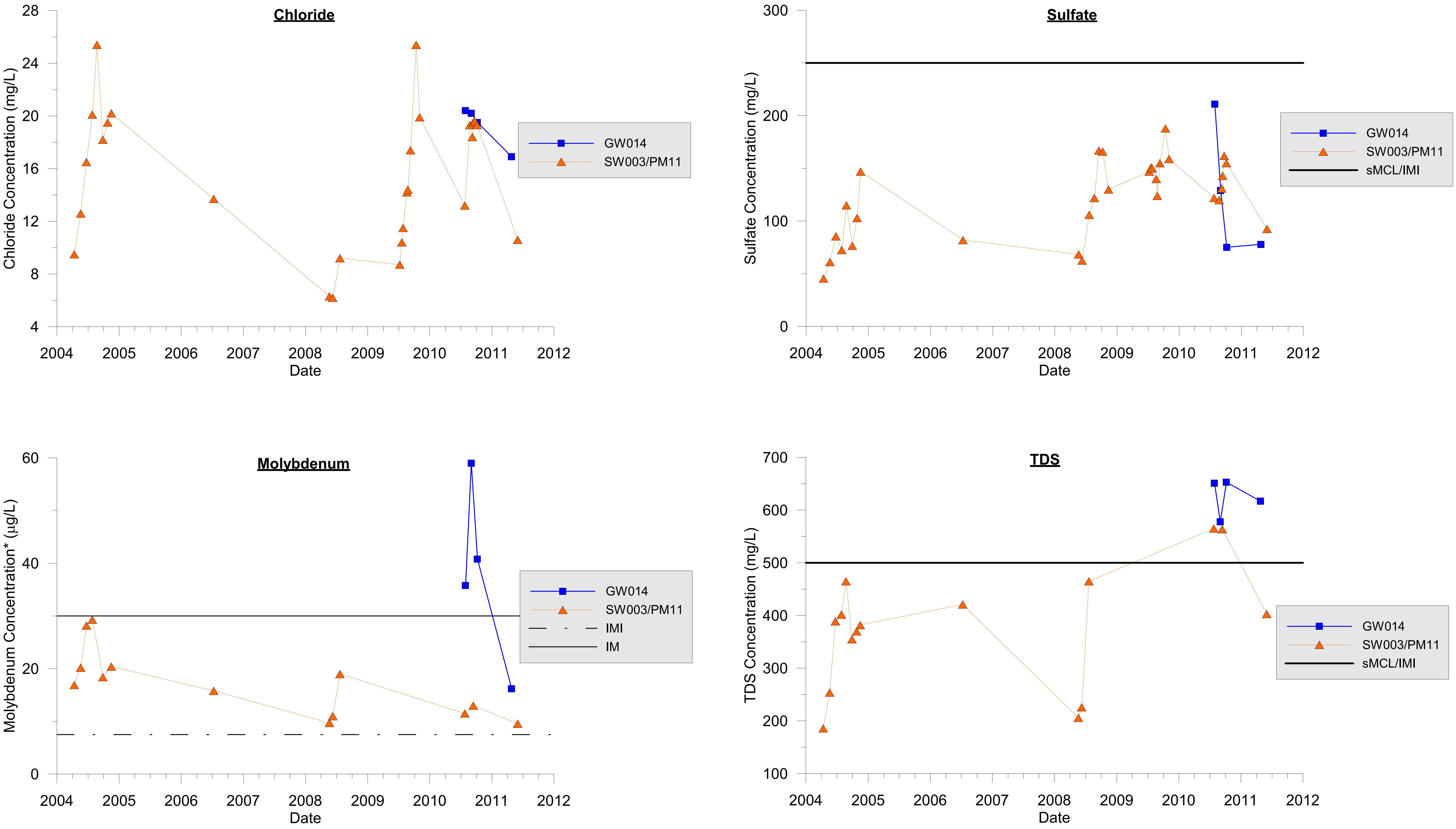


GW002 and Property Boundary Wells



* Non-detect concentrations shown as 1/2 the detection limit.

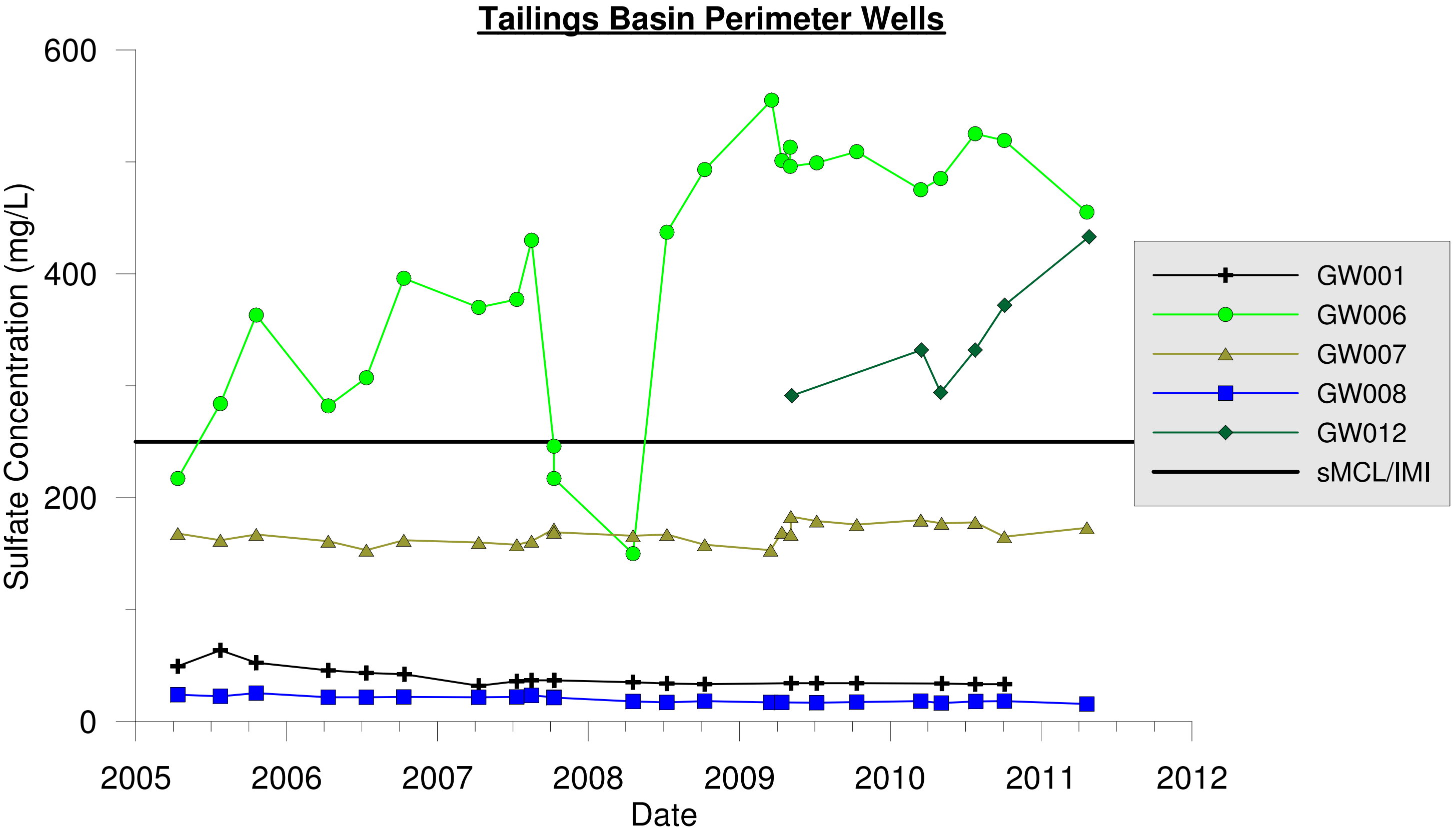
Figure 3-5 - Water Quality Data Comparison
GW014 and SW003/PM11
PolyMet Mining Inc./Cliffs Erie L.L.C.



* SW003/PM11 molybdenum concentrations are total, GW014 are dissolved.

P:\Mpls\23 MN\69\23691072 NPDES Reissuance Area 5-Tailings Basin\WorkFiles\Field_Studies\Tailings_Basin\Groundwater_Investigation\Well_data_for_Grapher\GW014_PM11_comp.grf

Figure 3-6 - Summary of Sulfate Groundwater Data
Tailings Basin Monitoring Wells
PolyMet Mining Inc./Cliffs Erie L.L.C.



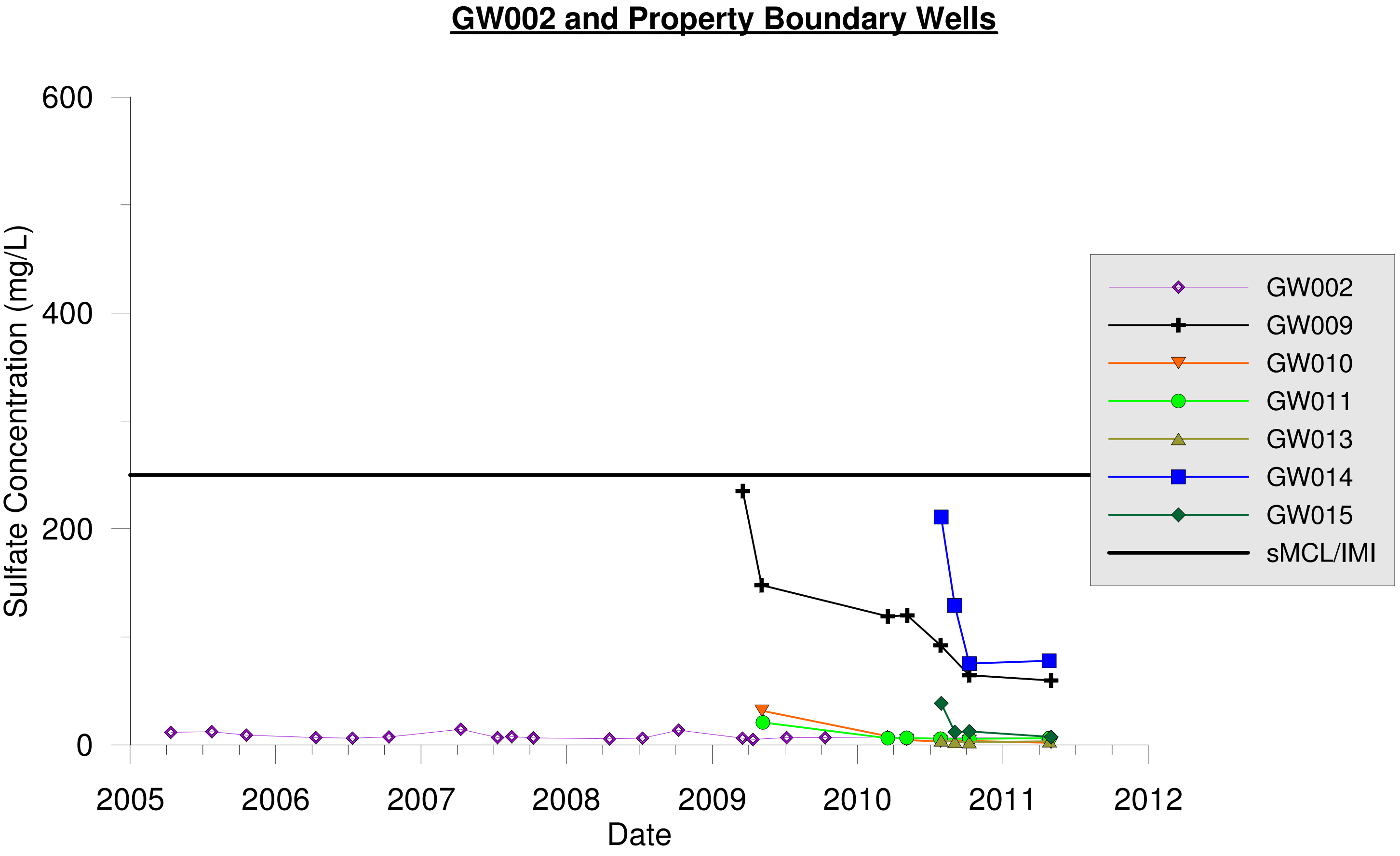
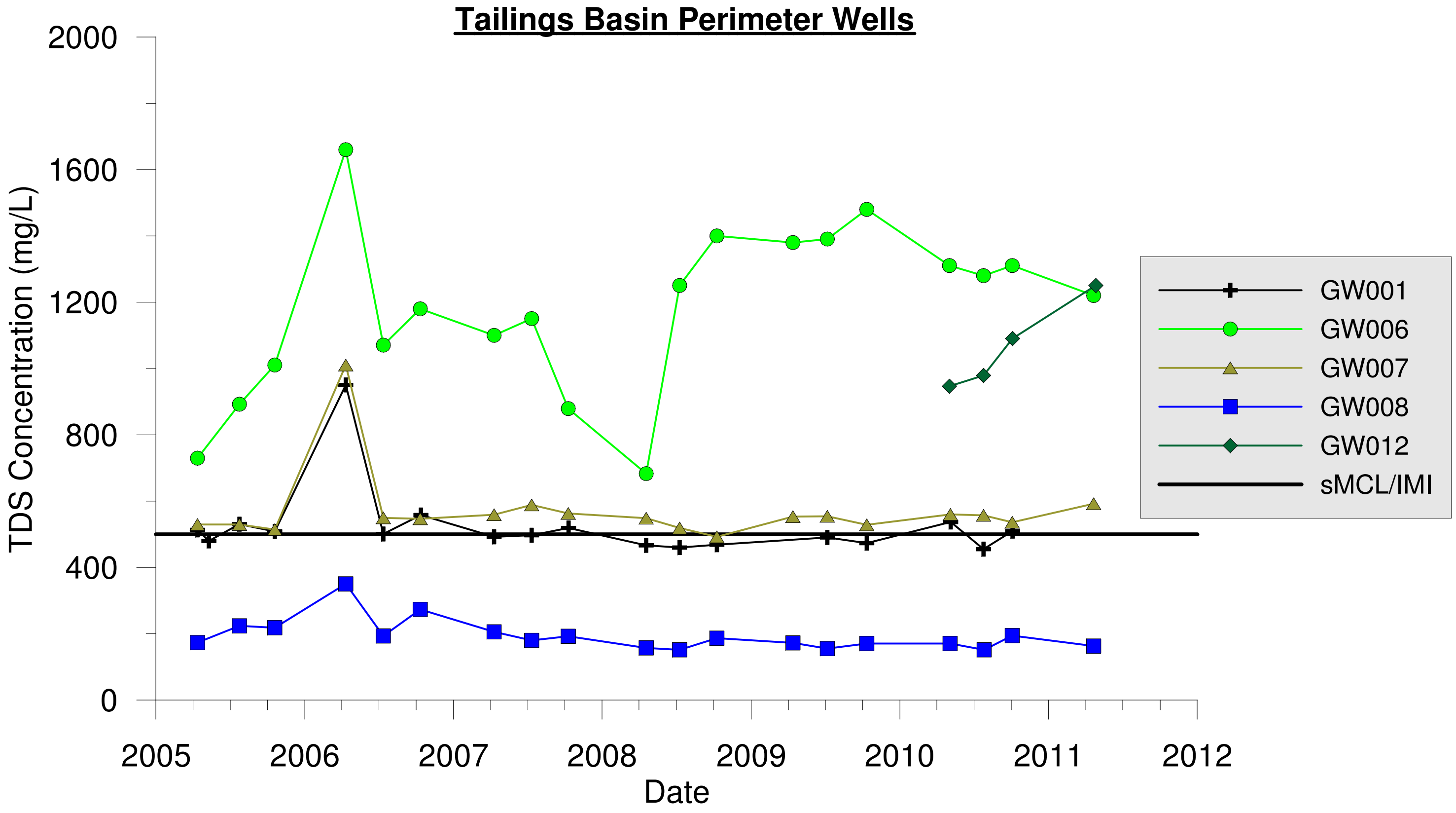
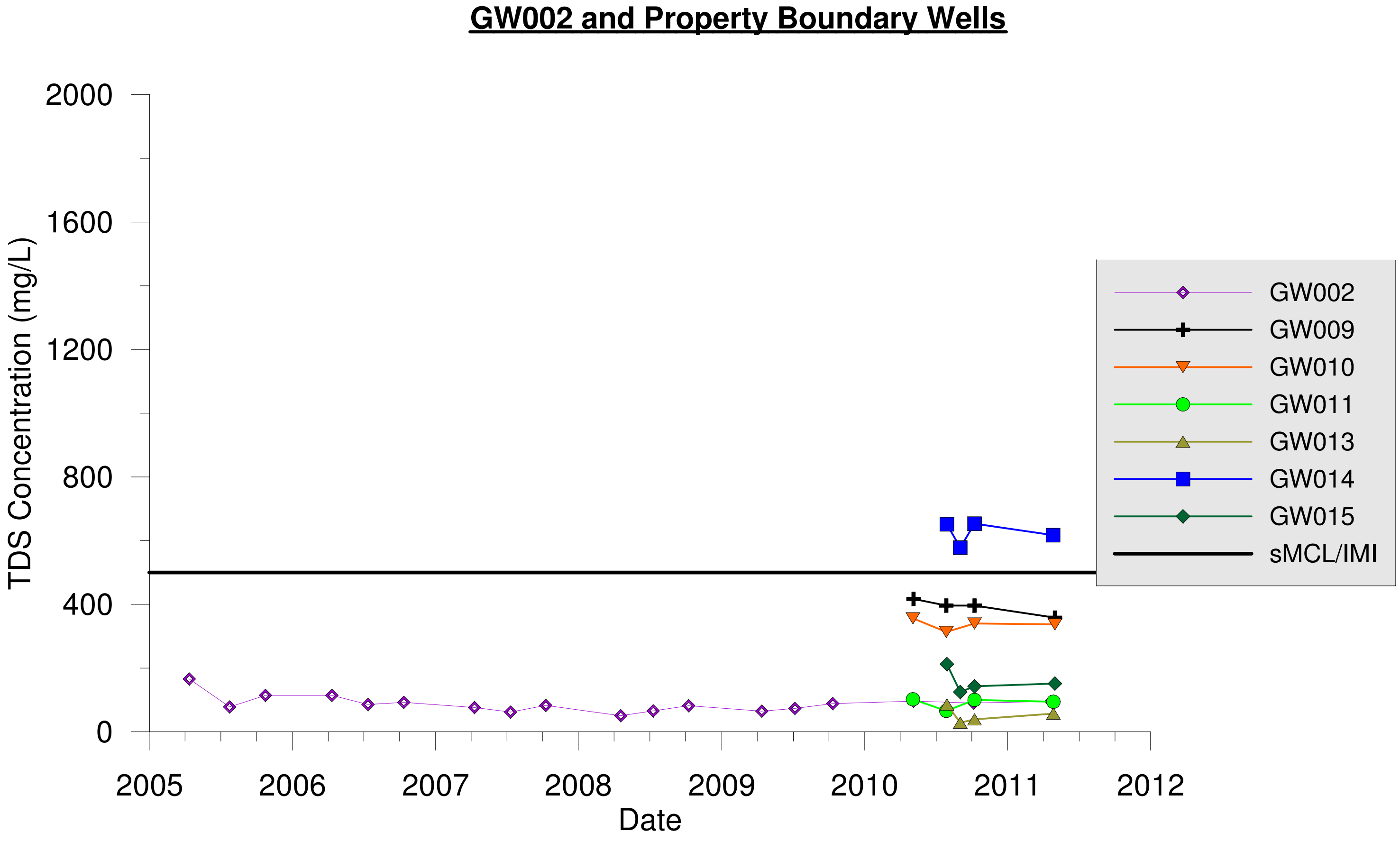


Figure 3-7 - Summary of Total Dissolved Solids Groundwater Data
Tailings Basin Monitoring Wells
PolyMet Mining Inc./Cliffs Erie L.L.C.





