SURFACE WATER QUALITY ASSESSMENT OF THE FLAMBEAU MINE SITE

WISCONSIN DEPARTMENT OF NATURAL RESOURCES

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EXECUTIVE SUMMARY

The Flambeau mine was an open pit copper sulfide mine located just south of Ladysmith in Rusk County, Wisconsin. The mine was actively operated between 1993 and 1997 by the Flambeau Mining Company (FMC). 1.8 million tons of ore containing 181,000 tons of copper and 900 tons of zinc were extracted from the mine and passed through the southeast corner of the mine site where Steam C, an intermittent tributary of the Flambeau River, is located. The pit was backfilled by 1998 and surface reclamation took place between 1998 and 2001. Water quality monitoring done at the site between 2002 and 2011 showed that Stream C and its contributing drainageways contained copper and zinc concentrations that frequently exceeded acute toxicity criteria (ATC). On average, copper exceeded ATC's in 92% of samples, and zinc exceeded ATC's in 46% of samples. Results of a bioassay test and the presence of a fish and macroinvertebrate community in Stream C suggest that any potential toxicity is not severe.

Stream C was not monitored prior to mining so a pre and post mining comparison is not possible. Monitoring of the Flambeau River did not show any significant changes in copper and zinc concentrations in response to mining activities. Copper and zinc concentrations in the two intermittent streams in the fully reclaimed areas of the Flambeau mine site were low. A nearby intermittent stream also had low concentrations of copper and zinc. Monitoring results from these three streams indicates that local background concentrations of copper and zinc are generally low.

The southeast corner of the mine site that drains to Stream C was not fully reclaimed and soil sampling by FMC in this area found multiple locations with elevated copper concentrations. Areas with high soil copper concentrations were generally correlated with high runoff water copper concentrations. Past remedial actions taken by FMC to remove or cap soil with high copper concentrations resulted in reduced copper concentrations in runoff water. FMC is currently pursuing additional remedial actions that are likely to result in reductions in copper and zinc concentrations in Stream C.

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INTRODUCTION

The Flambeau mine site comprises 181 acres located in Section 9, T34N, R6W, Rusk County, Wisconsin approximately two miles south of the City of Ladysmith (Figure 1 inset). The Flambeau Mining Company (FMC), a wholly owned subsidiary of the Kennecott Corporation, operated a 32 acre open pit copper sulfide mine at the site between 1993 and 1997. The pit was completely backfilled with waste rock amended with limestone by 1998 and surface reclamation activities continued until 2001.

Surface water monitoring conducted by FMC between 2002 and 2009 showed that Stream C and its contributing drainageways contained copper and zinc concentrations that frequently exceeded acute toxicity criteria (ATC). Stream C is an intermittent stream that drains the southeast corner of the Flambeau mine site including the area known as the Industrial Outlot. This area contained the ore storage, ore crushing, and transport facilities as well as the wastewater treatment and administrative buildings during the period of active mine operation.

The Wisconsin Department of Natural Resources (DNR) conducted water quality monitoring of Stream C and other nearby waters during 2010 and 2011 to better assess these water quality concerns. The monitoring effort included surface water, sediment, and macroinvertebrate sampling, and fish surveys. Surface water, soil, and sediment data collected by FMC was also reviewed and assessed. Potential sources of copper and zinc were examined based on sampling data evaluation, site observations, FMC reports, and other references.

The monitoring was intended to provide additional data to help determine whether Stream C should be added to DNR's 303d list of impaired waters. Impaired waters do not meet Wisconsin's water quality standards and are subsequently targeted for corrective actions. Specific conclusions and recommendations for corrective actions are not included as part of this assessment, but will be developed elsewhere. This assessment will also be used as a basis for developing future monitoring plans at the site.