P:\Mpls\23 MN\69\23691072 NPDES Reissuance Area 5-Tailings Basin\WorkFiles\Field_Studies\Tailings_Basin\Groundwater_Investigation\Well_data_for_Grapher\TB_wells_TDS.grf

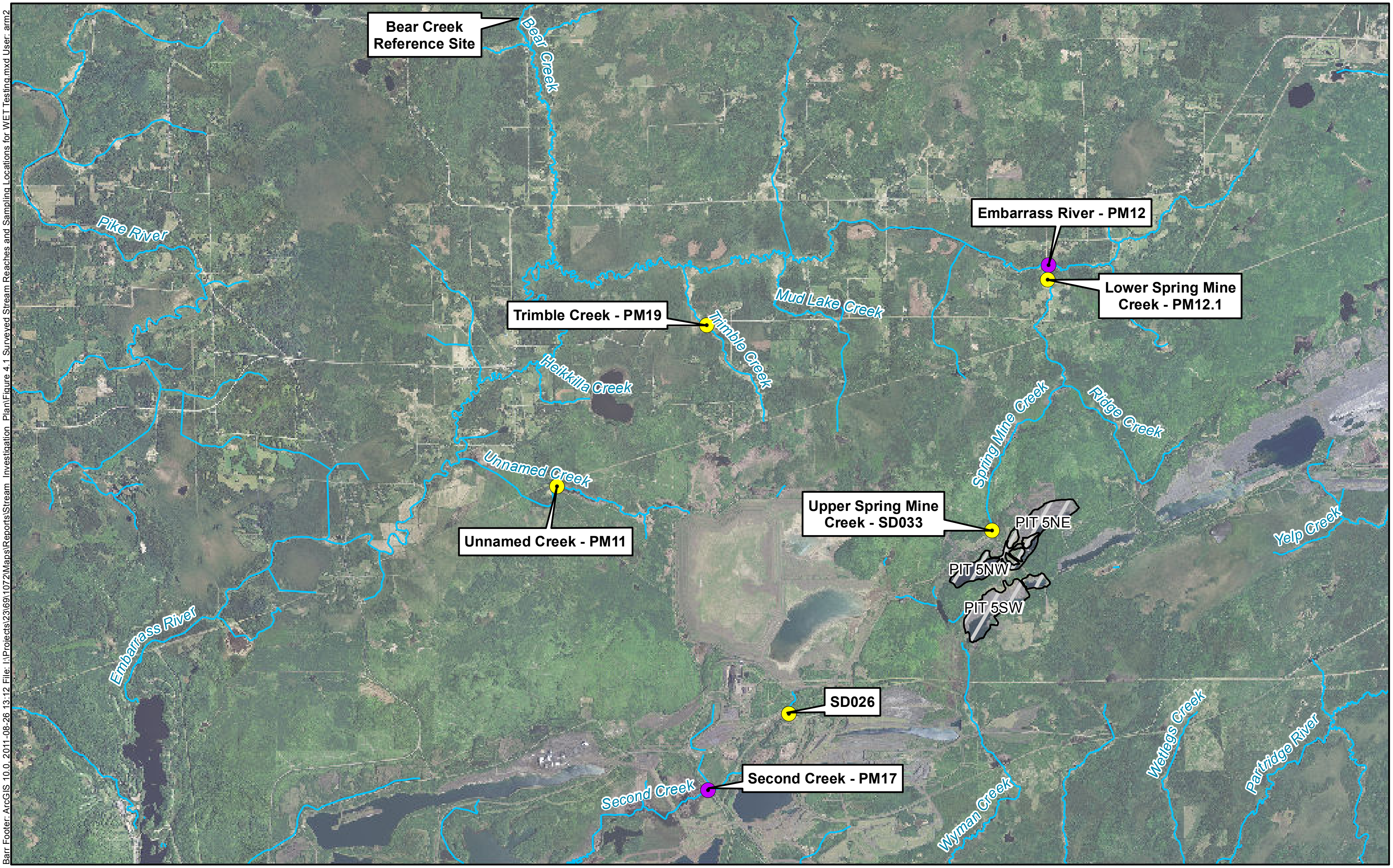


Figure 4.1
SURVEYED STREAM REACHES
AND SAMPLING LOCATIONS FOR
WHOLE EFFLUENT TOXICITY TESTING
St. Louis County, MN

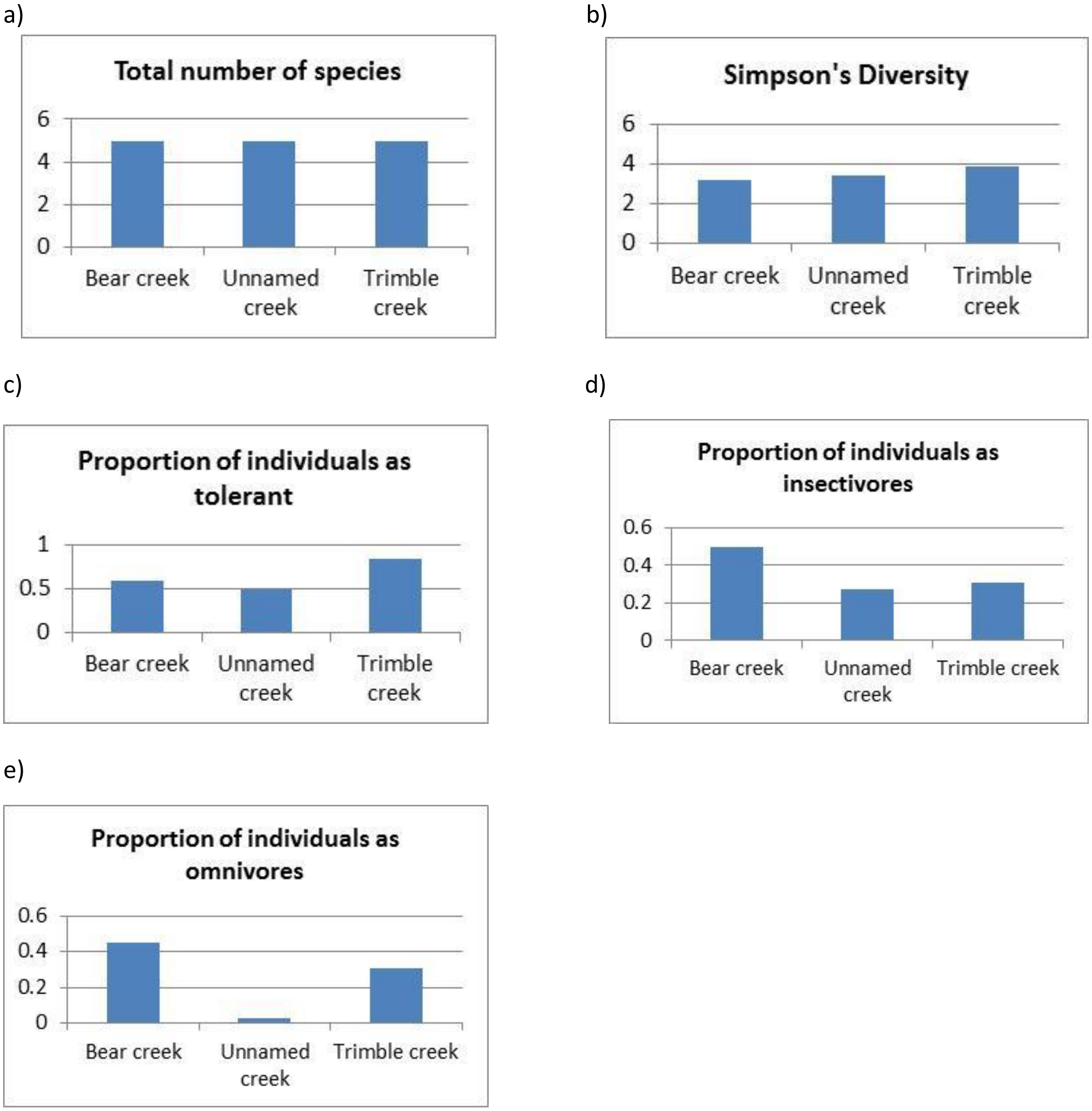


Figure 4-2 A comparison of the sites, Bear Creek, Unnamed Creek (PM11) and Trimble Creek (PM19) for the fish community measure – a) total number of species, (b) Simpson's diversity, (c) proportion of individuals as tolerant, (d) proportion of individuals as insectivores, and (e) proportion of individuals as omnivores.

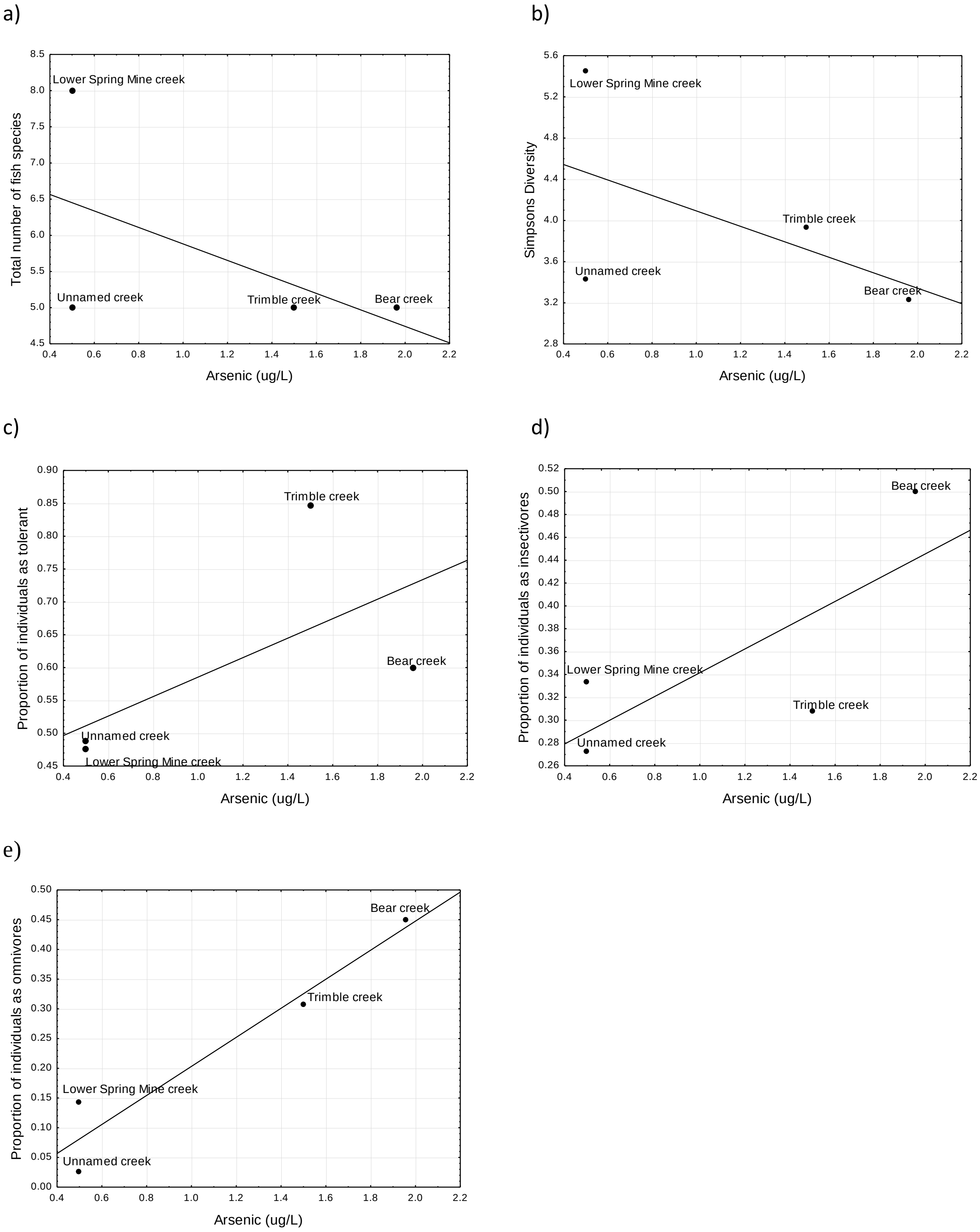
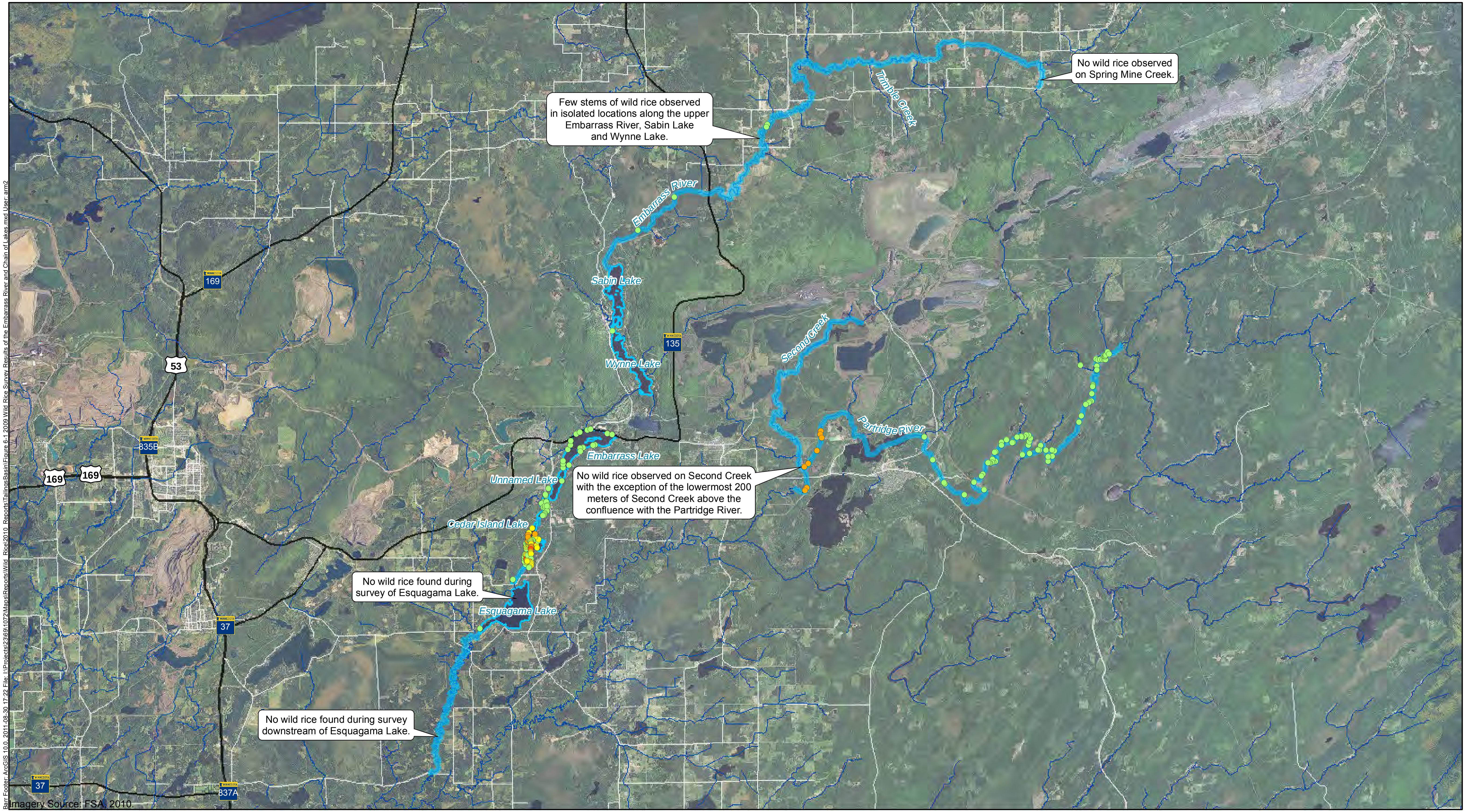


Figure 4-3 Relationship between fish community measures and arsenic concentration for the sites, Bear Creek, Unnamed Creek (PM11), Trimble Creek (PM19) and lower Spring Mine Creek (PM 12.1).



Imagery Source: FSA, 2010.

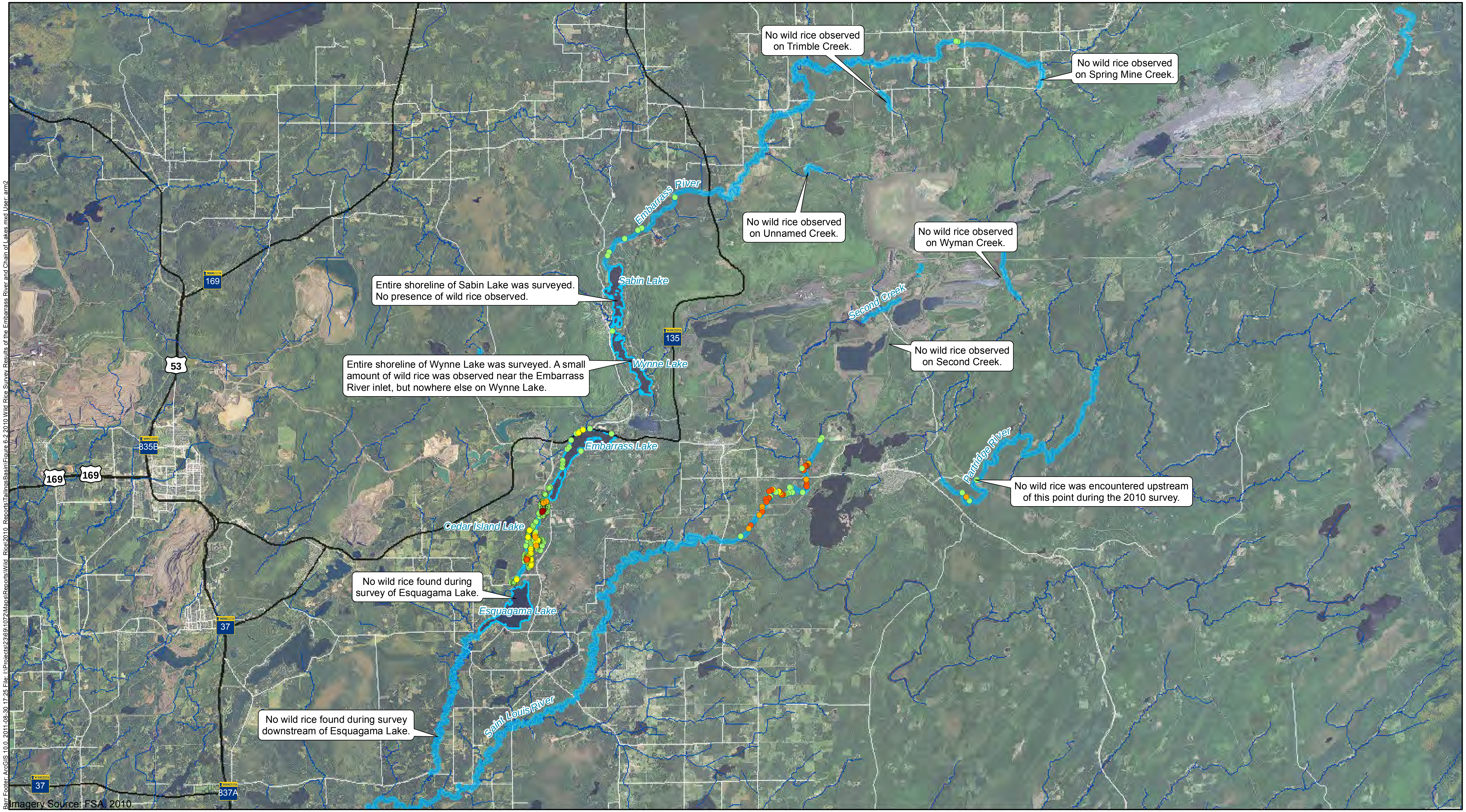
Wild Rice Density

- ● 1 <10% Wild Rice Coverage
- ● 2
- ● 3
- ● 4
- ● 5 >75% Wild Rice Coverage
- ▬ Stream or Shoreline Segment Surveyed in 2009

Data Sources: *2009 Wild Rice Survey and Sulfate Monitoring*
Prepared for Steel Dynamics, Inc. and Mesabi Mining, LLC, October 2009
2009 Wild Rice and Sulfate Monitoring
Prepared for PolyMet Mining Inc. – NorthMet Project, September 2009

0 1 2 4
Miles

Figure 6-1
2009 WILD RICE SURVEY RESULTS - EMBARRASS AND PARTRIDGE RIVER WATERSHEDS
Cliffs Erie, L.L.C. and
PolyMet Mining, Inc.
Hoyt Lakes, Minnesota



No wild rice observed on Trimble Creek.

No wild rice observed on Spring Mine Creek.

No wild rice observed on Unnamed Creek.

No wild rice observed on Wyman Creek.

Entire shoreline of Sabin Lake was surveyed. No presence of wild rice observed.

No wild rice observed on Second Creek.

Entire shoreline of Wynne Lake was surveyed. A small amount of wild rice was observed near the Embarrass River inlet, but nowhere else on Wynne Lake.

No wild rice was encountered upstream of this point during the 2010 survey.

No wild rice found during survey of Esquagama Lake.

No wild rice found during survey downstream of Esquagama Lake.