METHODS

SURFACE WATER MONITORING

There were sixteen sites in the monitoring program (Figures 1 and 2), including:

- Nine sites on Stream C and its contributing drainageways. (BO-1, C8-2, MC3-3, CP-4, C1- 5, EB-6, SC-7, SEB-11, ED-14)
- Two sites on the Flambeau River, one above and one immediately below the mouth of stream C. (FA-8, FB-9)
- Two sites on other intermittent streams draining the Flambeau mine site (Streams A and B).(SA-13, SB-12)
- One site on an intermittent reference stream 2 ½ miles southwest of the Flambeau mine site. (RS-10)
- One site at a Highway 27 ditch not draining to Stream C. (ND-15), and

- One site at the mouth of Meadow Brook, a perennial stream just south of the Flambeau mine site. (MB-16)

Most sites were monitored on 3 separate dates when surface runoff was occurring. Sites at the mouths of Stream C and the reference stream were also monitored twice during baseflow conditions (no recent runoff). Some sites that were added part way through the monitoring period were monitored on less than 3 dates.

Monitoring included the following field and laboratory tests:

Field tests: temperature, dissolved oxygen, conductivity, and pH

Laboratory tests (first 2 sampling dates): arsenic, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, zinc, hardness, and sulfate.

Laboratory tests (remaining sampling dates): copper, zinc, iron, manganese, hardness, and sulfate.

Metals were tested for total recoverable concentrations. Metals samples were preserved with nitric acid in the field. All samples were kept iced and shipped to the Wisconsin State Lab of Hygiene for analysis.

Samples from Stream C and the reference stream collected on June 19, 2011 were also tested for acute and chronic toxicity and dissolved organic carbon.

Surface water and soil monitoring data collected by FMC was reviewed and evaluated.

Drainage area boundaries for surface water monitoring sites were estimated using USGS quad maps (10 feet contour intervals) as well as 2 feet contour interval topographic maps provided in FMC reports for many areas. Observations of culvert locations and direction of flow during runoff events were also used, and occasionally altered boundaries substantially.

SEDIMENT MONITORING

Sediment samples were collected from the biofilter pond (2 sites), Stream C (4 sites) and the reference stream (2 sites)(Figures 4 and 2). Samples from the biofilter pond were collected with a stainless steel Eckmann dredge. Samples from the streams were collected with a stainless steel trowel. Samples were kept iced and shipped to the Wisconsin State Lab of Hygiene for analysis. Sediment samples were tested for arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, zinc, % solids, % volatile solids, % clay, % silt, and % sand.

Sediment monitoring data collected by FMC was reviewed and compared to data collected by DNR.

FISH SURVEYS

Fish surveys were conducted at Stream C and the reference stream in the fall of 2010 and the spring of 2011. A backpack shocker was used and collection of all fish and crayfish observed was attempted. Fish and crayfish were identified to species, counted, and released. Stream C was surveyed from its mouth to Copper Park Lane. The reference stream was surveyed from its mouth to a point at which a defined channel ended and a grassy swale began.

The biofilter pond was also checked for the presence of fish. A 200 feet length of shoreline was shocked with a backpack shocker.

MACROINVERTEBRATE SAMPLING

Kick net samples of macroinvertebrates were collected in October of 2010 from the lower ends of Stream C and the reference stream, and from the Flambeau River (Figures 5 and 2). For the Flambeau River, two samples were collected upstream of the mouths of both Stream C and the reference stream. Two samples were also collected downstream of the mouths of both Stream C and the reference stream. Samples from Stream C and the reference stream were collected in riffle areas with mostly gravel substrate. Samples from the Flambeau River were collected in run areas with mixed cobble and gravel substrate.

Samples from the lower ends of Stream C and the reference stream were also collected in May of 2011 in riffle areas with mostly cobble substrate. All samples were preserved in 85% ethanol and were analyzed by the Aquatic Entomology Laboratory at the University of Wisconsin, Stevens Point.

RESULTS AND DISCUSSION

WATERSHED AND MONITORING SITE CHARACTERISTICS

Stream C Watershed Area Characteristics and Surface Water Sampling Sites

The Stream C watershed is shown in Figure 1. The total watershed is the composite of the areas enclosed by yellow lines. Drainage areas for individual DNR sampling sites contributing to Stream C are also enclosed by yellow lines. Drainage areas for two DNR sampling sites (C1-5 and SC-7) are composites of all upstream drainage areas.