Wild Rice Density

- ● 1 <10% Wild Rice Coverage
- ● 2
- ● 3
- ● 4
- ● 5 >75% Wild Rice Coverage
- ▬ Stream or Shoreline Segment Surveyed in 2010

N

0 1 2 4

Miles

Data Sources: *2010 Wild Rice Survey and Sulfate Monitoring*
Prepared for Mesabi Mining, LLC, March 2011
2010 Wild Rice and Water Quality Monitoring Report
Prepared for PolyMet Mining Inc. – NorthMet Project, January 2011

Figure 6-2
2010 WILD RICE SURVEY RESULTS -
EMBARRASS AND PARTRIDGE RIVER WATERSHEDS
Cliffs Erie, L.L.C. and
PolyMet Mining, Inc.
Hoyt Lakes, Minnesota

Appendices

Appendix 3-A

Boring Logs

LOG OF Boring RS-31b/GW013

SHEET 1 OF 1

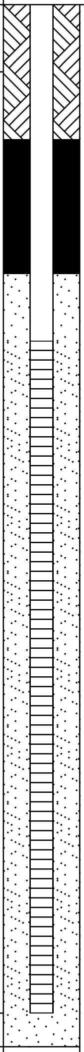
Client PolyMet
Project Name Tailings Basin GW Investigation
Number 23/69-1072
Location PolyMet

Drill Contractor Boart Longyear
Drill Method Rotosonic
Drilling Started 7/27/10 Ended 7/27/10
Logged By REE

Elevation --
Total Depth 15.5

DEPTH FEET	SAMP. LENGTH & RECOVERY	SAMP. NUMBER	%GR/SA/FINES	Color	Moisture	ASTM	LITHOLOGY	DESCRIPTION	DEPTH FEET
			20/65/5	Brown	Wet	PT		0-1': Peat, organic material	
						SM		1-15': Silty sand with gravel, medium-grained sand, large cobbles and boulder found in boring.	
				Grayish-brown				4': Color change to grayish brown	
5									5
10									10
15						BDRK		15-15.5': Granitic bedrock, weathered	15
								End of Boring - 15.5 feet	

WELL OR PIEZOMETER CONSTRUCTION DETAIL



PRO. CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **0-2.5 feet**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **0-5 feet**

GROUT
Type: **Cement**
Interval: **0-2 feet**

SEAL
Type: **Bentonite**
Interval: **2-4 feet**

SANDPACK
Type: **#30 Sand**
Interval: **4-15.5 feet**

SCREEN
Diameter: **2 inches**
Type: **#10 Slot PVC**
Interval: **5-15 feet**

Remarks: Monitoring Well GW-13

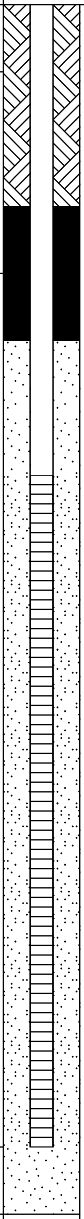
LOG OF Boring RS-32/GW014

SHEET 1 OF 1

Client PolyMet
Project Name Tailings Basin GW Investigation
Number 23/69-1072
Location PolyMet
Drill Contractor Boart Longyear
Drill Method Rotosonic
Drilling Started 7/26/10 Ended 7/26/10
Logged By REE
Elevation --
Total Depth 18.0

DEPTH FEET	SAMP. LENGTH & RECOVERY	SAMP. NUMBER	%GR/SA/ FINES	Color	Moisture	ASTM	LITHOLOGY	DESCRIPTION	DEPTH FEET
			5/60/35	Dark Gray	Wet	SM		0-1': Silty sand with organics, medium to fine-grained sand.	
			5/60/35	Strong Brown w/Gray Mottles		SC		1-4': Clayey sand, medium-grained sand, strong brown with dark gray mottles. 2 inch coarse sand lens.	
			5/55/40	Olive-gray		SM		4-17': Silty sand, medium to coarse-grained sand.	
5									5
10			5/70/25						10
15									15
						BDRK		17-18': Granitic bedrock.	
								End of Boring - 18 feet	

WELL OR PIEZOMETER CONSTRUCTION DETAIL



PRO. CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **0-2.5 feet**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **0-7 feet**

GROUT
Type: **Cement**
Interval: **0-3 feet**

SEAL
Type: **Bentonite**
Interval: **3-5 feet**

SANDPACK
Type: **#30 Sand**
Interval: **5-18 feet**

SCREEN
Diameter: **2 inches**
Type: **#10 Slot PVC**
Interval: **7-17 feet**

Remarks: Monitoring Well GW-14

LOG OF Boring RS-33/GW015

SHEET 1 OF 1

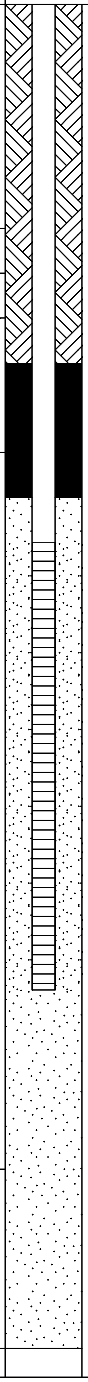
Client PolyMet
Project Name Tailings Basin GW Investigation
Number 23/69-1072
Location PolyMet

Drill Contractor Boart Longyear
Drill Method Rotosonic
Drilling Started 7/28/10 Ended 7/28/10
Logged By REE

Elevation --
Total Depth 30.0

DEPTH FEET	SAMP. LENGTH & RECOVERY	SAMP. NUMBER	%GR/SA/ FINES	Color	Moisture	ASTM	LITHOLOGY	DESCRIPTION
0					Wet			0-5': No recovery, likely peat.
5				Very dark Brown		PT		5-6': Peat, organic material.
6			5/90/5	Dark Grayish-brown		SP		6-7': Sand, medium to coarse-grained sand, some organics.
7			2/3/95	Gray		CL		7-10': Clay, high plasticity.
10			20/70/10			SP-SM		10-26': Sand with gravel and silt.
15								15-20': No recovery.
26						BDRK		26-30': Granitic bedrock, weathered.
30								End of Boring - 30 feet

WELL OR PIEZOMETER CONSTRUCTION DETAIL



PRO. CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **0-2.5 feet**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **0-12 feet**

GROUT
Type: **Cement**
Interval: **0-8 feet**

SEAL
Type: **Bentonite**
Interval: **8-11 feet**

SANDPACK
Type: **#30 Sand**
Interval: **11-30 feet**

SCREEN
Diameter: **2 inches**
Type: **#10 Slot PVC**
Interval: **12-22 feet**

Barr Engineering Co.
4700 West 77th Street, Suite 200
Minneapolis, MN 55435
Telephone: (952) 832-2600
Fax: (952) 832-2601

Remarks: Monitoring Well GW-15

Appendix 4-A

Physical Habitat and Water Chemistry Assessment Protocol

Minnesota Pollution Control Agency Biological Monitoring Program

PHYSICAL HABITAT AND WATER CHEMISTRY ASSESSMENT PROTOCOL FOR WADEABLE STREAM MONITORING SITES

I. PURPOSE

To describe the methods used by the Minnesota Pollution Control Agency's (MPCA) Biological Monitoring Program to collect physical habitat and water chemistry information at stream monitoring sites for the purpose of assessing water quality and developing biological criteria.

II. SCOPE/LIMITATIONS

This procedure applies to all wadeable monitoring sites for which an integrated assessment of water quality is to be conducted. An integrated assessment involves the collection of biological (fish and macroinvertebrate communities), physical habitat, and chemical information to assess stream condition.

III. GENERAL INFORMATION

Sites may be selected for assessment for a number of reasons including: 1) sites randomly selected for condition monitoring as part of the Environmental Monitoring and Assessment Program (EMAP), 2) sites selected for the development and calibration of biological criteria, and 3) sites selected to evaluate a suspected source of pollution. Although the reasons for monitoring a site vary, the physical habitat and water chemistry assessment protocols outlined in this document apply to all wadeable stream monitoring sites unless otherwise noted. For our purposes, wadeable sites constitute those that are sampled for fish utilizing a backpack electrofisher or stream electrofisher (see SOP--"***Fish Community Sampling Protocol for Stream Monitoring Sites***").

IV. REQUIREMENTS

A. Qualifications of crew leaders: The crew leader must be a professional aquatic biologist with a minimum of a Bachelor of Science degree in aquatic biology or closely related specialization. He or she must have a minimum of six months field experience in physical habitat sampling methodology. Field crew leaders should also possess excellent map reading skills and a demonstrated proficiency in the use of a GPS (Global Positioning System) receiver and orienteering compass.

B. Qualifications of field technicians/interns: A field technician/intern must have at least one year of college education and coursework in environmental and/or biological science.

C. General qualifications: All personnel conducting this procedure must have the ability to perform rigorous physical activity. It is often necessary to wade through streams and/or wetlands, canoe, or hike for long distances to reach a sampling site.

V. RESPONSIBILITIES

A. Field crew leader: Implement the procedures outlined in the action steps and ensure that the data generated meets the standards and objectives of the Biological Monitoring Program.

B. Technicians/interns: Implement the procedures outlined in the action steps, including maintenance and stocking of equipment, data collection and recording.

VI. QUALITY ASSURANCE AND QUALITY CONTROL

Compliance with this procedure will be maintained through annual internal reviews. Technical personnel will conduct periodic self-checks by comparing their results with other trained personnel. Calibration and maintenance of equipment will be conducted according to the guidelines specified in the manufacturer's manuals.

In addition to adhering to the specific requirements of this sampling protocol and any supplementary site specific procedures, the minimum QA/QC requirements for this activity are as follows:

A. Control of deviations: Deviation shall be sufficiently documented to allow repetition of the activity as performed.

B. QC samples: Ten percent of sites sampled in any given year are resampled as a means of determining sampling error and temporal variability.

C. Verification: The field crew leader will conduct periodic reviews of field personnel to ensure that technical personnel are following procedures in accordance with this SOP.

VII. TRAINING

A. All inexperienced personnel will receive instruction from a trainer designated by the program manager. Major revisions in this protocol require that all personnel be re-trained in the revised protocol by experienced personnel.

B. The field crew leader will provide instruction in the field and administer a field test to ensure personnel can execute this procedure.

VIII. ACTION STEPS

A. Equipment list: Verify that all necessary items are present before commencement of this procedure (Table 1).

B. Data collection method: The location and length of the sampling reach is determined during site reconnaissance (see SOP--"***Reconnaissance Procedures for Initial Visit to Stream Monitoring Sites***"). Sampling is conducted during daylight hours within the summer index period of mid-June through mid-September. Sampling should occur when streams are at or near base-flow. Water chemistry is sampled immediately prior to fish sampling. The physical habitat assessment is conducted after fish sampling, so as not to disturb the fish community.

Habitat within a station is quantified utilizing the transect-point method (modified from: Simonson, T.D., Lyons, J., and Kanehl, P.D. 1994. Guidelines for Evaluating Fish Habitat in Wisconsin Streams. Gen. Tech. Rep. NC-164. St. Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Experiment Station. 36 p.). Thirteen transects are established within the reach and four equally spaced points plus the thalweg are located along each transect. Measurements or visual estimates are made to characterize key components of the physical habitat structure important in influencing stream ecology. Key components include: channel morphology, substrate, cover, and riparian condition.

Three data sheets are required for the physical habitat and water chemistry assessment. One copy of the **Station Features** and **Visit Summary** form is needed for each site. One copy of the **Transect** form is needed for each of the thirteen transects (or only seven copies if forms are doubled-sided). Copies of these forms are attached. Guidelines for filling out each data sheet are described in the following pages.

C. Station Features Data Sheet

This data sheet describes the length and location of the major morphological features within a sampling station (bends, pools, riffles, runs, log jams, islands, and beaver dams). The **Station Features** data is collected in conjunction with the **Transect** data as you proceed from the downstream end to the upstream end of the station. The variables on this data sheet are as follows:

1) *Field Number* – A seven-digit code that uniquely identifies the station. The first two digits identify the year of sampling, the second two identify the major river basin, and the last three are numerically assigned in sequential order (example: 02UM001).

2) *Date* – The date habitat sampling is conducted in month/day/year format (MM/DD/YY).

3) *Crew* – The personnel who collected the habitat data.

4) *Distance From Start* (column) – The distance from the downstream end of the station to the downstream end of each *stream feature*. Bends, log jams, and beaver dams are measured only to their midpoint because they are features that are located within one of the channel morphology types (i.e. riffle, run, or pool). Measure distances to the nearest tenth of a meter following the center of the stream channel. The first value is always "0" to indicate the *stream feature* at the beginning of the station. As you proceed upstream it is not necessary to continue to measure from the downstream end of the station, as each successive **Transect** data sheet has the distance of that transect from the downstream end of the station recorded. The last value in this column is the total length of the station.

5) *Stream Feature* (column) – Record the major morphological features encountered as you proceed upstream. If a cross-section of stream contains two or more channel morphology types (i.e. riffle, run, or pool) record the dominant type. Stream features recorded include:

   Riffles: Portions of the stream channel where water velocities are fast, water depths are relatively shallow, and substrates are typically coarse. Steeper stream gradient results in obvious surface turbulence. Areas of high gradient that are deep, fast, and turbulent are called **rapids**.

   Runs: Water velocities may be moderately fast to slow but the water surface typically appears smooth with little or no surface turbulence. Generally, runs are deeper than a riffle and shallower than a pool. Runs with very slow water velocities are sometimes called **glides**. For our purposes, if the channel type is not considered a riffle or pool it is defined as a run.

   Pools: Water is slow and generally deeper than a riffle or run. Water surface is smooth, no turbulence. A general rule that can be used to distinguish a pool is if two or more of the following conditions apply; the stream channel is wider, deeper, or slower than average.

   Bends: A change in the direction of the stream channel of at least 60 degrees.

   Islands: Areas of land within the stream channel that is surrounded on all sides by water and is dry even when the stream is experiencing bankfull flow. Areas with nearly all of the stream's flow on one side and just a trickle of water on the other are not considered islands. Islands usually contain vegetation. **Bars**, channel features below the bankfull flow level that are dry during baseflow conditions, are not recorded.

   Log Jams: Woody material that is of sufficient size to appreciably alter the direction of flow or change the morphology within the stream channel. Large log jams can be similar in effect and appearance to beaver dams.

   Beaver Dams: Structures constructed by beavers that span the entire stream channel and block flow. Beaver dams consist of sticks and mud, but older dams may be overgrown with vegetation.

   Other noteworthy features include: **bridges**, **culverts**, **dams**, and **tributaries**. The last feature noted in this column is the upstream **end of the reach**.

6) *Length* (column) – The length, measured to the nearest tenth of a meter, of each *stream feature* encountered within the reach. The length of bends, log jams, and beaver dams are not recorded. It is not necessary to complete this column while in the field as this information is derived from the *Distance from start* and *Stream feature* columns.

7) *Distance Between Bends* – The distance (m) between successive bends contained within the station. The first row is the distance between the mid-point of the first and second bend. The second row is the distance between the second and third, and so forth. These values can be derived using the information contained in the columns *Distance from start* and *Stream feature*. The "sum" and "mean" rows summarize all the distances between bends within the station.

8) *Distance Between Riffles* – The distance (m) between successive riffles contained within the station. The first row is the distance between the upstream end of the first riffle and the downstream end of the next riffle upstream, and so forth. Distances can be derived using the *Distance from start* and *Stream feature* columns. The "sum" and "mean" rows summarize these distances.

9) *Length of Individual Riffles, Pools, and Runs* – The individual length (m) of each riffle, pool, or run within the station, which can be derived using the *Stream feature* and *Length* columns. The sum of their lengths is also recorded here.

D. Transect Data Sheet

Record the data generated from each of the thirteen transects on this data sheet. One data sheet is needed for each transect. To determine the placement of each of the thirteen transects within the station divide the station length (determined during reconnaissance) by thirteen, this number is the *transect spacing* or distance between transects. The first transect is located one half of the transect spacing distance from the downstream end of the station. Each subsequent transect is then the distance of one transect spacing from the previous transect. All numbers are rounded to the nearest half meter.

For example, if the station length is 150 m, 150 ÷ 13 = 11.5 (equals the transect spacing). The first transect would then be located a distance of 6 m from the downstream end of the station, 11.5 ÷ 2 = 5.75 (equals 6 rounded to the nearest half meter). The second transect would then be located a distance of 17.5 m from the downstream end of the station, 6 + 11.5 = 17.5, and so forth for subsequent transects.

Each transect consists of several measurements or visual estimates, made within 0.3 m x 0.3 m quadrates at set intervals, or along the transect line perpendicular to the stream channel. The variables on this data sheet are as follows:

D.1. Location Information

1) *Field Number* – Same as for **Stream Features** data sheet.

2) *Date* – Same as for **Stream Features** data sheet.

3) *Transect Number* – The number (1-13) of the current transect as you proceed upstream. The downstream most transect is number one, the next transect upstream is two, and so on.

4) *Crew* – Same as for **Stream Features** data sheet.

5) *Distance from Start* – The distance from the downstream end of the station to the current transect following the center of the stream channel, rounded to the nearest half meter.

6) *Stream Width* – The wetted width of the stream channel at the transect, measured to the nearest tenth of a meter. Exposed bars and boulders are included in the wetted width of the stream channel, but islands are not. Backwaters not in contact with the stream at the transect are also excluded. If a channel is split by an island(s), the wetted widths of each side channel should be combined so that a single number is recorded in *stream width*. In low gradient streams the wetted width is the defined portion of the stream channel, it does not include adjacent wetlands and areas of emergent vegetation.

7) *Channel Type* – Circle the predominant channel type at the transect. See the **Station Features** section for riffle, pool, and run definitions.

D.2. Transect Point Measurements: At each transect, measurements or visual estimates are made at five points along the transect. Variables quantified include: *water depth, depth of fines and water, embeddedness, substrate, percent algae, and percent macrophytes*. Four points are equally spaced across the stream channel and the fifth point is the thalweg, or deepest point along the transect line. Divide the *stream width* at the transect by five to determine the 1/5, 2/5, 3/5, and 4/5 locations across the wetted width of the stream channel. Measurements are made at each of these four locations moving from the right bank to the left bank along the transect. The right stream bank is on the right as you are facing downstream. For example, if the stream is 10 m wide, measurements are taken at the thalweg and along the transect at 2.0, 4.0, 6.0, and 8.0 m from the right bank. In some instances, the thalweg will occur at the same location as one of the four other points, in which case their measurement values will be the same.

1) *Water Depth* – The depth of the stream channel at each transect point. Measure the vertical distance of the water column from the streambed to the water surface to the nearest centimeter with a calibrated wading rod or meter stick. If the water depth is over 120 cm, record as >120 cm.

2) *Depth of Fines and Water* – The water depth plus the depth of fine sediments at each transect point. Fine sediments are those that are less than 2.0 mm in diameter and generally consist of sand, silt, clay, or detritus. Without using the weight of your body, push a wading rod into the sediment as far as possible, measure to the water surface to the nearest centimeter. This measurement is later converted to depth of fines by subtracting *water depth*.

3) *Embeddedness of Coarse Substrates* – The extent to which coarse substrates are surrounded by or covered with fine sediments. Coarse substrates consist of gravel, rubble/cobble, and boulders. If the dominant substrate within the quadrate is coarse, embeddedness should be visually estimated to the nearest 25%. Estimate the average percent embeddeness of coarse substrates within the 0.3 m x 0.3 m quadrate centered on the channel position. An embeddedness rating of 0% corresponds to very little or no fine sediments surrounding coarse substrates. Course substrate material completely surrounded and covered with sediment is considered 100% embedded. If the dominant substrate within a quadrate is anything other than gravel, rubble/cobble, or boulder then the column should be left null.

4) *Dominant Substrate* – The predominant substrate type within each quadrate. Visually estimate which substrate type is predominant within each quadrate and place a check mark in the appropriate column. If the stream bottom cannot be seen, use your hands and feet to determine the dominant substrate type. Choose from the following substrate types:

   Bedrock: A solid slab of rock, > 4000 mm in length (larger than a car).

   Boulder: Large rocks ranging from 250 mm to 4000 mm in diameter (basketball to car size).

   Rubble/Cobble: Rocks ranging in diameter from 64 mm to 250 mm (tennisball to basketball).

   Gravel: Rocks varying in diameter from 2 mm to 64 mm (BB to tennisball).

   Sand: Inorganic material that is visible as particles and feels gritty between the fingers. 0.06 mm to 2.0 mm in size.

   Silt: Fine inorganic material that is typically dark brown in color. Feels greasy between fingers and does not retain its shape when compacted into a ball. A person's weight will not be supported if the stream bottom consists of silt.

   Clay: Very fine inorganic material. Individual particles are not visible or are barely visible to the naked eye. Will support a person's weight and retains its shape when compacted.

   Detritus: Decaying organic material such as macrophytes, leaves, finer woody debris, etc. that may appear similar to silt when very fine.

   Other: Any substrate type not listed above, specify the type. Possibilities could include woody debris, culverts, tires, or mussel beds.

5) *Algae (%)* – Visually estimate the amount of algae within the quadrate, to the nearest 5 %. Algae can either be attached to the substrate in the form of a mat or crust; or filamentous algae, which forms dense mats of long, hair-like strands and is usually green in color.

6) *Macrophytes (%)* – Visually estimate the amount of aquatic vegetation within the quadrate, to the nearest 5 %. Aquatic macrophytes can be either submergent or emergent and are defined under *cover for fish*.

D.3. Cover and Land Use Characteristics

1) *Cover for Fish (%)* – The amount of cover or shelter available for fish along the transect. Visually estimate the percentage (nearest 5 %) occupied by each cover type along the transect within a 0.3 m band centered on the transect line. If a cover type is absent, enter a zero. In order to be considered cover, the water depth must be at least 15 cm where the cover type occurs. Cover for fish consists of objects or features dense enough to provide complete or partial shelter from the stream current or concealment from predators or prey.

   Undercut Banks: Stream banks where the stream channel has cut underneath the bank. The bank could overhang the water surface when water levels are low. The undercut bank must overhang (horizontally) the wetted stream channel a minimum of 15 cm and the bottom of the bank must be no more than 15 cm above the water level in order to be considered cover for fish.

   Overhanging Vegetation: Terrestrial vegetation overhanging the wetted stream channel that meets the same criteria for cover as undercut banks.

   Woody Debris: Logs, branches, or aggregations of smaller pieces of wood in contact with or submerged in water.

   Boulders: Large rocks as described under *Substrate*.

   Submergent Macrophytes: Vascular plants that have all of their biomass (except flowers) at or below the surface of the water. Examples include *Vallisneria*, *Elodea*, *Potamogeton*, *Nymphaea* and *Ceratophyllum*.

   Emergent Macrophytes: Vascular plants that typically have a significant portion of their biomass above the water surface. Examples include *Typha, Scirpus,* and *Zizania.*

   Other Debris: Additional objects that meet the criteria of cover, typically of human origin. Examples would include filamentous algae, culverts, docks, tires, discarded appliances, etc. Specify the type.

2) *Bank Erosion* – The amount of the stream bank that is exposed soil and therefore, susceptible to erosion. For each bank, along the transect line, use a wading rod or measuring tape to quantify the length (nearest 0.1 m) of bare soil. Measure the amount of exposed soil from the waters edge to the top of the stream bank, up to a maximum of 5 m. If there is no bare soil, record 0.

3) *Riparian Land Use* – The predominant land use within the riparian zone. For each bank, extending along the transect line, visually estimate the predominant land use within 30 m of the waters edge and place a check mark in the corresponding column. Repeat this same procedure for the riparian zone 30 – 100 m from the waters edge. Land use categories are as follows:

   Cropland: Land that is cultivated with crops for forage or cover. Includes those areas under intensive cropping or rotation, or that are regularly mowed for hay.

   Pasture: Land that is regularly grazed by livestock.

   Barnyard: Land associated with farmsteads and the adjoining farmyard area. Includes grain storage facilities, barns, farmhouses, and feedlots (areas used to confine and feed high densities of livestock).

   Developed: Land that has been modified (rural or urban) for commercial, industrial, or residential use. Includes commercial buildings/structures, parking lots, all roads, railroads, and power utilities. Also includes residential buildings, lawns, parks, golf courses, ball fields, etc. Specify the type in the space provided.

   Exposed Rock: Natural areas of rock outcrops that lack appreciable soil development or vegetative cover.

Meadow: Land dominated by grasses and forbs with little woody vegetation, which is not subject to regular mowing or grazing.

Shrub: Land consisting primarily of woody vegetation less than 3 m in height. Typical shrubs include alder, dogwood, and willows.

Woodland: Land dominated by deciduous or coniferous tree species, generally taller than 3 m.

Wetland: Low-lying areas that are saturated or inundated with water frequently or for considerable periods of time on an annual basis. Wetlands include bogs, marshes, and swamps and contain vegetation adapted for life in saturated conditions.

Other: If a land use category other than one of those listed above is predominant, specify the type.

4) *Riparian Buffer Width* – The amount of contiguous undisturbed land use within a 10 m buffer zone. For each bank, starting from the waters edge and extending out along the transect line 10 m, measure the width (nearest meter) of contiguous land that is considered undisturbed. Meadow, shrub, woodland, wetland, and exposed rock are considered undisturbed. If no undisturbed land uses are directly adjacent to the stream, then the riparian buffer width is 0 m. If more than 10 m is present, record it as >10 m.

5) *Canopy/Shading* – A measure of overhead canopy cover that is shading the stream channel. A concave spherical crown densiometer is utilized for this measurement. The densiometer must be taped as shown in Figure 1 to limit the number of grid intersections to 17. Hold the densiometer at elbow level in front of you, making sure the instrument is level using the bubble level, count and record the number (0 to 17) of grid intersections that have vegetation covering them. If the reflection of a tree, branch, or leaf overlies any of the intersection points, that particular intersection is counted as having cover. Perform this measurement from the center of the stream channel along the transect line in each of four directions; facing upstream, downstream, towards the left bank, and towards the right bank. In addition, perform the measurement at the wetted edge of both the left and right banks facing the stream bank.

E. Visit Summary Data Sheet

This data sheet contains location information, water chemistry data, and channel characteristics of the station. Some of the data is derived from maps or from the other data sheets. Record the following information on this data sheet:

E.1. Location Information

1) *Field Number* – Same as for **Station Features** data sheet.

2) *Date* – Same as for **Station Features** data sheet.

3) *Stream Name* – The name of the stream as shown on the most recent USGS 7.5" topographic map. Include all parts of the name (i.e. "North Branch", "Creek", "River", "Co. Ditch", etc.).

4) *Location* – A general description of where the sampling station is located. Usually includes the nearest road crossing and town. For example, "0.5 mi. downstream of C.R. 30, 4 mi. SW of Northome".

5) *County* – The county in which the station is located.

6) *Visit Result* – The result of the sampling trip, typically as it pertains to fish collection. Circle only one of the available choices. A visit or sampling trip is considered "reportable" when sampling is conducted for the first time at a station and no problems are encountered that would render the data questionable. If subsequent sampling trips are made to the same station and no sampling problems occur, the *visit result* is considered a "replicate". Circle "other", and explain in the space provided, in the event that the data generated is questionable or unsuitable for use. Reasons might include equipment problems, poor sampling efficiency, excessive water velocity, poor fish taxis, or other sampling deficiencies.

7) *GPS File Name* – The unique identifier of a rover file assigned by the GPS unit. If a GPS file is taken (to record the location of a sampling site), the unit will assign an eight-digit code consisting of a file prefix, date stamp, and time stamp that uniquely identifies that file. In most instances, it is not necessary to take a GPS file during the sampling visit because sampling sites are located and flagged during site reconnaissance. However, circumstances may occur that necessitate a file be taken during the sampling visit. These include but are not limited to: original reconnaissance file unreliable or inaccurate, flagging cannot be located, initial site location determined to be incorrect, and GPS file not obtained during initial site reconnaissance. If sampling and initial site reconnaissance are conducted at the same time, the GPS information should be recorded as part of the reconnaissance protocol. Consult the GPS user's manual and SOP--"***Reconnaissance Procedures for Initial Site Visit to Stream Monitoring Sites***" for additional guidance on GPS operation and protocol.

8) *Type of GPS Fix* – If a GPS file is taken during the sampling visit, indicate the position mode (3D or 2D) in which the GPS file was recorded.

9) *PDOP* – If a GPS file is taken during the sampling visit, record the approximate Position Dilution of Precision (PDOP) value that was observed while the GPS file was being recorded.

10) *Data Source* – The source or entity that generated the data. For Minnesota Pollution Control Agency (MPCA) staff within the Biological Monitoring Unit this field should be recorded as "MPCA".

11) *Project* – The specific project that the data collection effort is associated with. Some possibilities include EMAP, biocriteria development, problem investigation, and longitudinal survey.

E.2. Field Water Chemistry: Water chemistry parameters should be sampled immediately prior to fish sampling. All water chemistry parameters are measured from the same general location at a representative stream cross-section within the sampling reach. Samples are taken at a point that is judged to represent the water quality of the total instantaneous flow at the cross-section. Avoid sampling areas that are poorly mixed, contain springs, or are upstream of or immediately adjacent to tributaries within the sampling reach. Water chemistry measurements and water samples are taken at an intermediate depth in the water column without disturbing substrate materials or collecting floating materials and constituents from the water surface. Refer to the manufacturer's owners manual for guidance concerning the calibration and operation of water quality meters.

1) *Time* – The time of day (24-hour clock) that field water chemistry parameters are measured.

2) *Air Temp* – The ambient air temperature (°C) at the time of sampling, measure to the nearest degree with a dry thermometer.

3) *Water Temp* – The water temperature (°C) of the station at the time of sampling, measure to the nearest tenth of a degree with a thermometer or water quality meter.

4) *Conductivity* – Temperature compensated conductivity, or *specific conductance*, is the parameter actually being determined and is a measure of the ability of water to carry an electrical current. Consult your conductivity meter's manual for guidance measuring specific conductance (measured in µmhos/cm) compensated for temperature to 25 °C.

5) *Dissolved Oxygen* – The amount of oxygen present in a water sample, expressed as milligrams of oxygen per liter of water (mg/L). Two water samples should be taken and measured for dissolved oxygen concentrations using a DO meter or the Winkler Titration Method.

6) *Turbidity* – The light scattering property associated with suspended particles in the water, measured with a turbidimeter in nephelometric turbidity units (NTUs). A turbid sample will appear cloudy. A water sample is taken in a 500-ml plastic bottle rinsed with stream water three times. Due to the sensitivity of the turbidimeter to road dust and other conditions encountered while in the field, place the sample on wet ice until days end and measure turbidity in a more suitable environment (office or hotel room).

7) *pH* – A measure of the negative log of the hydrogen ion [H^+] concentration in the water. Pure water has a pH of 7.00 and is considered neutral. Measure pH utilizing a temperature compensating pH meter.

8) *Stream Flow* – Also known as discharge, it is the volume of water moving downstream per unit time, and is the product of current velocity and the dimensions of the stream channel. Measure the instantaneous flow rate (cubic meters/second) at a suitable stream cross-section using a current meter. Detailed guidelines for determining stream flow at a station are available from the USGS.

9) *Transparency* – A measure of water clarity, an indicator of the water's ability to transmit light. Stream transparency serves as an indirect measure of the amount of dissolved and suspended materials present. Measure (nearest cm) with a transparency tube, a clear tube 60 cm in length with a secci-type disk at the bottom.

10) *Water Level* – An estimation of water level as it relates to summer base flow expectations. Check the appropriate category and measure the vertical distance (nearest 0.1 m) above or below the normal water line. In most streams, the "normal" water level can be determined with relative ease by observing channel characteristics.

E.3 Lab Water Chemistry: Water samples taken for laboratory analyses typically include total phosphorus (P), total suspended solids (TSS), ammonia nitrogen (NH^3+NH^4), and nitrite-nitrate (NO^2+NO^3). Additional parameters may be measured in special circumstances. Samples taken for laboratory analyses are subject to the same general guidelines concerning sampling location and time as outlined above under *field water chemistry*. Sterilized sample bottles are obtained from the Minnesota Department of Health. Before collecting samples, label the containers with the *date* and *field number* with a waterproof pen or pencil. Collect a 250 ml nutrients sample and a one-liter general chemistry sample for laboratory analysis. The bottles should be lowered mouth down to an intermediate depth and then turned upstream to collect the sample, the Dept. of Health does not recommend rinsing their sample bottles. Immediately after sample collection, 5 ml of 10% sulfuric acid preservative solution is added to the nutrients sample. Both sample bottles must be stored at 4 ° C and shipped to the Dept. of Health Water Lab within the minimum holding times.

1) *Collection Time (field sample)* – The time of day (24-hour clock) that water samples for laboratory analysis are collected.

2) *Collection Time (field duplicate)* – A field duplicate is a second sample taken immediately following an initial sample in the same manner and location. Duplicate samples are taken at 10% of all sampling sites for quality assurance and control (QA/QC) purposes. If a duplicate water sample is taken, record the time (24 hour clock) here.

E.4 Channel Characteristics

1) *Transect Spacing* – Document the distance (m) that was used to space transects from one another (see **Transect** data sheet section).

2) *Station Length* – The actual length (m) of the sampling reach as determined during the physical habitat assessment. The station length should be recorded directly from the **Stream Features** data sheet, as measured from the start of the station to the upstream end of the reach, rounded to the nearest meter. This measurement of station length is considered more accurate than the measurement conducted during the initial site reconnaissance.

3) *Channel Condition* – The condition of the stream channel at the station, check the category that best describes the state of the stream channel: natural channel, old channelization, recent channelization, or concrete channel.

4) *Mean Distance Between Bends* – The average distance (m) between successive bends contained within the station. Obtained from the **Station Features** data sheet.

5) *Mean Distance Between Riffles* – The average distance (m) between successive riffles contained within the station. Obtained from the **Station Features** data sheet

6) *Total Length of Riffles, Pools, and Runs* – The sum of the lengths (m) for all riffles, pools, and runs contained within the station. Obtained from the **Station Features** data sheet.

7) *Total Number of Riffles, Pools, Runs, Bends, and Log Jams* – The number of each of these stream features contained within the station. Obtained from the **Station Features** data sheet.

E.5. Comments/Notes: Record any additional information about the station in the space provided.

Table 1. Equipment List – This table identifies all equipment needed in the field in order to implement the sampling protocol as described.

Physical Habitat Sampling

Measuring tape (m) – for measuring distances

Wading rod – for measuring depths and short distances

Spherical crown densiometer (concave) – to measure canopy cover

Water Chemistry Sampling

Thermometer – for measuring air and water temperature

Conductivity meter – for measuring conductivity

Turbidimeter – for measuring turbidity

D.O. meter or Winkler-Titration kit – for measuring dissolved oxygen

pH meter – for measuring pH

Current meter – for measuring stream discharge

Transparency tube – for measuring stream water transparency

1-L plastic bottle – to collect general chemistry sample for lab analysis

250-ml plastic bottle – to collect nutrients sample for lab analysis

500-ml plastic bottle – to collect turbidity sample

5-ml of 10% sulfuric acid – for preserving nutrients sample

Cooler and ice – for holding and preserving water samples

Miscellaneous

Clipboard – to store forms and record data

Forms – for recording data

Pencil – for filling out forms

GPS – to locate and document sampling location (if necessary)

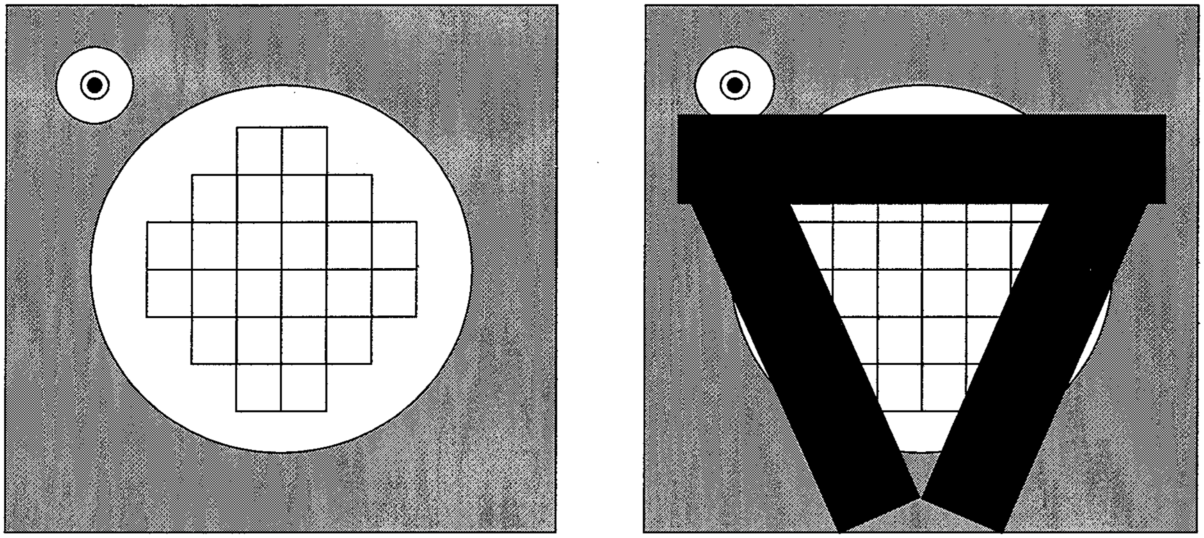


Figure 1. Illustration depicting how a spherical crown densiometer should be taped to limit the number of grid intersections to 17.

STATION FEATURES

MPCA

Field Number:________________ Date(mm/dd/yy):______________ Crew:__________________

DISTANCE FROM START (m)	STREAM FEATURE (Riffle, Pool, Run, Bend Log Jam, etc.) *	LENGTH (m)
0		

DISTANCE SUMMARY

Distance Between Bends(m):	Distance Between Riffles(m):
1st - 2nd:______________	1st - 2nd:______________
2nd - 3rd:______________	2nd - 3rd:______________
3rd - 4th:______________	3rd - 4th:______________
4th - 5th:______________	4th - 5th:______________
5th - 6th:______________	5th - 6th:______________
6th - 7th:______________	6th - 7th:______________
7th - 8th:______________	7th - 8th:______________
8th - 9th:______________	8th - 9th:______________
9th - 10th:______________	9th - 10th:______________
10th - 11th:______________	10th - 11th:______________
11th - 12th:______________	11th - 12th:______________
12th - 13th:______________	12th - 13th:______________
13th - 14th:______________	13th - 14th:______________
14th - 15th:______________	14th - 15th:______________
Sum:______________	Sum:______________
Mean:______________	Mean:______________

Length (m) Of Individual Riffles, Pools, And Runs:

1st Riffle:________	1st Pool:________	1st Run:________
2nd Riffle:________	2nd Pool:________	2nd Run:________
3rd Riffle:________	3rd Pool:________	3rd Run:________
4th Riffle:________	4th Pool:________	4th Run:________
5th Riffle:________	5th Pool:________	5th Run:________
6th Riffle:________	6th Pool:________	6th Run:________
7th Riffle:________	7th Pool:________	7th Run:________
8th Riffle:________	8th Pool:________	8th Run:________
9th Riffle:________	9th Pool:________	9th Run:________
10th Riffle:________	10th Pool:________	10th Run:________
11th Riffle:________	11th Pool:________	11th Run:________
12th Riffle:________	12th Pool:________	12th Run:________
13th Riffle:________	13th Pool:________	13th Run:________
14th Riffle:________	14th Pool:________	14th Run:________
15th Riffle:________	15th Pool:________	15th Run:________
Sum:________	Sum:________	Sum:________

* For riffles, runs, and pools note distance from start at beginning of feature. For bends, log jams, etc., note center-point.

(Revised Dec. 2002)

Station Features Continued:

DISTANCE FROM START (m)	STREAM FEATURE (Bend, Riffle, Pool, Run, Log Jam, etc.) *	LENGTH (m)
0		

TRANSECT

MPCA

Field Number:____________________ Date (mm/dd/yy):______________ Transect Number (1-13):________

Crew:____ Distance from Start (m):___________

Stream Width (m):_________________ Channel Type (circle one): Riffle Pool Run

Channel Position (fifths of wetted stream width and deepest point, 0 = rightbank *)	1/5	2/5	3/5	4/5	Deep
Water Depth (cm)					
Depth of Fines and Water (cm)					
Embeddedness of Coarse Substrates (nearest 25%)					

Check Dominant Substrate Type in Quadrate:

Channel Position (fifths of wetted stream width and deepest point, 0 = rightbank *)	1/5	2/5	3/5	4/5	Deep
Bedrock (solid slab)					
Boulder (basketball or bigger)					
Rubble/Cobble (tennis ball to basketball)					
Gravel (BB to tennis ball)					
Sand (gritty, visible, < BB)					
Silt					
Clay					
Detritus					
Other (specify)					

Note Amount Observed on Quadrate:

Channel Position (fifths of wetted stream width and deepest point, 0 = rightbank *)	1/5	2/5	3/5	4/5	Deep
Algae (attached & filamentous., nearest 5%)					
Macrophytes (nearest 5%)					

Cover for Fish: *Percent length of transect* ***(over at least 15 cm water depth)*** *with:*
___Undercut Banks _____Overhanging Vegetation _____Woody Debris _____Boulders
___Submergent Macrophytes _____Emergent Macrophytes _____Other (specify):______________________

Bank Erosion: *Length (nearest 0.1 m) of bare soil,* ***within 5 m of waters edge****, along transect:*
LEFT BANK *: __________(m) RIGHT BANK *: __________ (m)

Riparian Land Use: *Dominant land use* ***within 30 m of stream edge*** *(along transect):* ***(L / R)*** *
___/___Cropland ___/___Pasture ___/___Barnyard ___/___Developed ___/___Exposed Rock
___/___Meadow ___/___Shrubs ___/___Woodland ___/___Wetland ___/___Other (specify):___________

Riparian Land Use: *Dominant land use* ***from 30 to 100 m of stream edge*** *(along transect):* ***(L / R)*** *
___/___Cropland ___/___Pasture ___/___Barnyard ___/___Developed ___/___Exposed Rock
___/___Meadow ___/___Shrubs ___/___Woodland ___/___Wetland ___/___Other (specify):__________

Riparian Buffer Width: *Length (nearest meter) of undisturbed land use along transect,* ***within 10 m of stream:***
LEFT BANK *: __________(m) RIGHT BANK *: __________ (m)

Canopy/Shading (Densiometer reading, note #/17 that are shaded):

___Center Upstream ___Center Left ___Center Downstream ___Center Right ___Left Bank * ___Right Bank *

* Right Bank and Left Bank identified while facing downstream.

(Revised Dec 2002)

MPCA STREAM HABITAT ASSESSMENT (MSHA)
PROTOCOL FOR STREAM MONITORING SITES

I. PURPOSE

To describe the methods used by the Minnesota Pollution Control Agency's (MPCA) Biological Monitoring Program to collect qualitative physical habitat information at stream monitoring sites for the purpose of assessing water quality and developing biological criteria.