The largest drainage areas upstream of the Flambeau mine site are those for sites ED-14 and MC3-3 (52.5 acres and 42.9 acres respectively). The two areas are generally separated by the rail spur (Figure 4) for the mine, although a small area of drainage on the north side of the rail spur drains to MC3-3. These two areas are mostly undeveloped woods and wetlands, with some influence from the rail spur, one residence, Highway 27 (Figure 4) runoff, Jensen Road runoff, and a graveled access road between Jensen Road and the rail spur.

The next downstream site contributing drainage to Stream C is C8-2, which drains an area of 9.7 acres. The area is mix of woods, grassland, and wetland. It is also influenced by Highway 27 runoff and includes an area that was once disturbed by mining activities.

Sampling site BO-1 is the outflow of the biofilter pond. It receives drainage from the Industrial Outlot area (Figure 4) west of Stream C, an area of 23.1 acres. The area contains three buildings, a water storage structure, a large paved parking area, the equestrian trailhead and parking area, the biofilter pond, and grassland areas. A number of actions have been taken by FMC in this area to reduce copper and zinc concentrations in runoff entering the biofilter pond. Past actions include removal of soil from previously unpaved parking areas, capping of these areas with asphalt, replacement of drainage ditch soils, removal of rail spur ballast, and capping of the rail spur with topsoil (further described in results and discussion section).

Sampling site CP-4 drains a 1.5 acre area which is mostly grassland, and is influenced by Copper Park Lane (Figure 4) runoff and a very short section of Highway 27 runoff.

Sampling site C1-5 is located on Stream C shortly below Copper Park Lane. It receives drainage from all the upstream drainage areas as well as runoff from the north side of Copper Park Lane, west of Stream C, and runoff from the south side of Copper Park Lane, east of Stream C.

Sampling site SEB-11 drains a small wooded area of about 2.1 acres and appears to be influenced by residential wastewater.

Sampling site EB-6's drainage area (38.3 acres) straddles Highway 27 and is a mix of woods, wetlands, residential areas, and business areas. It is also influenced by runoff from Highway 27 and Jensen Road.

Sampling site SC-7 is at the mouth of Stream C and is influenced by all upstream land uses. The total area of the Stream C watershed is 220 acres.

Other Surface Water Sampling Sites and Their Drainage Areas

Sampling site FA-8 is along the east bank of the Flambeau River shortly above the mouth of Stream C.

Sampling site FB-9 is along the east bank of the Flambeau River just below the mouth of Stream C and is within the mixing zone of Stream C water with Flambeau River water.

Sampling site RS-10 is located near the mouth of an unnamed intermittent stream located 2 ½ miles southwest of the Flambeau Mine site (Figure 2). This unnamed stream also discharges to the Flambeau River and has been used as a reference stream for comparison to Stream C. The stream has a watershed of 250 acres, which is just slightly larger than the Stream C watershed. Land use is a mix of woods, pasture, cropland, wetland, and a farm residence with a barn.

Sampling site SB-12 is located near the mouth of Stream B that drains the central area of the reclaimed mine site including most of the area underlain by the former mine pit. The 95.7 acre drainage area (Figure 3) is mostly grassland with some wetland.

Sampling site SA-13 is located near the mouth of Stream A that drains the north side of the reclaimed mine site, as well as an area east of Highway 27. The 152 acre drainage area (Figure 3) is a mixture of woodland, wetland, and grassland. It receives some runoff from Highway 27.

Sampling site ND-15 drains a 4.4 acre area on the west side of Highway 27. Drainage from the area flows northward to the Flambeau River. The area is mostly residential and receives runoff from Highway 27.

Sampling site MB-16 is located near the mouth of Meadow Brook, which is a perennial stream. It has a watershed of 7.7 mi^2 that contains a mix of agricultural land, woodland, and wetland. Some residential and industrial areas are also present.