II. SCOPE/LIMITATIONS

This procedure applies to all river and stream monitoring sites for which an integrated assessment of water quality is to be conducted. An integrated assessment involves the collection of biological (fish and macroinvertebrate communities), physical habitat, and chemical information to assess stream condition.

III. GENERAL INFORMATION

Sites may be selected for assessment for a number of reasons including: 1) sites randomly selected for condition monitoring as part of the Environmental Monitoring and Assessment Program (EMAP), 2) sites selected for the development and calibration of biological criteria, and 3) sites selected to evaluate a suspected source of pollution. Although the reasons for monitoring a site vary, the MSHA protocol described in this document applies to all monitoring sites unless otherwise noted.

IV. REQUIREMENTS

A. Qualifications of crew leaders: The crew leader must be a professional aquatic biologist with a minimum of a Bachelor of Science degree in aquatic biology or closely related specialization. He or she must have a minimum of six months field experience in physical habitat sampling methodology. Field crew leaders should also possess excellent map reading skills and a demonstrated proficiency in the use of a GPS (Global Positioning System) receiver and orienteering compass.

B. Qualifications of field technicians/interns: A field technician/intern must have at least one year of college education and coursework in environmental and/or biological science.

C. General qualifications: All personnel conducting this procedure must have the ability to perform rigorous physical activity. It is often necessary to wade through streams and/or wetlands, canoe, or hike for long distances to reach a sampling site.

V. RESPONSIBILITIES

A. Field crew leader: Implement the procedures outlined in the action steps and ensure that the data generated meets the standards and objectives of the Biological Monitoring Program.

B. Technicians/interns: Implement the procedures outlined in the action steps, including maintenance and stocking of equipment, data collection and recording.

VI. QUALITY ASSURANCE AND QUALITY CONTROL

Compliance with this procedure will be maintained through annual internal reviews. Technical personnel will conduct periodic self-checks by comparing their results with other trained personnel.

In addition to adhering to the specific requirements of this sampling protocol and any supplementary site specific procedures, the minimum QA/QC requirements for this activity are as follows:

A. Control of deviations: Deviation shall be sufficiently documented to allow repetition of the activity as performed.

B. QC samples: Ten percent of sites sampled in any given year are resampled as a means of determining sampling error and temporal variability.

C. Verification: The field crew leader will conduct periodic reviews of field personnel to ensure that technical personnel are following procedures in accordance with this SOP.

VII. TRAINING

A. All inexperienced personnel will receive instruction from a trainer designated by the program manager. Major revisions in this protocol require that all personnel be re-trained in the revised protocol by experienced personnel.

B. The field crew leader will provide instruction in the field and administer a field test to ensure personnel can execute this procedure.

VIII. ACTION STEPS

A. Equipment list: Verify that either a form and pencil, or a field computer is present before commencement of this procedure.

B. Data collection method: The location and length of the sampling reach is determined during site reconnaissance (see SOP--"***Reconnaissance Procedures for Initial Visit to Stream Monitoring Sites***"). Unless otherwise instructed, observations of physical habitat characteristics should be limited to the sampling reach. Sampling is conducted during daylight hours within the summer index period of mid-June through mid-September. Sampling should occur when streams are at or near base-flow. The habitat evaluation is conducted immediately after fish sampling in order to provide the evaluator a perspective of the fish habitat within the reach.

Habitat characteristics are recorded using a qualitative, observation based method (modified from: Rankin 1989. The Qualitative Habitat Evaluation Index (QHEI): Rationale, Methods, and Application. Ohio EPA, Division of Water Quality Planning and Assessment, Ecological Analysis Section, Columbus, Ohio.). The Ohio QHEI is a physical habitat index designed to provide an empirical evaluation of the lotic macrohabitat characteristics that are important to fish communities and which are generally important to other aquatic life. Although similar to the Ohio QHEI, the MSHA has been modified to more adequately assess important characteristics influencing Minnesota streams. The MSHA incorporates measures of watershed land use, riparian quality, bank erosion, substrate type and quality, instream cover, and several characteristics of channel morphology.

Observations are recorded on the **MPCA Stream Habitat Assessment Worksheet**. A copy is attached and guidelines for filling out this data sheet are described in the following pages.

C. MPCA Stream Habitat Assessment Data Sheet

This data sheet describes the presence and abundance of instream and riparian characteristics within the sampling reach. The variables recorded are as follows:

C.1. Stream Documentation

A) *Stream* – The name of the stream as shown on the most recent USGS 7.5" topographic map. Include all parts of the name (i.e. South Branch Wild Rice River).

B) *County* – The county in which the station is located.

C) *Date* – The date habitat sampling is conducted in month/day/year format (MM/DD/YY).

D) *Field Number* – A seven-digit code that uniquely identifies the station. The first two digits identify the year of sampling, the second two identify the major river basin, and the last three are numerically assigned in sequential order (example: 02UM001).

E) *Person Scoring* – The personnel completing the MSHA. This person(s) should have walked or boated the entire stream reach paying particular attention to habitat features.

F) *Site Location* – A general description of where the sampling station is located. Usually includes the nearest road crossing and town. For example, "0.5 mi. downstream of C.R. 30, 4 mi. SW of Northome".

C.2. Surrounding Land Use: Record the predominant land use on each bank within approximately 2 to 3 square miles, not just the surrounding area of the site. The emphasis should be on upstream land use. Check either the most predominant land use, or choose two and average the scores. A land use or aerial map can be used for this assessment if available. Land use categories are as follows:

Forest, Wetland, Prairie, Shrub: Land that is dominated by trees, low-lying areas saturated with water, grasses and forbs, or woody vegetation less than 3 m. in height.

Old Field/Hay Field: Land that is used for agricultural purposes other than row crops or pasture.

Fenced Pasture: Land that is regularly grazed by livestock, but is fenced to prevent livestock from entering streams.

Conservation Tillage, No Till: Land that is currently in agricultural production, but retains the vegetative material from the previous year's crop to protect the soil.

Residential/Park: Land that has been modified for residential use (i.e. backyards, city parks).

Urban/Industrial: Land that has been modified for commercial or industrial use (i.e. parking lots, malls).

Open Pasture: Land that is regularly grazed by livestock, but is not fenced to prevent livestock from entering streams.

Row Crop: Land that is currently in intensive agricultural production, and doesn't use any conservation tactics (i.e. corn, soybeans, beets, potatoes).

C.3. Riparian Zone (Check the most appropriate category for each bank)

A) *Riparian Width* – Estimate the width of the undisturbed vegetative zone adjacent to the stream. Beneficial vegetation types include stable grasses, trees, and shrubs with low runoff potential. Disturbed vegetation is not included in the riparian width (i.e. mowed grass).

B) *Bank Erosion* – Estimate the percentage of the stream bank that is actively eroding. To be considered as erosion, the banks must be actively eroding through break down, soil sloughing, or false banks. False banks are natural banks that have been cut back, usually by livestock trampling.

C) *Shade* – Estimate the percentage of overhead canopy cover that is shading the stream channel. Professional judgment may be required to rate stream shading characteristics in larger streams and rivers as 100% shade cover would not be expected in these systems even in the absence of disturbance. The general intent of the rating is to evaluate the condition of stream canopy characteristics.

C.4. Instream Zone

A) *Substrate* – Document the two predominant substrate types for each channel type present within the reach. One substrate type may be recorded where > 80% of the channel is dominated by a single substrate type. For each channel type present within the reach, estimate the percent of the stream channel represented by that channel type. The percentages should add up to 100. For example, if the majority of your reach was a run, with a few pools and one riffle, the percentage could be 75% run, 20% pool, and 5% riffle. The definitions for each channel and substrate type are as follows:

Channel Types

Pool: Water is slow and generally deeper than a riffle or run. Water surface is smooth, no turbulence. A general rule that can be used to distinguish a pool from a run or riffle is if two or more of the following conditions apply; the stream channel is wider, deeper, or slower than average.

Riffle: Higher gradient areas where the water is fast and turbulent, water depths are relatively shallow, and substrates are typically coarse. Water surface is visibly broken.

Run: The water may be moderately fast to slow but the water surface typically appears smooth with little or no surface turbulence. Generally, runs are deeper than a riffle and shallower than a pool.

Glide: Similar to a run, but where there is no visible flow and the channel is too shallow for a pool. Examples include a channelized stream with a uniform depth and flow. This term should not be used in conjunction with pools, riffles, and runs in a natural stream setting.

Substrate Types

Boulder: Large rocks ranging from 250 mm to 4000 mm in diameter (basketball to car size).

Cobble: Rocks ranging in diameter from 64 mm to 250 mm (tennisball to basketball).

Gravel: Rocks varying in diameter from 2 mm to 64 mm (BB to tennisball).

Sand: Inorganic material that is visible as particles and feels gritty between the fingers, 0.06 to 2.0 mm in size.

Clay: Very fine inorganic material. Individual particles are not visible or are barely visible to the naked eye. Will support a person’s weight and retains its shape when compacted.

Bedrock: A solid slab of rock, > 4000 mm in length (larger than a car).

Silt: Fine inorganic material that is typically dark brown in color. Feels greasy between fingers and does not retain its shape when compacted into a ball. A person’s weight will not be supported if the stream bottom consists of silt.

Muck: A fine layer of black completely decomposed vegetative organic matter.

Detritus: Decaying organic material such as macrophytes, leaves, finer woody debris, etc. that may appear similar to silt when very fine.

Sludge: A thick layer of organic matter of animal or human origin, often originating from wastewater.

B) *Embeddedness* – Indicate the percentage to which coarse substrates are surrounded by or covered with fine sediments throughout the reach. Coarse substrates consist of gravel, cobble, and boulders. An embeddedness rating of 0% corresponds to very little or no fine sediments surrounding coarse substrates. Course substrate material completely surrounded and covered with sediment is considered 100% embedded. If course substrates are not present in the reach, check “no course substrate”.

C) *Substrate Types* – Record the number of substrate types present within the reach, either less than or equal to 4, or greater then 4.

D) *Water Color* – Record the predominant color of the water by checking the appropriate category. Definitions are as follows:

Clear: Water is transparent, and objects are clearly visible underwater.

Stained: Water is colored due to minerals in the water, but objects are still visible.

Turbid: Water is colored and not transparent; brown due to silt, green due to algae, or other.

E) *Cover Type* – Indicate the types of cover available to fish within the reach (check all that apply). Cover for fish consists of objects or features dense enough to provide complete or partial shelter from the stream current or concealment from predators or prey. In order to be considered cover, the water depth must be at least 10 cm where the cover type occurs. Definitions are as follows:

Undercut Banks: Stream banks where the stream channel has cut underneath the bank. The bank could overhang the water surface when water levels are low. The undercut bank must overhang (horizontally) the wetted stream channel a minimum of 15 cm and the bottom of the undercut bank must be no more than 15 cm above the water level in order to be considered cover for fish.

Overhanging Vegetation: Terrestrial vegetation overhanging the wetted stream channel. Vegetation must be no more than 15 cm above the water level to be considered cover for fish.

Deep Pools: Area where the channel is particularly deep, often near a bend.

Logs or Woody Debris: Logs, branches, or aggregations of smaller pieces of wood in contact with or submerged in water.

Boulders: Large rocks as described under *Substrate Types.*

Rootwads: Aggregation of tree roots that extend into the stream.

Emergent Macrophytes: Vascular plants that typically have a significant portion of their biomass above the water surface. Examples include *Typha*, *Scirpus*, and *Zizania*.

Floating Leaf Macrophytes: Vascular plants with a significant amount of their biomass floating on the water in the form of leaves and flowers. Examples include duckweed and water lily.

Submergent Macrophytes: Vascular plants that have all of their biomass (except flowers) at or below the surface of the water. Examples include *Vallisneria*, *Elodea*, *Potamogeton*, *Nymphaea* and *Ceratophyllum*.

F) *Cover Amount* – Estimate the total percentage of fish cover within the reach. If the channel is completely filled with aquatic vegetation, check the “choking vegetation only” option.

C.5. <u>Channel Morphology (Check the most appropriate category for each)</u>

A) *Depth Variability* – The difference in thalweg depth between the shallowest stream cross section and the deepest stream cross section. The thalweg depth is the deepest point along a stream cross section. Indicate the degree to which the thalweg depths vary within the stream reach.

B) *Channel Stability* – The ability of a stream channel to maintain its bed and banks, without eroding or moving particles downstream. A riffle that forms diagonally across the channel and has a high amount of fine substrates that change location is indicative of an unstable stream bed. Channelized streams often have high bank stability but low bed stability as the substrate is typically comprised of fine materials that are susceptible to moving downstream. Ratings are as follows:

High: Channel with stable banks and substrates, little or no erosion of the banks, and little or no bedload within the stream. Artificial channels (i.e. concrete) exhibit a high degree of stability even though they typically have a negative effect on biological communities.

Moderate/High: Channel has the ability to maintain stable riffle, run, and pool characteristics. A minor amount of bank erosion and/or bedload is present.

Moderate: Channel that exhibits some instability, characterized by erosion, bedload, or shows the effects of wide fluctuations in water level.

Low: Channels that have a high degree of bedload and severely eroding banks. A homogenous stream bed characterized by shifting sand substrates has low stability.

C) *Velocity Types* – Indicate which flow types are present within the reach (check all that apply). The definitions are as follows:

Torrential: Extremely turbulent and fast flow; water surface is broken, usually limited to gorges and dam spillways.

Fast: Mostly non-turbulent flow with small standing waves in riffle-run areas, water surface may be partially broken.

Moderate: Non-turbulent flow that is detectable (i.e. floating objects are visibly moved downstream).

Slow: Water flow is detectable, but barely perceptible.

Eddies: Areas of circular motion within the current, usually formed in pools immediately downstream of riffles/runs.

Interstitial: Water flow that infiltrates a streambed, and moves through gravel substrates in riffle-run areas.

Intermittent: No flow is present, with standing pools separated by dry reaches.

D) *Sinuosity* – Indicate the degree to which the stream meanders. Sinuosity is defined as the ratio of stream channel distance to straight line distance between two points on a stream. For wide streams or rivers it may be necessary to consider a longer stream reach, as the true meander cycle is often not adequately represented in these systems within the sampling reach. Ratings are as follows:

Excellent: Streams exhibiting a high degree of meandering. Presence of 2 or more well defined bends (deep areas outside and shallow areas on the inside of the bend).

Good: Stream with more than 2 bends, with at least one well defined bend.

Fair: Channel with 1 or 2 poorly defined outside bends, or slight meandering within a modified reach.

Poor: Straight channel with no bends in the reach. Channelized streams or ditches are often rated as poor.

E) *Pool Width/Riffle Width* – Indicate the ratio of pool width to riffle width within the reach. If there is no riffle at the site select “no riffle”.

F) *Channel Development* – Indicate the complexity of the stream channel or the degree to which the stream has developed different channel types, creating sequences of riffles, runs, and pools. In small streams, riffles, runs, and pools must occur more than once within the sampling reach. The ratings of channel development are as follows:

Excellent: Well defined riffles present with gravel, cobble, or boulder substrates; pools vary in depth, and there is a clear transition between pools, riffles, and runs. Multiple sequences of riffles, runs, and pools are present within the reach.

Good: Riffles, runs, and pools are all present, but with less frequency, and are less distinct. Riffles have large substrates (gravel, rubble, or boulder), and pools have variation in depth.

Fair: Riffles are absent or poorly developed (shallow with sand and fine gravel substrates). Some deeper pools may exist, but transitions are generally not abrupt.

Poor: Riffles are absent; pools if present are shallow or lack variation in depth. Channelized streams generally have poor channel development.

G) Present Water Level – An estimation of water level as it relates to summer base flow expectations. In most streams, the "normal" water level can be determined with relative ease by observing channel characteristics.

D. Scoring the MSHA

Following are instructions on how to score the completed MSHA form. The maximum score is 100.

D.1. Surrounding Land Use: Average the scores of the two banks. For example, if residential/park was the land use selected on the left bank, and forest, wetland, prairie, shrub was selected on the right bank, then the land use score would be (2+5)/2=3.5. In the case of two land uses selected for one bank, the two scores are averaged together, and then averaged with the score of the other bank. The maximum land use score is 5.

D.2. Riparian Zone: Average the scores of the two banks for Riparian Width, Bank Erosion, and Shade; then add the three scores. For example, if moderate riparian width (3) was chosen for the left bank and very narrow (1) on the right bank; little bank erosion (4) on the left bank, and moderate (3) on the right bank; heavy shade (5) on the left bank, and substantial (4) on the right bank; the riparian zone score would be: [(3+1)/2] + [(4+3)/2] + [(5+4)/2] = 10. The maximum riparian score is 15.

D.3. Instream Zone

A) Substrate, Embeddedness, and Substrate Types – Add the scores of substrate, embeddedness, and substrate type. The substrate score is calculated by adding the two substrate scores for each channel type, multiplying by the percentage of the channel type, and adding the scores for each channel type present. If only one substrate type is chosen because it makes up more than 80% of the channel type, multiply the one substrate score by 2 before multiplying it by the percentage of the channel type. The maximum substrate score is 27.

B) Cover Type and Cover Amount – Add the scores of cover type and cover amount. The cover score can range from 1 to 8. The highest macrophyte score is 1, even if all three macrophyte types are present. The maximum cover score is 17.

D.4. Channel Morphology: Add the scores of Depth Variability, Channel Stability, Velocity Types, Sinuosity, Pool Width/Riffle Width, and Channel Development. The maximum channel morphology score is 36.

D.5. Total Score: Add the Surrounding Land Use, Riparian Zone, Instream Zone, and Channel Morphology scores together to get the total MSHA score for the site.

MPCA STREAM HABITAT ASSESSMENT

(revised 3-07)

1. Stream Documentation

Stream ____________________

County ____________________ Date ____________________

Field Number ____________________ Person Scoring ____________________

Site Location ____________________

MSHA SCORE

Max = 100 ☐

2. Surrounding Land Use (check the most predominant or check two and average scores) [L=left bank/R =right bank, facing downstream]

L	R			L	R		
☐	☐	Forest, Wetland, Prairie, Shrub	[5]	☐	☐	Residential/Park	[2]
☐	☐	Old Field/Hay Field	[3]	☐	☐	Urban/Industrial	[0]
☐	☐	Fenced Pasture	[2]	☐	☐	Open Pasture	[0]
☐	☐	Conservation Tillage, No Till	[2]	☐	☐	Row Crop	[0]

Land Use

Max=5 ☐

3. Riparian Zone (check the most predominant)

A. Riparian Width

L	R			
☐	☐	Extensive	> 300’	[5]
☐	☐	Wide	150’-300’	[4]
☐	☐	Moderate	30’-150’	[3]
☐	☐	Narrow	15’-30’	[2]
☐	☐	Very Narrow	3’-15’	[1]
☐	☐	None		[0]

B. Bank Erosion

L	R			
☐	☐	None		[5]
☐	☐	Little	5-25%	[4]
☐	☐	Moderate	25-50%	[3]
☐	☐	Heavy	50-75%	[1]
☐	☐	Severe	75-100%	[0]

C. Shade

L	R			
☐	☐	Heavy	>75%	[5]
☐	☐	Substantial	50-75%	[4]
☐	☐	Moderate	25-50%	[2]
☐	☐	Light	5-25%	[1]
☐	☐	None		[0]

Riparian

Max=15 ☐

4. Instream Zone

A. Substrate (check two for each channel type)

	[10] Boulder	[9] Cobble	[8] Gravel	[7] Sand	[5] Clay	[5] Bedrock	[2] Silt	[1] Muck	[1] Detritus	[0] Sludge	Channel Type %
Pool	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	________
Riffle	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	________
Run	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	________
Glide	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	________

B. Embeddedness

☐	None		[5]
☐	Light	25-50%	[3]
☐	Moderate	50-75%	[1]
☐	Severe	75-100%	[-1]
☐	No coarse substrate		[0]

C. Substrate Types

☐	>4	[2]
☐	<=4	[0]

D. Water Color

- ☐ Clear
- ☐ Stained

Turbid
- ☐ Brown
- ☐ Green
- ☐ Other

Substrate

Max=27 ☐

E. Cover Type (check all that apply)

☐	Undercut Banks	[1]
☐	Overhanging Vegetation	[1]
☐	Deep Pools	[1]
☐	Logs or Woody Debris	[1]
☐	Boulders	[1]
☐	Rootwads	[1]
☐	Macrophytes:	[1]

- ☐ Emergent
- ☐ Floating Leaf
- ☐ Submergent

F. Cover Amount (check one)

☐	Extensive	>50%	[10]
☐	Moderate	25-50%	[7]
☐	Sparse	5-25%	[3]
☐	Nearly Absent		[0]
☐	Choking Vegetation only		[-1]

Cover

Max=17 ☐

5. Channel Morphology

A. Depth Variability

☐	Greatest Depth >4X Shallow Depth	[6]
☐	Greatest Depth 2-4X Shallow Depth	[3]
☐	Greatest Depth <2X Shallow Depth	[0]

B. Channel Stability

☐	High	[9]
☐	Moderate/High	[6]
☐	Moderate	[3]
☐	Low	[0]

C. Velocity Types (check all that apply)

☐	Torrential	[-1]
☐	Fast	[1]
☐	Moderate	[1]
☐	Slow	[1]
☐	Eddies	[1]
☐	Intermittent	[-2]
☐	Interstitial	[-1]

D. Sinuosity

☐	Excellent	[6]
☐	Good	[4]
☐	Fair	[2]
☐	Poor	[0]

E. Pool Width/Riffle Width

☐	Pool Width > Riffle Width	[2]
☐	Pool Width = Riffle Width	[1]
☐	Pool Width < Riffle Width	[0]
☐	No Riffle	[0]

F. Channel Development

☐	Excellent	[9]
☐	Good	[6]
☐	Fair	[3]
☐	Poor	[0]

G. Present Water Level

- ☐ Flood
- ☐ High
- ☐ Normal
- ☐ Low
- ☐ Interstitial

Channel Morphology

Max=36 ☐

VISIT SUMMARY **MPCA**

LOCATION INFORMATION ==

Field Number:____________ Date (mm/dd/yy):____________ Stream Name:________________________

Location:____ County:____________________

Visit Result (circle one): Reportable - Replicate - Other (explain)___________________________

GPS File Name:________________________ Type of GPS Fix: ☐ 2D ☐ 3D PDOP:___________
(only if GPS taken during visit)

Data Source:________________________________ Project:______________________________________

FIELD WATER CHEMISTRY ===

Time (24 hr clock):_______________ Air Temp.(°C):______________ Water Temp.(°C):______________

Conductivity (umhos@25°C):____________________ Dissolved Oxygen (mg/l):____________________

Turbidity (ntu):__________________ pH:________________ Stream Flow (m^3/s):_________________

Transparency Tube (cm):______ Water Level: ☐ Normal ☐ Below______(m) ☐ Above______(m)

LAB WATER CHEMISTRY ==

Collection Time (field sample):________________ Collection Time (field duplicate):________________

CHANNEL CHARACTERISTICS ===

Transect Spacing (m):____________ Station Length (m) (from stream features form):_______________

Channel Condition (check appropriate box):

☐ Natural Channel ☐ Old Channelization ☐ Recent Channelization ☐ Concrete Channel

Mean Distance Between Bends (m):_____________ Mean Distance Between Riffles (m):_____________

Total Length (Sum) of All (m): Riffles:______________ Pools:______________ Runs:______________

Total Number of: Riffles:_______ Pools:_______ Runs:_______ Bends:_______ Log Jams:______

COMMENTS/NOTES: ____

____

____

(Revised Dec. 2002)

Appendix 4-B

Stream Habitat and Evaluation Form

MPCA STREAM HABITAT ASSESSMENT (MSHA) PROTOCOL FOR STREAM MONITORING SITES

I. PURPOSE

To describe the methods used by the Minnesota Pollution Control Agency's (MPCA) Biological Monitoring Program to collect qualitative physical habitat information at stream monitoring sites for the purpose of assessing water quality and developing biological criteria.