FMC Surface Water Sampling Sites

Primary surface water sites monitored by FMC between 2002 and 2011 are shown in Figure 3. FMC sites that are comparable to DNR sites are indicated in the Figure. Appendix 2 contains data collected by FMC from the sites shown in Figure 3. FMC also collected samples from a variety of other surface water monitoring sites between 2002 and 2011. Data from these sites was reviewed and is mentioned in later discussion, but is not otherwise presented in this report.

SURFACE WATER QUALITY

General Water Quality Conditions

Surface water quality data collected by DNR and much of the data collected by FMC is contained in Appendices 1 and 2. Table 1 lists mean concentrations for various water quality parameters. Mean pH values for monitoring sites within the Stream C watershed ranged from 5.4 to 6.95, with a combined mean of 6.4. Dissolved oxygen (D.O.) concentrations were > 5 mg/l at all sites on most dates (Appendix 1). June 19, 2011 monitoring showed D.O. concentrations < 5 mg/l at six of the eight sites measured in the Stream C watershed. D.O. concentrations were as low as 1.3 mg/l. Highway 27 ditch samples had the lowest D.O. concentrations. Warmer temperatures in June would increase rates of organic matter decomposition in wetland areas, resulting in lower D.O. concentrations.

For the DNR samples (Appendix 1) metal concentrations other than copper and zinc did not approach acute or chronic toxicity criteria at any of the monitoring sites, except for a single sample from the west ditch of Highway 27 (site C8-2) that had a lead concentration of 5.3 ug/l. The hardness for that sample was too low to allow determination of the chronic or acute toxicity criteria.

Acute Toxicity Criteria for Copper and Zinc

Acute toxicity criteria (ATC) are protective standards for Wisconsin surface waters. They are based on laboratory testing of a variety of diverse aquatic organisms. Copper and zinc ATC's are the maximum daily concentrations which ensure adequate protection of sensitive species of aquatic life from acute toxicity and will adequately protect the designated fish and aquatic life uses of the surface water if not exceeded more than once every three years (Wisconsin Administrative Code 2000). Copper and zinc ATC's are influenced by water hardness, since these metals are more toxic in soft water than in hard water. Formulas are applied to determine copper and zinc ATC's based on the hardness measured in the water sample.

Water hardness in the Flambeau mine area is very low and generally ranges from 10 – 50 mg/l (as $CaCO_3$). This results in very low values for copper and zinc ATC's. Copper ATC's can be as low as 3 ug/l and zinc ATC's can be as low as 18 ug/l.

ATC's for copper and zinc are based on total recoverable concentrations. Total recoverable metal concentrations include both dissolved forms and most forms attached to particulate matter. Thirty-three surface water samples collected by FMC during 2008 were tested for both total recoverable and dissolved copper (Foth 2008). On average, total recoverable and dissolved copper concentrations were very similar. Runoff water at most sites is relatively clear, indicating suspended solids (particulate) concentrations are low. Much of the copper may be attached to dissolved organic matter which would keep it in a dissolved form.

ATC's for copper and zinc were frequently exceeded in many surface water samples from the Stream C watershed (Appendix 2). For sampling site C1-5 (FMC SW-C1), located on Stream C just below Copper Park Lane, zinc ATC's were exceeded on all 13 sampling dates between 2002 and 2011. Copper ATC's were exceeded on 12 of the 13 dates, with the sample from one date having a hardness level too low to allow determination of the copper ATC.

Copper

Mining Activities as a Copper Source

The Flambeau Mine was the first copper sulfide mine to be permitted under Wisconsin's current mining statures. Ore shipment began in spring of 1993 and continued until August 1997. During the life of the mine, over 1.8 million tons of ore were shipped off site producing 181,000 tons of copper, 334,000 ounces of gold and 3.3 million ounces of silver (NRPC 2005).