II. SCOPE/LIMITATIONS

This procedure applies to all river and stream monitoring sites for which an integrated assessment of water quality is to be conducted. An integrated assessment involves the collection of biological (fish and macroinvertebrate communities), physical habitat, and chemical information to assess stream condition.

III. GENERAL INFORMATION

Sites may be selected for assessment for a number of reasons including: 1) sites randomly selected for condition monitoring as part of the Environmental Monitoring and Assessment Program (EMAP), 2) sites selected for the development and calibration of biological criteria, and 3) sites selected to evaluate a suspected source of pollution. Although the reasons for monitoring a site vary, the MSHA protocol described in this document applies to all monitoring sites unless otherwise noted.

IV. REQUIREMENTS

A. Qualifications of crew leaders: The crew leader must be a professional aquatic biologist with a minimum of a Bachelor of Science degree in aquatic biology or closely related specialization. He or she must have a minimum of six months field experience in physical habitat sampling methodology. Field crew leaders should also possess excellent map reading skills and a demonstrated proficiency in the use of a GPS (Global Positioning System) receiver and orienteering compass.

B. Qualifications of field technicians/interns: A field technician/intern must have at least one year of college education and coursework in environmental and/or biological science.

C. General qualifications: All personnel conducting this procedure must have the ability to perform rigorous physical activity. It is often necessary to wade through streams and/or wetlands, canoe, or hike for long distances to reach a sampling site.

V. RESPONSIBILITIES

A. Field crew leader: Implement the procedures outlined in the action steps and ensure that the data generated meets the standards and objectives of the Biological Monitoring Program.

B. Technicians/interns: Implement the procedures outlined in the action steps, including maintenance and stocking of equipment, data collection and recording.

VI. QUALITY ASSURANCE AND QUALITY CONTROL

Compliance with this procedure will be maintained through annual internal reviews. Technical personnel will conduct periodic self-checks by comparing their results with other trained personnel.

In addition to adhering to the specific requirements of this sampling protocol and any supplementary site specific procedures, the minimum QA/QC requirements for this activity are as follows:

A. Control of deviations: Deviation shall be sufficiently documented to allow repetition of the activity as performed.

B. QC samples: Ten percent of sites sampled in any given year are resampled as a means of determining sampling error and temporal variability.

C. Verification: The field crew leader will conduct periodic reviews of field personnel to ensure that technical personnel are following procedures in accordance with this SOP.

VII. TRAINING

A. All inexperienced personnel will receive instruction from a trainer designated by the program manager. Major revisions in this protocol require that all personnel be re-trained in the revised protocol by experienced personnel.

B. The field crew leader will provide instruction in the field and administer a field test to ensure personnel can execute this procedure.

VIII. ACTION STEPS

A. Equipment list: Verify that either a form and pencil, or a field computer is present before commencement of this procedure.

B. Data collection method: The location and length of the sampling reach is determined during site reconnaissance (see SOP--"***Reconnaissance Procedures for Initial Visit to Stream Monitoring Sites***"). Unless otherwise instructed, observations of physical habitat characteristics should be limited to the sampling reach. Sampling is conducted during daylight hours within the summer index period of mid-June through mid-September. Sampling should occur when streams are at or near base-flow. The habitat evaluation is conducted immediately after fish sampling in order to provide the evaluator a perspective of the fish habitat within the reach.

Habitat characteristics are recorded using a qualitative, observation based method (modified from: Rankin 1989. The Qualitative Habitat Evaluation Index (QHEI): Rationale, Methods, and Application. Ohio EPA, Division of Water Quality Planning and Assessment, Ecological Analysis Section, Columbus, Ohio.). The Ohio QHEI is a physical habitat index designed to provide an empirical evaluation of the lotic macrohabitat characteristics that are important to fish communities and which are generally important to other aquatic life. Although similar to the Ohio QHEI, the MSHA has been modified to more adequately assess important characteristics influencing Minnesota streams. The MSHA incorporates measures of watershed land use, riparian quality, bank erosion, substrate type and quality, instream cover, and several characteristics of channel morphology.

Observations are recorded on the **MPCA Stream Habitat Assessment Worksheet**. A copy is attached and guidelines for filling out this data sheet are described in the following pages.

C. MPCA Stream Habitat Assessment Data Sheet

This data sheet describes the presence and abundance of instream and riparian characteristics within the sampling reach. The variables recorded are as follows:

C.1. Stream Documentation

A) *Stream* – The name of the stream as shown on the most recent USGS 7.5" topographic map. Include all parts of the name (i.e. South Branch Wild Rice River).

B) *County* – The county in which the station is located.

C) *Date* – The date habitat sampling is conducted in month/day/year format (MM/DD/YY).

D) *Field Number* – A seven-digit code that uniquely identifies the station. The first two digits identify the year of sampling, the second two identify the major river basin, and the last three are numerically assigned in sequential order (example: 02UM001).

E) *Person Scoring* – The personnel completing the MSHA. This person(s) should have walked or boated the entire stream reach paying particular attention to habitat features.

F) *Site Location* – A general description of where the sampling station is located. Usually includes the nearest road crossing and town. For example, "0.5 mi. downstream of C.R. 30, 4 mi. SW of Northome".

C.2. Surrounding Land Use: Record the predominant land use on each bank within approximately 2 to 3 square miles, not just the surrounding area of the site. The emphasis should be on upstream land use. Check either the most predominant land use, or choose two and average the scores. A land use or aerial map can be used for this assessment if available. Land use categories are as follows:

Forest, Wetland, Prairie, Shrub: Land that is dominated by trees, low-lying areas saturated with water, grasses and forbs, or woody vegetation less than 3 m. in height.

Old Field/Hay Field: Land that is used for agricultural purposes other than row crops or pasture.

Fenced Pasture: Land that is regularly grazed by livestock, but is fenced to prevent livestock from entering streams.

Conservation Tillage, No Till: Land that is currently in agricultural production, but retains the vegetative material from the previous year's crop to protect the soil.

Residential/Park: Land that has been modified for residential use (i.e. backyards, city parks).

Urban/Industrial: Land that has been modified for commercial or industrial use (i.e. parking lots, malls).

Open Pasture: Land that is regularly grazed by livestock, but is not fenced to prevent livestock from entering streams.

Row Crop: Land that is currently in intensive agricultural production, and doesn't use any conservation tactics (i.e. corn, soybeans, beets, potatoes).

C.3. Riparian Zone (Check the most appropriate category for each bank)

A) *Riparian Width* – Estimate the width of the undisturbed vegetative zone adjacent to the stream. Beneficial vegetation types include stable grasses, trees, and shrubs with low runoff potential. Disturbed vegetation is not included in the riparian width (i.e. mowed grass).

B) *Bank Erosion* – Estimate the percentage of the stream bank that is actively eroding. To be considered as erosion, the banks must be actively eroding through break down, soil sloughing, or false banks. False banks are natural banks that have been cut back, usually by livestock trampling.

C) *Shade* – Estimate the percentage of overhead canopy cover that is shading the stream channel. Professional judgment may be required to rate stream shading characteristics in larger streams and rivers as 100% shade cover would not be expected in these systems even in the absence of disturbance. The general intent of the rating is to evaluate the condition of stream canopy characteristics.

C.4. Instream Zone

A) *Substrate* – Document the two predominant substrate types for each channel type present within the reach. One substrate type may be recorded where > 80% of the channel is dominated by a single substrate type. For each channel type present within the reach, estimate the percent of the stream channel represented by that channel type. The percentages should add up to 100. For example, if the majority of your reach was a run, with a few pools and one riffle, the percentage could be 75% run, 20% pool, and 5% riffle. The definitions for each channel and substrate type are as follows:

Channel Types

Pool: Water is slow and generally deeper than a riffle or run. Water surface is smooth, no turbulence. A general rule that can be used to distinguish a pool from a run or riffle is if two or more of the following conditions apply; the stream channel is wider, deeper, or slower than average.

Riffle: Higher gradient areas where the water is fast and turbulent, water depths are relatively shallow, and substrates are typically coarse. Water surface is visibly broken.

Run: The water may be moderately fast to slow but the water surface typically appears smooth with little or no surface turbulence. Generally, runs are deeper than a riffle and shallower than a pool.

Glide: Similar to a run, but where there is no visible flow and the channel is too shallow for a pool. Examples include a channelized stream with a uniform depth and flow. This term should not be used in conjunction with pools, riffles, and runs in a natural stream setting.

Substrate Types

Boulder: Large rocks ranging from 250 mm to 4000 mm in diameter (basketball to car size).

Cobble: Rocks ranging in diameter from 64 mm to 250 mm (tennisball to basketball).

Gravel: Rocks varying in diameter from 2 mm to 64 mm (BB to tennisball).

Sand: Inorganic material that is visible as particles and feels gritty between the fingers, 0.06 to 2.0 mm in size.

Clay: Very fine inorganic material. Individual particles are not visible or are barely visible to the naked eye. Will support a person’s weight and retains its shape when compacted.

Bedrock: A solid slab of rock, > 4000 mm in length (larger than a car).

Silt: Fine inorganic material that is typically dark brown in color. Feels greasy between fingers and does not retain its shape when compacted into a ball. A person’s weight will not be supported if the stream bottom consists of silt.

Muck: A fine layer of black completely decomposed vegetative organic matter.

Detritus: Decaying organic material such as macrophytes, leaves, finer woody debris, etc. that may appear similar to silt when very fine.

Sludge: A thick layer of organic matter of animal or human origin, often originating from wastewater.

B) *Embeddedness* – Indicate the percentage to which coarse substrates are surrounded by or covered with fine sediments throughout the reach. Coarse substrates consist of gravel, cobble, and boulders. An embeddedness rating of 0% corresponds to very little or no fine sediments surrounding coarse substrates. Course substrate material completely surrounded and covered with sediment is considered 100% embedded. If course substrates are not present in the reach, check “no course substrate”.

C) *Substrate Types* – Record the number of substrate types present within the reach, either less than or equal to 4, or greater then 4.

D) *Water Color* – Record the predominant color of the water by checking the appropriate category. Definitions are as follows:

Clear: Water is transparent, and objects are clearly visible underwater.

Stained: Water is colored due to minerals in the water, but objects are still visible.

Turbid: Water is colored and not transparent; brown due to silt, green due to algae, or other.

E) *Cover Type* – Indicate the types of cover available to fish within the reach (check all that apply). Cover for fish consists of objects or features dense enough to provide complete or partial shelter from the stream current or concealment from predators or prey. In order to be considered cover, the water depth must be at least 10 cm where the cover type occurs. Definitions are as follows:

Undercut Banks: Stream banks where the stream channel has cut underneath the bank. The bank could overhang the water surface when water levels are low. The undercut bank must overhang (horizontally) the wetted stream channel a minimum of 15 cm and the bottom of the undercut bank must be no more than 15 cm above the water level in order to be considered cover for fish.

Overhanging Vegetation: Terrestrial vegetation overhanging the wetted stream channel. Vegetation must be no more than 15 cm above the water level to be considered cover for fish.

Deep Pools: Area where the channel is particularly deep, often near a bend.

Logs or Woody Debris: Logs, branches, or aggregations of smaller pieces of wood in contact with or submerged in water.

Boulders: Large rocks as described under *Substrate Types.*

Rootwads: Aggregation of tree roots that extend into the stream.

Emergent Macrophytes: Vascular plants that typically have a significant portion of their biomass above the water surface. Examples include *Typha*, *Scirpus*, and *Zizania*.

Floating Leaf Macrophytes: Vascular plants with a significant amount of their biomass floating on the water in the form of leaves and flowers. Examples include duckweed and water lily.

Submergent Macrophytes: Vascular plants that have all of their biomass (except flowers) at or below the surface of the water. Examples include *Vallisneria*, *Elodea*, *Potamogeton*, *Nymphaea* and *Ceratophyllum*.

F) *Cover Amount* – Estimate the total percentage of fish cover within the reach. If the channel is completely filled with aquatic vegetation, check the “choking vegetation only” option.

C.5. <u>Channel Morphology (Check the most appropriate category for each)</u>

A) *Depth Variability* – The difference in thalweg depth between the shallowest stream cross section and the deepest stream cross section. The thalweg depth is the deepest point along a stream cross section. Indicate the degree to which the thalweg depths vary within the stream reach.

B) *Channel Stability* – The ability of a stream channel to maintain its bed and banks, without eroding or moving particles downstream. A riffle that forms diagonally across the channel and has a high amount of fine substrates that change location is indicative of an unstable stream bed. Channelized streams often have high bank stability but low bed stability as the substrate is typically comprised of fine materials that are susceptible to moving downstream. Ratings are as follows:

High: Channel with stable banks and substrates, little or no erosion of the banks, and little or no bedload within the stream. Artificial channels (i.e. concrete) exhibit a high degree of stability even though they typically have a negative effect on biological communities.

Moderate/High: Channel has the ability to maintain stable riffle, run, and pool characteristics. A minor amount of bank erosion and/or bedload is present.

Moderate: Channel that exhibits some instability, characterized by erosion, bedload, or shows the effects of wide fluctuations in water level.

Low: Channels that have a high degree of bedload and severely eroding banks. A homogenous stream bed characterized by shifting sand substrates has low stability.

C) *Velocity Types* – Indicate which flow types are present within the reach (check all that apply). The definitions are as follows:

Torrential: Extremely turbulent and fast flow; water surface is broken, usually limited to gorges and dam spillways.

Fast: Mostly non-turbulent flow with small standing waves in riffle-run areas, water surface may be partially broken.

Moderate: Non-turbulent flow that is detectable (i.e. floating objects are visibly moved downstream).

Slow: Water flow is detectable, but barely perceptible.

Eddies: Areas of circular motion within the current, usually formed in pools immediately downstream of riffles/runs.

Interstitial: Water flow that infiltrates a streambed, and moves through gravel substrates in riffle-run areas.

Intermittent: No flow is present, with standing pools separated by dry reaches.

D) *Sinuosity* – Indicate the degree to which the stream meanders. Sinuosity is defined as the ratio of stream channel distance to straight line distance between two points on a stream. For wide streams or rivers it may be necessary to consider a longer stream reach, as the true meander cycle is often not adequately represented in these systems within the sampling reach. Ratings are as follows:

Excellent: Streams exhibiting a high degree of meandering. Presence of 2 or more well defined bends (deep areas outside and shallow areas on the inside of the bend).

Good: Stream with more than 2 bends, with at least one well defined bend.

Fair: Channel with 1 or 2 poorly defined outside bends, or slight meandering within a modified reach.

Poor: Straight channel with no bends in the reach. Channelized streams or ditches are often rated as poor.

E) *Pool Width/Riffle Width* – Indicate the ratio of pool width to riffle width within the reach. If there is no riffle at the site select “no riffle”.

F) *Channel Development* – Indicate the complexity of the stream channel or the degree to which the stream has developed different channel types, creating sequences of riffles, runs, and pools. In small streams, riffles, runs, and pools must occur more than once within the sampling reach. The ratings of channel development are as follows:

Excellent: Well defined riffles present with gravel, cobble, or boulder substrates; pools vary in depth, and there is a clear transition between pools, riffles, and runs. Multiple sequences of riffles, runs, and pools are present within the reach.

Good: Riffles, runs, and pools are all present, but with less frequency, and are less distinct. Riffles have large substrates (gravel, rubble, or boulder), and pools have variation in depth.

Fair: Riffles are absent or poorly developed (shallow with sand and fine gravel substrates). Some deeper pools may exist, but transitions are generally not abrupt.

Poor: Riffles are absent; pools if present are shallow or lack variation in depth. Channelized streams generally have poor channel development.

G) Present Water Level – An estimation of water level as it relates to summer base flow expectations. In most streams, the "normal" water level can be determined with relative ease by observing channel characteristics.

D. Scoring the MSHA

Following are instructions on how to score the completed MSHA form. The maximum score is 100.

D.1. Surrounding Land Use: Average the scores of the two banks. For example, if residential/park was the land use selected on the left bank, and forest, wetland, prairie, shrub was selected on the right bank, then the land use score would be (2+5)/2=3.5. In the case of two land uses selected for one bank, the two scores are averaged together, and then averaged with the score of the other bank. The maximum land use score is 5.

D.2. Riparian Zone: Average the scores of the two banks for Riparian Width, Bank Erosion, and Shade; then add the three scores. For example, if moderate riparian width (3) was chosen for the left bank and very narrow (1) on the right bank; little bank erosion (4) on the left bank, and moderate (3) on the right bank; heavy shade (5) on the left bank, and substantial (4) on the right bank; the riparian zone score would be: [(3+1)/2] + [(4+3)/2] + [(5+4)/2] = 10. The maximum riparian score is 15.

D.3. Instream Zone

A) Substrate, Embeddedness, and Substrate Types – Add the scores of substrate, embeddedness, and substrate type. The substrate score is calculated by adding the two substrate scores for each channel type, multiplying by the percentage of the channel type, and adding the scores for each channel type present. If only one substrate type is chosen because it makes up more than 80% of the channel type, multiply the one substrate score by 2 before multiplying it by the percentage of the channel type. The maximum substrate score is 27.

B) Cover Type and Cover Amount – Add the scores of cover type and cover amount. The cover score can range from 1 to 8. The highest macrophyte score is 1, even if all three macrophyte types are present. The maximum cover score is 17.

D.4. Channel Morphology: Add the scores of Depth Variability, Channel Stability, Velocity Types, Sinuosity, Pool Width/Riffle Width, and Channel Development. The maximum channel morphology score is 36.

D.5. Total Score: Add the Surrounding Land Use, Riparian Zone, Instream Zone, and Channel Morphology scores together to get the total MSHA score for the site.

MPCA STREAM HABITAT ASSESSMENT

(revised 3-07)

1. Stream Documentation

Stream ______________________________

County ______________________ Date ______________

Field Number ______________ Person Scoring ______________

Site Location ______________________________

MSHA SCORE

Max = 100 ☐

2. Surrounding Land Use (check the most predominant or check two and average scores) [L=left bank/R =right bank, facing downstream]

L	R			L	R		
☐	☐	Forest, Wetland, Prairie, Shrub	[5]	☐	☐	Residential/Park	[2]
☐	☐	Old Field/Hay Field	[3]	☐	☐	Urban/Industrial	[0]
☐	☐	Fenced Pasture	[2]	☐	☐	Open Pasture	[0]
☐	☐	Conservation Tillage, No Till	[2]	☐	☐	Row Crop	[0]

Land Use

Max=5 ☐

3. Riparian Zone (check the most predominant)

A. Riparian Width

L	R			
☐	☐	Extensive	> 300’	[5]
☐	☐	Wide	150’-300’	[4]
☐	☐	Moderate	30’-150’	[3]
☐	☐	Narrow	15’-30’	[2]
☐	☐	Very Narrow	3’-15’	[1]
☐	☐	None		[0]

B. Bank Erosion

L	R			
☐	☐	None		[5]
☐	☐	Little	5-25%	[4]
☐	☐	Moderate	25-50%	[3]
☐	☐	Heavy	50-75%	[1]
☐	☐	Severe	75-100%	[0]

C. Shade

L	R			
☐	☐	Heavy	>75%	[5]
☐	☐	Substantial	50-75%	[4]
☐	☐	Moderate	25-50%	[2]
☐	☐	Light	5-25%	[1]
☐	☐	None		[0]

Riparian

Max=15 ☐

4. Instream Zone

A. Substrate (check two for each channel type)

	Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Silt	Muck	Detritus	Sludge	Channel Type %
	[10]	[9]	[8]	[7]	[5]	[5]	[2]	[1]	[1]	[0]	
Pool	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	________
Riffle	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	________
Run	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	________
Glide	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	________

B. Embeddedness

☐	None		[5]
☐	Light	25-50%	[3]
☐	Moderate	50-75%	[1]
☐	Severe	75-100%	[-1]
☐	No coarse substrate		[0]

C. Substrate Types

☐	>4	[2]
☐	<=4	[0]

D. Water Color

☐ Clear

☐ Stained

Turbid

☐ Brown

☐ Green

☐ Other

Substrate

Max=27 ☐

E. Cover Type (check all that apply)

☐	Undercut Banks	[1]
☐	Overhanging Vegetation	[1]
☐	Deep Pools	[1]
☐	Logs or Woody Debris	[1]
☐	Boulders	[1]
☐	Rootwads	[1]
☐	Macrophytes:	[1]

- ☐ Emergent
- ☐ Floating Leaf
- ☐ Submergent

F. Cover Amount (check one)

☐	Extensive	>50%	[10]
☐	Moderate	25-50%	[7]
☐	Sparse	5-25%	[3]
☐	Nearly Absent		[0]
☐	Choking Vegetation only		[-1]

Cover

Max=17 ☐

5. Channel Morphology

A. Depth Variability

☐	Greatest Depth >4X Shallow Depth	[6]
☐	Greatest Depth 2-4X Shallow Depth	[3]
☐	Greatest Depth <2X Shallow Depth	[0]

D. Sinuosity

☐	Excellent	[6]
☐	Good	[4]
☐	Fair	[2]
☐	Poor	[0]

F. Channel Development

☐	Excellent	[9]
☐	Good	[6]
☐	Fair	[3]
☐	Poor	[0]

B. Channel Stability

☐	High	[9]
☐	Moderate/High	[6]
☐	Moderate	[3]
☐	Low	[0]

E. Pool Width/Riffle Width

☐	Pool Width > Riffle Width	[2]
☐	Pool Width = Riffle Width	[1]
☐	Pool Width < Riffle Width	[0]
☐	No Riffle	[0]

C. Velocity Types (check all that apply)

☐	Torrential	[-1]
☐	Fast	[1]
☐	Moderate	[1]
☐	Slow	[1]
☐	Eddies	[1]
☐	Intermittent	[-2]
☐	Interstitial	[-1]

G. Present Water Level

- ☐ Flood
- ☐ High
- ☐ Normal
- ☐ Low
- ☐ Interstitial

Channel Morphology

Max=36 ☐

Appendix 4-C

EMAP SOP4 – Invertebrate Sampling Procedures

Subject: Invertebrate Sampling Procedures

I. PURPOSE

To describe methods used in the collection of stream invertebrates for the purpose of developing biological criteria used in assessing water quality.

II. REFERENCES

A. Source Documents

U.S. Environmental Protection Agency (USEPA). 1994. Environmental Monitoring and Assessment Program - Surface Waters and Region 3 Regional Environmental Monitoring and Assessment Program: 1994 pilot field operations and methods manual for streams. U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory. Cincinnati, OH. EPA/620/5-94/004.

Barbour, M. T., J. Gerritsen, and J. S. White. 1996. Development of the Stream Condition Index (SCI) for Florida. Florida Department of Environmental Protection, Tallahassee, Florida. 105 pp.

B. Other References

U.S. Environmental Protection Agency (USEPA). 1996. Biological Criteria: Technical Guidance for Streams and Small Rivers. Revised Edition. Office of Water, Washington DC. EPA/822/B-96/001.

U.S. Environmental Protection Agency (USEPA). 1997. Revision to Rapid Bioassessment Protocols for Use in Streams and Rivers (Draft). Office of Water, Washington D.C. EPA/841/D-97/002.

III. SCOPE/LIMITATIONS

This procedure applies to all site visits in which stream invertebrates are to be collected for the development of biological criteria and/or the assessment of water quality.

IV. DEFINITIONS

Integrated monitoring A stream monitoring technique to assess water quality using chemical, biological and physical indicators.

Environmental Monitoring and Assessment Program (EMAP): U.S. Environmental Protection Agency program designed to determine the status, extent, changes, and trends in the condition of our national ecological resources on regional and national scales.

Biological Criteria: Narrative expressions or numerical values that describe the reference biological integrity of a specified habitat. Biological criteria are the benchmarks for judging the condition of aquatic communities.

Qualitative Multihabitat Sample (QMH): A method of sampling invertebrates which involves sampling a variety of invertebrate habitats, including the following substrata: rocky substrates, vegetation, undercut banks, snags, leafpacks, and soft sediment.

V. GENERAL INFORMATION

The methods described herein are to be applied to all wadeable streams included in the MPCA's integrated stream condition monitoring program. This document is not meant to be used by itself, consult one of the documents indicated in the box below if any of the described situations apply. For most efficient use of time and resources, crew leaders must be in constant communication with crews sampling for fish, preventing duplication of effort. It must be understood that this method is not to be applied to streams sampled for fish that are not wadeable.

Data generated from samples collected using the described method can be used for any of the following reasons: 1) Development of regional biological criteria, 2) Calibration of biological criteria, 3) Ambient water quality assessment, 4) Water quality assessment of sites suspected of a having a problematic source of pollution.

NOTE

SOP1 - Site Reconnaissance: A site reconnaissance should be done by the first crew to visit a site. After the initial recon has been done, no more are required. One must be done before any sampling can take place.

SOP2 - Chemical Assessment: A chemical assessment should be done by the first crew to visit a site following a site reconnaissance. These procedures can be completed during a single site visit.

SOP3 - Habitat Assessment: A habitat assessment should be done during the same visit as the chemical assessment. If a habitat assessment is to be done during the same visit as an invertebrate collection, the invertebrate collection should be done first.

VI. REQUIREMENTS

A. Qualifications of Crew Leaders
A crew leader must be a professional aquatic biologist with a minimum of a Bachelor of Science degree in biology with an aquatic entomology, invertebrate, zoology, fisheries, or closely related specialization. Additionally, they must have at least 6 months experience working under a macroinvertebrate biologist in the areas of invertebrate sampling methodology and taxonomy.

B. Qualifications of field technicians/interns
A field technician/intern must have at least one year of college education and had coursework in environmental and/or biological science.

C. General Qualifications
All personnel conducting this procedure must have excellent map reading skills and a demonstrated proficiency in the use of a GPS receiver and an orienteering compass. Because sites may be located miles from the nearest vehicle assessable road, it is often necessary to wade through streams and/or wetlands, canoe, or hike for long distances to reach a site. Personnel conducting this procedure must have the physical ability to accomplish this.

VII. RESPONSIBILITIES

A. Field Crew Leader
Ensures that data generated using this procedure meet the standards and objectives of the integrated condition monitoring program. Carries out the procedures outlined in the action steps.

B. Technical personnel
Carries out the procedures outlined in the action steps, including maintenance and stocking of equipment, date collection and recording.

VII. QUALITY ASSURANCE AND QUALITY CONTROL

Compliance with this procedure will be maintained through annual internal reviews. Technical personnel will conduct periodic self-checks by comparing their results with other trained personnel. Calibration and maintenance of equipment will be conducted according to the guidelines specified in the manufacturer manuals.

VII. QUALITY ASSURANCE AND QUALITY CONTROL (continued)

In addition to adhering to the specific requirements of this sampling protocol and any supplementary site specific procedures, the QA/QC requirements for this protocol are as follows:

A. Control of Deviations
Deviations from the procedure shall be sufficiently documented to allow repetition of the activity as actually performed.

B. QC Samples
Ten percent of all sites sampled on any given year are resampled as a means of determing sampling error.

C. Verification
The field crew leader will conduct periodic reviews of field personnel to ensure that technical personnel are following the procedures according to this SOP.

IX. TRAINING

A. All personnel will receive training annually from a trainer designated by the program manager. Major revisions in this procedure will require that all personnel be retrained in the revised procedure by an authorized trainer.

B. Training activities will include instruction in the field as well as a field test to ensure that personnel can implement this procedure.

X. ACTION STEPS

A. Equipment List

Ensure that all of the following items are presents before implementing this procedure:

Two D-frame dipnets with 500 micron mesh nets, preferably Wildco, turtox design
Two sieve buckets with 500 micron sieves
Stream Invertebrate Visit Form
Stream verification form, previously completed with attached copies of 1:24,000 USGS topographical map
Minnesota Atlas and Gazateer (Delorme)
Pencils
Permanent/Alcohol proof markers

A. Equipment List (continued)

Labeling tape
Invertebrate sample identification labels
100% reagent alcohol, enough to preserve one days worth of samples, ca. 1 gallon/site
Waterproof notebook
Chest-high waders
Rain-gear
Jars or bottles in which sample is to be preserved; preferably non-breakable synthetic, minimum 1 litre capacity
Box or crate to store sample bottles
Canoe
Backpack

B. Method

The multihabitat method entails collecting a composite sample from up to five different habitat types. The goal of this method is to get a sample representative of the invertebrate community of a particular sampling reach, it is also to collect and process that sample in a time and cost effective manner. For that reason the habitats described below are relatively non-specific, being chosen to represent broad categories rather than microhabitats. Every broad category includes numerous microhabitats, some of which will not be sampled. It is to the discretion of the sampler which microhabitats are to be sampled. As a general rule, sample in manner that reflects the most common microhabitat of any given broad habitat category. The habitats to be sampled include:

Hard bottom (riffle/cobble/boulder)

This category is intended to cover all hard, rocky substrates, not just riffles. Runs and wadable pools often have suitable “hard” substrates, and should not be excluded from sampling. The surfaces of large boulders and areas of flat, exposed bedrock are generally quite unproductive, avoid including these habitats in the sampling area if possible. This is a general rule, if a particular stream has productive exposed bedrock, or boulder surfaces, those habitats should be considered sampleable.

Aquatic Macrophytes (submerged/emergent vegetation)

Any vegetation found at or below the water surface should be considered in this category. Emergent vegetation is included because all emergent plants have stems that extend below the water surface, serving as suitable substrate for macroinvertebrates. Do not sample the emergent portion of any plant.

B. Method (continued)

Undercut Banks (undercut banks/overhanging veg)

This category is meant to cover in-bank or near-bank habitats, shaded areas away from the main channel that typically are buffered from high water velocities.

Snags (snags/rootwads)

Snags include any piece of large woody debris found in the stream channel. Logs, tree trunks, entire trees, tree branches, large pieces of bark, and dense accumulations of twigs should all be considered snags. Rootwads are masses of roots extending from the stream bank.

Leaf Packs

Leaf packs are dense accumulations of leaves typically present in the early spring and late fall They are found in deposition zones, generally near stream banks, around logjams, or in current breaks behind large boulders.

Sampling consists of dividing 20 sampling efforts equally among the dominant, productive habitats present in the reach. If 2 habitats are present, each habitat should receive 10 sampling efforts. If 3 habitats are present, the two most dominant habitats should receive 7 jabs, the third should receive 6 jabs. If a productive habitat is present in a reach but not in great enough abundance to receive an equal proportion of sampling efforts, it should be thoroughly sampled and the remaining samples should be divided among the remaining habitat types present.

A sample effort is defined as taking a single dip or sweep in a common habitat. A sweep is taken by placing the D-net on the substrate and disturbing the area directly in front of the net opening equal to the net width, ca. $1ft^2$. The net should be swept several times over the same area to ensure that an adequate sample is collected. Each effort should cover approximately $.09m^2$ of substrate. Total area sampled is ca. $1.8m^2$.

Once a site reach has been found or newly established, invertebrate sampling should follow. If a habitat assessment and chemical analysis is to be done it should follow invertebrate sampling.

NOTE

Before leaving the vehicle be sure that the following equipment is brought to the site: two d-frame dipnets, one (or two) sieve buckets, habitat partition form, site file, compass, GPS receiver, backpack filled with sample bottles (optional), alcohol (optional)

B. Method (continued)

1. Before sampling can begin, the Crew Leader and field tech must determine which habitats are present in the reach. This should be a cooperative effort. This is done by walking the length of the stream and determining which productive habitats dominate the stream reach. A site visit form should be filled out during this process. Ideally the stream should be viewed from the top of the stream bank, but this is generally the exception rather than the rule. For this reason, great care must be taken to walk gingerly along the stream edge, or any streamside exposed areas. If this is not possible, stay to one side of the stream so as to disturb as little substrate as possible.

NOTE

Since sampling should be conducted in a downstream to upstream fashion, it will save time to start the initial visual inspection of the stream from the upstream end of the sampling reach, and walk downstream. This will allow you to start sampling at the down stream end of the reach as soon the inspection is completed.

It is difficult to estimate total stream coverage of certain habitats due to their linear or three dimensional natures. Undercut banks and overhanging vegetation appear linear, snags are three dimensional, as are vegetation mats, and emergent vegetation. For these reasons best professional judgment must be used to determine what level of effort is adequate to equal one “sample effort” for any given substrate. Keep in mind that this method is considered semiquantitative, rulers and grids are not necessary to effectively implement this procedure. Following are some suggestions as to how approach each habitat for the perspective of

Hard bottom: Riffles are basically two dimensional areas, and should be thought of as such when trying to determine how dominant the riffle habitat is in a stream. It must be kept in mind that the riffle is likely to be the most productive and diverse habitat in the reach, relatively speaking. The field personnel must not get overzealous, the purpose of this method is to get a representative sample. The temptation will undoubtedly exist to spend all day in the riffle areas, this must be avoided. Sampling in this habitat type is relatively simple. The D-net should be place firmly, and squarely on the substrate downstream of the area to be sampled. If the water is shallow enough, the area directly in front of the net should be disturbed with the hands, taking care to wash large rock off directly into the net. If the water

is too deep for this, kicking the substrate in front of the net is adequate. Watch for stoneflies trying to crawl out of the net!

Vegetation: Aquatic vegetation is either completely submerged, mostly submerged and partially floating on the waters surface, or partially submerged and mostly extended above the waters surface. Things like Potamageton sp., coontail, and milfoil tend to clump and float at the waters surface. These types of plants should be sampled with an upward sweep of the net. If the net fills with weeds, the weeds should be hand washed vigorously or jostled in the net for a few moments and then discarded. Emergent plants such as reed canary grass and various plants in the rush family, should be sampled with horizontal and vertical sweeps of the net until it is felt that the area being swept has been adequately sampled. Plants like floating bur reed, and water celery tend to float in long strands with the current. They can be floating on the surface of completely submerged. These plants should be sample as emergent plants with horizontal and vertical sweeps in a downstream to upstream motion.

Undercut banks/ Overhanging Vegetation: Undercut banks and overhanging vegetation follow the line of the stream bank. Undercut banks can vary in how undercut they are. An additional problem is that many banks appear undercut, but when investigated prove not to be. For these reasons banks should be prodded to determine how deeply they are undercut. Overhanging vegetation should be treated the same way. Sampling should consist of upward thrusts of the net, beating the undercut portion of the bank or the overhanging vegetation, so as to dislodge any clinging organisms.

Snags: Snags and rootwads can be large or small, long or wide, simple or twisted masses of logs or twigs that don’t have any consistent shape. Best professional judgment must be used to determine what a “sampling effort” is. Approximating the amount of sampleable surface area is a sensible method with larger tree trunks or branches. Where as masses of smaller branches and twigs must be given a best guess. Given their variable nature, there is not one best method for sampling snags. Using something like a toilet brush works well for large pieces of wood, whereas kicking and beating with the net works best for masses of smaller branches. The person taking the sample must determine the best method for each particular situation.

B. Method (continued)

Leaf packs: Leaf packs are simple, but messy to sample. One square foot of leaf pack surface area that has two cubic feet of leaf underneath should be sampled near the surface. Whereas a shallow leafpack can be sampled in it's entirety. Sweeping to the bottom of every leafpack could create a disproportionately large amount of sample volume being collected for relatively small sample area. In most situations leaf packs will not be dominate enough to be included in a sample. If leaf packs are sampled, it is suggested that time be spent streamside washing invertebrates off of leaves and discarding the leaves, as a leaf pack sample can easily become overwhelmingly large.

2. After the number of productive, sampleable habitats have been determined, the sampling team should proceed in a downstream to upstream manner, sampling the various habitats present.

NOTE

In order to get complete samples, the contents of the D-net should be emptied into a sieve bucket frequently. This prevents the back flow of water resulting from a clogged net. In larger streams it is convenient for each sampler to have a sieve bucket. This allows samplers to sample independent of each other, avoiding frequent stream crossings which can alter the stream bed.

NOTE

While sampling it may become necessary to clean the sample of muddy, fine sediment. This can be done by filling the sieve bucket with clean water and allowing the resulting mucky water to drain. Care must be taken not twist and turn the bucket to much, this creates a washing machine action which separates insects from their delicate parts quite effectively.

B. Method (continued)

3. Once sampling is complete the sample material should be preserved as quickly as possible. Transfer the sample material from the sieve bucket to the sample containers. Fill sample containers to the top with 100% reagent alcohol. Be sure to thoroughly clean the bucket as well as sampling nets of all invertebrates. The use of forceps might be necessary to dislodge some of the smaller organisms.

4. With labeling tape, label the outside of the container with field number, date, site name, initials of those who collected samples, and number of containers, i.e 1 of 3, and Place a properly filled out sample label in each sample container.

XI. REQUIRED RECORDS

Stream Invertebrate Visit Form

A. The Stream Invertebrate Visit Form should be filled out during the streamside survey, or notes should be taken on field note books and transferred to visit form. This information will be placed in the biological database.

Quantitative Riffle Sample (optional):

These samples are being taken by the MPCA as a means to determining the best method for sampling streams with dominant riffle/run features.

If a riffle is present in the sampling reach, or in close proximity to the reach, a riffle sample should be taken. This should be a “quality” riffle, that is, a riffle that consists of gravel and/or cobble of varying sizes, and has adequate flow for sampling. The flow should be fast enough to wash dislodged organisms into the sampling net.

Three quantitative riffle samples should be taken. They do not need to be side by side. They should be spread throughout the riffle area.

Appendix 4-D

Invertebrate Identification and Enumeration

SOP BMIP03
Invertebrate Identification and Enumeration

STEP

Materials:

1. Waterproof paper labels and water/solvent proof marker
2. 80 percent ethanol
3. Squeeze bottles (for ethanol and water)
4. 4 oz. jars, with plastic or foam-line cap
5. Dissecting scope with a 10x minimum power
6. Fine tipped forceps, watchmaker type
7. Vials, with polyseal caps -2,4, and 8 dram

Methods:

Sort sample according to SOP BMIP03, placing the picked organisms in 2 or 4 dram vials

Mulit-habitat sub-sample / quantitative sample:

Empty contents of vial(s) into a petri-dish

When sorting, chironomids should be counted and separated into their own individual vial. Chironmids are not identified past the family level, they are sent to an external lab for identification. It is imperative that they be enumerated correctly. In the chironomid vial include a label with a Site ID number, site name, latitude, longitude, collection date. An additional label including taxonomic identification, and number of individuals in the vial should also be included

To facilitate identification, sort organisms according to major taxonomic groups, i.e. stoneflies, caddisflies, bottles. Different groups can be placed in separate, 60mm petri-dishes or kept separate in several larger petri-dishes.

Identify organisms to the lowest practical taxonomic level. The desired level is genus. Organisms should be counted as they are identified, and removed to another dish or placed back in the sample vial to avoid miscounting.

Final identifications are to be made by experienced taxonomists. Preliminary identifications made by interns, or inexperienced taxonomists must be verified by a staff member whose name appears on the invertebrate QC list. The lab maintains a library of taxonomic reference materials. When making identifications, the taxonomist should refer to the taxonomic reference list for the preferred reference for each major group. The lab also maintains a reference collection the can be used to check identifications. Many taxonomic references contain high quality pictures, **identifications are never to be made using pictures alone**. The proper way to make an identification includes taking a specimen through a dichotomous key, checking range distribution, checking habitat preference, and checking for seasonal emergence and growth patterns. If any questions remain about the identity of a specimen, consult another staff taxonomist, or a regional or taxonomic group specialist. A list of regional and group specialists is maintained in the lab.