A review of FMC reports to DNR, and other Flambeau mine related documents, suggests several mining activities that could have resulted in the dispersal of copper-bearing ore throughout adjacent areas during the period the mine was in operation. Mining activities such as blasting, bulldozing, truck loading and unloading, ore crushing (up to 250 tons per hour) and rail car loading (State of Wisconsin 1991) could have generated quantities of fine dust that could have been transported by the wind and deposited on nearby areas. Some losses of fine particulate ore and ore oxidation products from rail car spillage on the rail spur (FMC 2004) are also likely. Although the Industrial Outlot included a truck washing station, inadvertent tracking of copper rich soil by vehicles onto roadways is another way copper could have been transported to nearby areas.

During reclamation of the mine site most of the disturbed areas, including the pit and soil stockpiles, were re-capped with native topsoil. However, the 32 acre Iindustrial Outlot at the southeast corner of the mine site (Figure 4) was not re-capped with topsoil to allow the buildings and infrastructure to be put to other uses. The Industrial Outlot contained, or was adjacent to an ore crusher, an ore stockpile area, a rail spur where ore was loaded into rail cars, a vehicle washing area, and runoff ponds. The rail spur (Figure 4) extended east of Highway 27, so ore-laden rail cars were also present there at times.

Surface Water Copper Concentrations

Table 2 compares copper and zinc concentrations found at 22 surface water monitoring sites. The sites have been arranged by increasing mean copper concentrations. The lowest mean copper concentrations (<5 ug/l) were found in:

- the Flambeau River above Stream C,
- the Flambeau River below Stream C,
- a reference stream located 2 ½ miles southwest of Stream C,
- Stream A and Stream B which drain portions of the former mine site, and
- Meadow Brook, a perennial stream located just south of the mine site.

Mean copper concentrations < 5 ug/l appear to be representative of local background conditions for streams not significantly influenced by localized copper sources. Nearly all of Stream B's watershed and portions of Stream A's watershed are underlain by areas of formerly active mining activities, including the former mine pit. These areas were re-capped with native topsoil following mine closure, which appears to have been effective at minimizing copper concentrations in runoff from those watersheds.

Pre-mining copper concentrations were measured for the Flambeau River and the data does not indicate any significant change in copper concentrations in the Flambeau River due to mining activities (FMC 2012). The dilutional capacity of the Flambeau River would make it difficult to detect copper additions that are not relatively substantial. The river has a mean flow of 1,834 ft^3/second (cfs) and a mean copper concentration of 1.5 ug/l. An inflow of 1 cfs with a copper concentration of 500 ug/l, for example, would only raise the River's copper concentration by 0.3 ug/l, which would probably not be a discernable increase.

Most remaining surface water monitoring sites with mean copper concentrations > 5 ug/l are influenced by former mining activities or by runoff from Highway 27. The biofilter inlet site (BFSW-C1) had the highest mean copper concentration (651 ug/l). This site receives drainage from much of the Industrial Outlot area, where several locations were found to have high soil copper concentrations. Remedial actions have greatly reduced copper concentrations at this site (see discussion below).

The two ditch sites on the north side of Copper Park Lane (SW-CP-02 and CP-4) had the second and third highest mean copper concentrations (162 and 144 ug/l). High soil copper concentrations were found in the drainage area for site SW-CP-02 and remedial actions were taken which reduced surface water copper concentrations there (see discussion below). No soil sampling or remedial actions have occurred in the drainage area for site CP-4. The high copper concentrations in surface water there suggests high soil copper concentrations may also be present.

Site SW-C8 / C8-2 along the west side of Highway 27 had the fourth highest mean copper concentration (92.8 ug/l). Drainage area characteristics and potential copper sources for the site are discussed in the "Trends in Copper Concentrations" section below.

Site SW-C1 / C1-5 on Stream C below Copper Park Lane had a mean copper concentration of 27.5 ug/l. This reflects a mix of drainage received from mine impacted areas and Highway 27, and natural background copper concentrations. Copper concentrations at this site regularly exceeded the acute toxicity criteria (ATC). Pre-mining copper concentrations were not determined for Stream C, so a direct comparison of pre-mining and post-mining copper concentrations in the stream is not possible.

Site SW-C6 / SC-7 at the mouth of Stream C had a mean copper concentration of 19.1 ug/l. The decline in Stream C copper concentration between Copper Park Lane and the mouth is due to dilution by inflowing water with lower copper concentrations in the lower section of the Stream C watershed. Copper concentrations still exceed ATC's in 90% of the samples collected at this site.

The Flambeau River below the mouth of Stream C (SW-3 / FB-9) had a slightly higher mean copper concentration (2.7 ug/l) than the Flambeau River above the mouth of Stream C (SW-2 / FA-8)(1.5 ug/l copper). The difference may not be statistically significant, but mixing Stream C water with a mean copper concentration of 19.1 ug/l and Flambeau River water with a mean copper concentration of 1.5 ug/l would be expected to produce a somewhat elevated copper concentration in a very small area of the Flambeau River. The copper concentrations in the Flambeau River below the mouth of Stream C are still quite low and did not exceed ATC's with the exception of an April 25, 2008 sample that had a copper concentration of 5.6 ug/l and an ATC of 5.1 ug/l (Appendix 2). Variability in sampling and lab testing probably makes this difference insignificant.

<u>Soil Copper Concentrations</u>

Soil samples collected in the Stream A and B watersheds by FMC in 2008 after mine reclamation were found to mostly have low copper concentrations. Five samples had copper concentrations ranging from 8 to 13 mg/kg (Foth 2008). Two samples which appear to be associated with trails had copper concentrations of 43 and 94 ug/l. Four samples from the general mine area that are unlikely to be influenced by mining activities had copper concentrations ranging from 12 to 17 mg/kg (S-RR-08, S-RR-09, S-L-01, S-GP-01) (Foth 2008). It appears that copper concentrations < 20 mg/kg are representative of local background conditions for soil.

Soil sampling by FMC in 2005 identified numerous areas with elevated soil copper concentrations in the Industrial Outlot area (Foth and Van Dyke 2006). The highest soil copper concentration reported was 2,900 mg/kg and was located at a former vehicle washing station. The high soil concentration reported at this location, suggests that vehicles at the mine site may have accumulated significant amounts of copper-laden dust or soil while the mine was in operation. Unwashed or incompletely washed vehicles leaving the mine site may have carried such material onto nearby roadways. Fourteen of the eighteen soil sample results reported from the Industrial Outlot in May, 2006 had copper concentrations > 100 mg/kg.

High soil copper concentrations were found in the ditch on the north side of Copper Park Lane, west of Stream C in 2008. Six samples had copper concentrations ranging from 82 to 890 mg/kg, with a mean of 239 mg/kg. Two samples collected on the south side of Copper Park Lane had copper concentrations of 79 and 83 mg/kg (Foth 2008). Soil samples results were not reported for the area east of Stream C along Copper Park Lane. Runoff water samples collected by DNR from the north ditch in that area had high copper concentrations (mean = 144 ug/l), suggesting soils in that area may also be high in copper.

High soil copper concentrations were also found in the finer soils (sand sized and finer) above and below the ballast material in the rail spur within the Industrial Outlot area (Foth 2003). Copper concentrations in those samples ranged from 40 to 3,400 mg/kg, with a mean of 386 mg/kg.

Soil sampling by FMC has also identified areas with elevated soil copper concentrations outside of the Industrial Outlot area. Five samples collected near the H and H building, a storage building for mine-related equipment, (Figure 4) had a mean copper concentration of 112 mg/kg (Foth 2008). Sampling locations were reportedly "placed where impacts due to vehicle traffic may be the largest." Samples collected along the first 200 feet of the rail spur east of Highway 27 had copper concentrations ranging from 28 to 120 mg/kg, with a mean of 59 mg/kg (FMC 2004). Samples were taken in the fine gravel underlying the coarse ballast, after the ballast was removed. Finer soil materials (silts and clays) will tend to hold more copper, so fine gravel samples may not reflect maximum copper concentrations in the rail spur bed there.