When large numbers of individual taxa are present a laboratory counter should be used to keep a running total. Counters should be labeled to avoid confusion if using more than one counter.

If an organism is encountered for the first time in the laboratory, remove it to it's own vial for inclusion in the reference collection. Make a note of this on the Invertebrate Identification and Enumeration Sheet.

When adding an organism to the reference collection, place it in a 4 dram vial with two labels. One label including a taxonomic identification, taxonomist name and date of identification. The other including, Site ID number, site name, state, county, latitude and longitude - or a brief location description- and collection date.

Large/Rare Sample:

The Large/Rare sample should be identified and enumerated separate from the main sub-sample.

Sort organisms according to major taxonomic groups, i.e. stoneflies, caddisflies, beetles Different groups can be placed in separate, 60mm petri dishes or kept separate in several larger petri-dishes.

Identify organisms to the lowest practical taxonomic level. The goal is to identify organisms to Genus. Organisms should be counted as they are identified, and removed to another dish or placed back in the sample vial to avoid miscounting.

Record numbers of Large/Rare organisms in the Large/Rare column of the Invertebrate Identification and Enumeration Sheet.

It is imperative that organisms which are a part of the large/rare sample are kept separate from the multihabitat subsample, and quantitative sample.
Large/rare organisms are only used in taxa richness measures, so it is most important that there presence is noted.

Macroinvertebrate Identification Lab Bench Sheet

Field Number	**Sample Date**
Site Name	**Taxonomist:**
Sample Type QMH* QR HD other_________	**Date of Sample ID:** ____/____/____

*A processed QMH sample consists of 2 parts, the subsample(ss) and large/rare (l/r), both parts must be identified

Order/Family	Genus	Species/Notes	ss	l/r
Ephemeroptera				
Baetiscidae	Baetisca			
Caenidae	Bracycercus			
	Caenis			
Ephemerellidae	Attenella			
	Ephemerella			
	Serratella			
Ephemeridae	Ephemera			
	Hexagenia			
Leptohyphidae	Tricorythodes			
Leptophlebiidae	Leptophlebia			
	Paraleptophlebia			
Polymitarcidae	Ephoron			
Potamanthidae	Anthopotamus			
Heptageniidae	Epeorus			
	Heptagenia			
	Stenacron			
	Stenonema			
Isonychiidae	Isonychia			
Ametropodidae	Ametropus			
Baetidae	Acerpenna			
	Baetis			
	Callibaetis			
	Heterocloeon			

notes/additional taxa

Plecoptera				
Leuctridae				
Taeniopterygidae				
Perlidae	Acroneuria			
	Agnetina			
	Attaneuria			
	Neoperla			
	Paragnetina			
	Perlinella			
Perlodidae				
Pteronarcyidae	Pteronarcys			

notes/additional taxa

Lepidoptera				
Pyralidae	Paraponyx			
	Petrophila			

notes/additional taxa

Megaloptera				
Corydalidae	Chauliodes			
	Corydalus			
	Nigronia			
Sialidae	Sialis			

notes/additional taxa

sopoda				
sselidae	Asselus			

otes/additional taxa

Order/Family	Genus	Species/Notes	ss	
Odonata				
Calopterygidae	Calopteryx			
	Hetaerina			
Coenagrionidae	Argia			
	Enallagma			
	Nehalennia			
Lestidae	Lestes			
Aeshnidae	Aeschna			
	Anax			
	Basiaeschna			
	Boyeria			
Cordulegastridae	Cordulegaster			
Corduliidae	Cordulia			
	Dorocordulia			
	Epitheca			
	Somatochlora			
Gomphidae	Dromogomphus			
	Gomphurus			
	Gomphus			
	Hagenius			
	Ophiogomphus			
	Phanogomphus			
	Progomphus			

notes/additional taxa

Hemiptera				
Belostomatidae	Belstoma			
	Corixidae			
Corixidae	Hesperocorixa			
	Sigara			
	Trichocorixa			
Nepidae	Ranatra			
Notonectidae	Buenoa			
	Notonecta			

notes/additional taxa

Amphipoda				
Talitridae	Hyallela	azteca		
Gammaridae	Gammarus			

notes/additional taxa

Decapoda				
Cambaridae	Cambarus			
	Orconectes			
	Procambarus			

notes/additional taxa

Pelecypoda				
Sphaeriidae				
Corbiculidae				
Unionidae				

notes/additional taxa

ntered into DataInverts by______ --- (initials) date_________

Trichoptera				
Dipseudopsidae	Phylocentropus			
Hydropsycidae	Ceratopsyche			
	Cheumatopsyche			
	Diplectrona			
	Hydropsyche			
	Potamyia			
Philopotamidae	Chimarra			
	Dolophilodes			
Polycentropodidae	Cernotina			
	Cymellus			
	Neureclipsis			
	Paranyctiophylax			
	Polycentropus			
Psychomyiidae	Lype			
	Psychomyia			
Glossosomatidae	Agapetus			
	Glossosoma			
	Protoptila			
Hydroptilidae	Hydroptila			
	Leucotrichia			
	Mayatrichia			
	Oxyethira			
	Orthotrichia			
Rhyacophilidae	Rhyacophila			
Brachyecentridae	Brachycentrus			
	Micrasema			
Helicopsychidae	Helicopsyche			
Lepidostomatidae	Lepidostoma			
Leptoceridae	Ceraclea			
	Leptocerus			
	Mystacides			
	Nectopsyche			
	Oecetis			
	Trianodes			
Limnephilidae	Limnephilus			
	Hydatophylax			
Molannidae	Molanna			
Phryganeidae	Phryganea			
	Ptilostomis			
Sericostomatidae	Agarodes			

notes/additional taxa

Gastropoda				
ncylidae	Ferrissia			
lanorbidae	Helisoma			
	Promentus			
	Planorbula			
	Gyraulus			
ivaparidae	Campeloma			
ymnaeidae	Lymnaea			
	Bulimnea			
	Fossaria			
ydrobiidae	Amnicola			
leuroceridae	Pleurocera			
hysidae	Physa			

tes/additional taxa

		Species/Notes	SS	
Diptera				
Ceratopogonidae	Alluaudomyia			
	Atrichopogon			
	Bezzia			
	Ceratopogon			
	Culicoides			
	Nilobezzia			
	Palpomyia			
	Probezzia			
	Sphaeromias			
Chironomidae	G.			
Dixidae	Dixa			
	Dixella			
Simuliidae	Simulium			
Tipulidae	Antocha			
	Dicranota			
	Hexatoma			
	Limnophila			
	Limonia			
	Pilaria			
	Tipula			
Athericidae	Atherix			
Empididae	Hemerodromia			
Tabanidae	Chrysops			
	Tabanus			

notes/additional taxa

Coleoptera				
Dytiscidae	Agabus			
	Laccophilus			
	Liodessus			
Gyrinidae	Dineutus			
	Gyrinus			
Elmidae	Ancyronyx			
	Dubiraphia			
	Macronychus			
	Optioservus			
	Stenelmis			
Hydrophilidae	Berosus			
	Helocombus			
	Laccobius			
	Sperchopsis			
	Tropisternus			
Annelida	Oligochaeta			
	Hirudinea			

notes/additional taxa

Hydracarina (trombidoformes, acarina)				
Nematoda				

notes/additional taxa

-MPCA Biological Monitoring Program-

Macroinvertebrate Identification QC Form

Field Number	Sample Date	Identifiers' Initials		Discrepancies		Comments	Total # of Conflicts	Total # of Taxa	Precision	
		Original ID	QC ID	Original Identification	QC Identification				Original ID	QC ID

Appendix 4-E

Fish Community Sampling Protocol for Stream Monitoring Sites

Minnesota Pollution Control Agency Biological Monitoring Program

FISH COMMUNITY SAMPLING PROTOCOL FOR STREAM MONITORING SITES

I. PURPOSE

To describe the methods used by the Minnesota Pollution Control Agency's (MPCA) Biological Monitoring Program to collect fish community information at stream monitoring sites for the purpose of assessing water quality and developing biological criteria.

II. SCOPE/LIMITATIONS

This procedure applies to all monitoring sites for which an integrated assessment of water quality is to be conducted. An integrated assessment involves the collection of biological (fish and macroinvertebrate communities), physical habitat, and chemical information to assess stream condition.

III. GENERAL INFORMATION

Sites may be selected for assessment for a number of reasons including: 1) sites randomly selected for condition monitoring as part of the Environmental Monitoring and Assessment Program (EMAP), 2) sites selected for the development and calibration of biological criteria, and 3) sites selected to evaluate a suspected source of pollution. Although the reasons for monitoring a site vary, the fish community sampling protocol described in this document applies to all monitoring sites unless otherwise noted.

IV. REQUIREMENTS

A. Qualifications of crew leaders: The crew leader must be a professional aquatic biologist with a minimum of a Bachelor of Science degree in aquatic biology or closely related specialization. He or she must have a minimum of six months field experience in fish community sampling methodology and fish taxonomy. Field crew leaders should also possess excellent map reading skills and a demonstrated proficiency in the use of a GPS (Global Positioning System) receiver and orienteering compass.

B. Qualifications of field technicians/interns: A field technician/intern must have at least one year of college education and coursework in environmental and/or biological science.

C. General qualifications: All personnel conducting this procedure must have the ability to perform rigorous physical activity. It is often necessary to wade through streams and/or wetlands, canoe, or hike for long distances to reach a sampling site

V. RESPONSIBILITIES

A. Field crew leader: Implement the procedures outlined in the action steps and ensure that the data generated meets the standards and objectives of the Biological Monitoring Program.

B. Technicians/interns: Implement the procedures outlined in the action steps, including maintenance and stocking of equipment, data collection and recording.

VI. QUALITY ASSURANCE AND QUALITY CONTROL

Compliance with this procedure will be maintained through annual internal reviews. Technical personnel will conduct periodic self-checks by comparing their results with other trained personnel. Calibration and maintenance of equipment will be conducted according to the guidelines specified in the manufacturer's manuals.

In addition to adhering to the specific requirements of this sampling protocol and any supplementary site specific procedures, the minimum QA/QC requirements for this activity are as follows:

A. Control of deviations: Deviation shall be sufficiently documented to allow repetition of the activity as performed.

B. QC samples: Ten percent of sites sampled in any given year are re-sampled as a means of determining sampling error and temporal variability.

C. Verification: The field crew leader will conduct periodic reviews of field personnel to ensure that technical personnel are following procedures in accordance with this SOP.

VII. TRAINING

A. All inexperienced personnel will receive instruction from a trainer designated by the program manager. Major revisions in this protocol require that all personnel be re-trained in the revised protocol by experienced personnel.

B. The field crew leader will provide instruction in the field and administer a field test to ensure personnel can execute this procedure.

VIII. ACTION STEPS

A. Equipment list: Verify that all necessary items are present before commencement of this procedure (Table 1).

B. Data collection method: The location and length of the sampling reach is determined during site reconnaissance (see SOP--"***Reconnaissance Procedures for Initial Visit to Stream Monitoring Sites***"). The reach length, 35 times the mean stream width (MSW), is based on the distance necessary to capture a representative and repeatable sample of the fish community within a stream segment (following: Lyons, J. 1992. The length of stream to sample with a towed electrofishing unit when fish species richness is estimated. North American Journal of Fisheries Management. 16:241-256.). Sampling is conducted during daylight hours within the summer index period of mid-June through mid-September. Sampling should occur when streams are at or near base-flow because flood or drought events can have a profound effect on fish community structure and sampling efficiency.

For wadeable streams, fish community sampling is conducted in conjunction with the physical habitat assessment protocol (see SOP--"***Physical Habitat and Water Chemistry Assessment Protocol for Wadeable Stream Monitoring Sites***"). Fish sampling should be conducted before the physical habitat assessment so as not to disturb the fish community prior to sampling. Sample all habitat types available to fish within the reach in the approximate proportion that they occur. An effort is made to collect all fish observed. Fish < 25 mm in total length are not counted as part of the catch.

All fish that are alive after processing should be immediately returned to the stream, unless they are needed as voucher specimens. Considerable effort should be expended to minimize handling mortality, such as using a live well, quickly sorting fish into numerous wet containers, and replacing their water supply.

Fish survey results are recorded on the **Fish Survey Record** data sheet. A copy is attached and guidelines for filling out this data sheet are described in the following pages.

C. Fish Survey Record Data Sheet

This data sheet summarizes the location, sampling characteristics, and fish community composition of the sampling site. The variables recorded are as follows:

C.1. Location and Sampling Characteristics

1) *Field Number* – A seven-digit code that uniquely identifies the station. The first two digits identify the year of sampling, the second two identify the major river basin, and the last three are numerically assigned in sequential order (example 02UM001).

2) *Date* – The date fish sampling is conducted in month/day/year format (MM/DD/YY).

3) *Stream Name* – The name of the stream as shown on the most recent USGS 7.5" topographic map. Include all parts of the name (i.e. "North Branch", "Creek", "River", "Ditch", etc.).

4) *County* – The county in which the station is located.

5) *Location* – A general description of where the sampling station is located. Usually includes the nearest road crossing and town. For example, "0.5 mi. downstream of C.R. 30, 4 mi. SW of Northome".

6) *Crew* – The personnel who conducted fish community sampling.

7) *Gear Type* – The specific type of electrofisher utilized for fish collection. The MPCA's Biological Monitoring Program utilizes four electrofishing gear types. Care is taken to select the gear type that will most effectively sample the fish community. Gear selection is dictated by stream width, depth, and accessibility. General guidelines for determining the appropriate gear type and their use are as follows:

   Backpack: Generally used in small, wadeable streams (typically < 8 m MSW and < 50 mi^2 drainage area). A single electrofishing run is conducted in an upstream direction. In very small streams (<2 m wide) it is possible to sample most of the available habitat but in larger streams it is often necessary to meander between habitat types. Two personnel are necessary; one to carry the unit and operate the anode and another to collect the fish.

   Stream-shocker: Used in larger, wadeable streams and rivers (typically > 8 m MSW and 50-500 mi^2 drainage area). The stream-shocker is a towable unit that can effectively sample larger streams because it has additional power capabilities and employs two anodes, thus increasing the electrified zone. Five personnel are required for operation, one to control the electrofisher, two to direct the anodes, and two to net fish. A single electrofishing run is conducted in an upstream direction weaving between habitat types. When stream-shocker access is too difficult or the site is a wide, shallow riffle it may be necessary to sample larger streams utilizing two backpack electrofishers simultaneously.

   Mini-boom: Used in non-wadeable streams and rivers that are either too small or that do not afford the access necessary to utilize a boom-shocker. The mini-boom electrofisher is a jon-boat that is light enough to be portaged, yet provides a stable work platform. Personnel consist of one person to operate the boat, monitor the control box, and ensure the safety of a single fish collector on the bow. A single electrofishing run is conducted in a downstream direction weaving between habitat types.

   Boom-shocker: Used in large, accessible rivers. Three electrofishing runs are made in a downstream direction, one each along the right bank, left bank, and mid-channel. Personnel consist of one person to drive the boat, monitor the control box, and ensure the safety of the two fish collectors on the bow.

8) *Channel Position* – If the site is sampled with a boom-shocker, circle the appropriate channel position of the electrofishing run (determined while facing downstream); right bank, left bank, or mid-channel. A separate **Fish Survey Record** data sheet is used for each of the three runs.

9) *Distance* – The length of stream sampled for fish, measured to the nearest meter following the center of the stream channel. If the entire reach is electrofished, the distance sampled for fish is the same as the *station length* recorded on the **Visit Summary** data sheet (see SOP--"***Physical Habitat and Water Chemistry Assessment Protocol for Wadeable Stream Monitoring Sites***"). In the event the entire station cannot be electrofished, measure the portion of the reach that was not sampled and subtract this distance from the

station length to calculate the distance sampled for fish. Possible explanations include the occurrence of a culvert or beaver impoundment within the reach.

10) *Time Fished* – The number of seconds electrofished. Reset the timer on the electrofisher before each sampling event.

11) *Identified By* – The person(s) who field identified the fish collected, must meet the minimum requirements of a field crew leader described previously.

C.2. <u>Fish Community Composition</u>

1) *Species* – The common name of each fish species collected during the electrofishing run. If a fish cannot be identified to species with certainty, identify to the lowest possible taxon (e.g. to genus) and voucher for later lab identification.

2) *Length Range* – The minimum and maximum length for each fish species collected (fish < 25 mm are excluded). Measure to the nearest millimeter using <u>Maximum Total Length</u> protocol: the distance from the anterior-most part of the fish to the posterior-most tip of the caudal fin while it is being compressed. If only one individual of a fish species is captured, record the length as both the minimum and maximum total length.

3) *Weight* – The total wet weight of each fish species collected. Together, weigh all individuals of the same species to the nearest 0.5 gram. Multiple batch weights may be necessary if scale capacity is exceeded; these can be recorded on the back of the data sheet in the space provided. Only species totals should be recorded here.

4) *No.* – The total number of individuals of each fish species.

5) *Anomalies* – Record the total number and type of anomalies observed on all individuals of a fish species. Recognized anomalies and their codes are located on the bottom of the **Fish Survey Record** data sheet.

6) *Voucher* – The number of specimens of each fish species retained for verification and deposition in the Minnesota Bell Museum of Natural History. For fish that are identified with certainty to species level, several individuals of each species should be preserved in 10% formalin solution (37% formaldehyde:water) in the "A- jar". For each species of fish, document the number of individuals preserved in this data field.

   All fish that could not be identified to the species level should be preserved in a separate container (B-jar) in 10% formalin solution. Record the number preserved.

   Voucher containers should be labeled externally and internally. On the outside of the jar write the field number, sampling date, and jar identification (A or B) with a permanent marker. Place a label inside each jar identifying the field number, sampling date, stream name, jar identification, county, gear type, and collectors. Write this information on an index weight label in pencil or a solvent proof marker. If an "A" and "B" jar are used, tape them together.

   For specimens that are too large to preserve, a photograph may be taken to serve as a voucher. Place a card with the site field number and sampling date visibly into the picture frame with the fish positioned in a manner that allows key characteristics to be identified.

C.3. <u>Individual or Batch Measurements</u>: Often times it is necessary to weigh large fish individually or conduct multiple batch weights for a species of fish, these measurements can be recorded in this section of the data sheet. The data fields are the same as those described above. After fish processing is complete, combine the information for fish of the same species so that only species totals are recorded in the previous section.

Table 1. Equipment List – This table identifies all equipment needed in the field in order to implement the sampling protocol as described.

Electrofisher – for sampling the fish community, use appropriate gear type
(includes control box, generator, anode(s), and cathode)

Nets – for collection of fish; 1/8” mesh, fiberglass handles

Rubber gloves – for safety during electrofishing; electrically rated

Holding tank – for holding fish during electrofishing; of sufficient size to minimize stress

Wet containers – for holding fish during processing; of sufficient size and number to minimize stress

Balance or spring scales – for weighing fish

Measuring board – for measuring total length of fish

Waders – for safety during electrofishing

Polarized sunglasses – for aid in capturing fish

Clipboard – to store forms and record data

Forms – for recording data

Pencil – for filling out forms

Permanent marker – for labeling voucher bottle

Taxonomic key – to assist in identifying fish

Voucher bottle – for storing preserved specimens

Formalin – for preserving voucher specimens

Labels – to label voucher jars

Camera – to document fish species collected that are too large to preserve

FISH SURVEY RECORD

MPCA

Field Number:	Date (mm/dd/yy):
Stream Name:	County:
Location:	Crew:

Gear Type: (circle one) Backpack Stream-Shocker Boom-Shocker Mini-Boom

Channel Position: (circle one if boom-shocking site) Right Bank Mid-Channel Left Bank

Distance (m):	Time Fished (sec):	Identified By:

Species (common name)	Length Range (mm)	Weight (g)	Number	Anomalies	Voucher
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					
13.					
14.					
15.					
16.					
17.					
18.					
19.					
20.					
21.					
22.					
23.					
24.					
25.					
26.					
27.					

Anomalies: A-anchor worm; B-black spot; C-leeches; D-deformities; E-eroded fins; F-fungus; L-lesions; N-blind; P=parasites; PL-parasite lesion; Y-popeye; S-emaciated; W-swirled scales; T-tumors; Z-other. (Heavy (H) or Light (L) code may be combined with above codes.)

(Cont.)

Species (common name)	Length Range (mm)	Weight (g)	Number	Anomalies	Voucher
28.					
29.					
30.					
31.					
32.					
33.					
34.					
35.					
36.					
37.					

INDIVIDUAL OR BATCH MEASUREMENTS

Species (common name)	Length Range (mm)	Weight (g)	Number	Anomalies	Voucher
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
12.					
13.					
14.					
15.					
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25.					
26.					
27.					
28.					
29.					
30.					

(Revised Dec. 2002)