Surficial soil pH's at most sampling sites were slightly acidic, thereby potentially contributing to increased copper mobility in local surface water. Soils sampled along Highway 27 had a mean pH of 5.8 (Foth 2008). Soils sampled near the H and H building had a mean pH of 5.6. Soil sampled along the rail spur east of Highway 27 had a mean pH of 5.8 (FMC 2004). Soils sampled in the reclaimed mine area had a mean pH of 6.0. Two soil samples collected on the south side of Copper Park Lane had a mean pH of only 4.6 (Foth 2008), possibly due to sulfide deposition in this area. The finer soils (sand sized and finer) above and below the ballast material in the rail spur within the Industrial Outlot area had pH's as low as 2.5 (Foth 2003), almost certainly due to the oxidation of spilled sulfide ore. The pH range in those samples was

2.5 to 5.9, with a mean of 4.2. Only two soil samples collected on the north side of Copper Park Lane had pH's > 7, with a mean of 7.6 (Foth 2008).

Organic soil materials tend to contain more copper than mineral soil materials. At eight sites sampled along Highway 27 organic materials contained 59 to 783% (mean = 234%) of the copper in adjoining mineral material (Foth 2008).

Reductions in Runoff Water Copper Concentrations in Response to Remedial Actions

High soil copper concentrations are generally associated with high copper concentrations in runoff water. Remedial actions have been taken by FMC which removed or capped areas of high soil copper concentrations in the Industrial Outlot area. The surface water testing results indicate that these actions have been successful in reducing copper concentrations in runoff water.

In 2006, graveled parking areas in the Industrial Outlot identified by FMC as having elevated levels of copper were partially excavated and then overlain with geotextile fabric, four inches of crushed limestone, and three inches of asphalt pavement. The perimeter ditch around the parking area was also modified by removing existing surface soil, installing a geotextile fabric, and covering the surface with four to six inches of crushed limestone (Foth and Van Dyke 2006).

Copper concentrations in runoff from the remediated area, as represented by the biofilter pond inflow site (BFSW-C1) declined from a mean of 1,035 ug/l prior to the remedial actions to a mean of 48 ug/l after removal of the impacted soils. Biofilter pond outflow site (BFSW-C2) copper concentrations declined from a mean of 50 ug/l to a mean of 13 ug/l (Appendix 2). The biofilter pond appears to have generally provided good levels of copper capture, both before and after remedial actions in the drainage area. Prior to these remedial actions, inflowing copper concentrations were reduced from 88 to 97% (mean = 93)(1-(outflow conc./ inflow conc.) x 100). After the remedial actions, inflowing copper concentrations were reduced from 0 to 83% (mean = 60%). However, copper reduction estimates are based on one inflow sample and one outflow sample per sampling event. For some sampling events, inflow and outflow samples were collected on the same date. For others, outflow samples were collected one day later than inflow samples. Since inflowing water will pass slowly through the biofilter pond to the outlet, single inflow and outflow samples may not accurately reflect biofilter pond copper removal. Shortly after a rainfall, a portion of the outflow will probably be rain water that has fallen directly on the pond surface.

The biofilter pond has an impermeable geomembrane liner that does not allow water to infiltrate into the ground. The geomembrane liner and the overlying sediment in the pond are scheduled to be removed and the pond converted to an infiltration basin in spring of 2012 (Foth 2011). Drainage modifications were made and another infiltration pond was constructed at the west end of the Industrial Outlot in 2011 to better manage stormwater. These actions should further reduce copper inputs to Stream C from the biofilter pond's former drainage area.

In November 2008 the ditch on the north side of Copper Park Lane had six inches of soil removed and replaced due to elevated copper concentrations (FMC 2009). Subsequently, copper concentrations in runoff from the ditch declined from a mean of 255 ug/l to a mean of 68 ug/l (based on two pre-treatment and two post-treatment samples)(Appendix 2).

In an earlier remedial action, rails and ties were removed from the rail spur west of Highway 27 and 200 feet east of Highway 27 in 2003. Ballast material and some gravel found to contain elevated levels of copper were also removed from the rail spur prior to capping with six to twelve inches of topsoil and seeding in 2004 (FMC 2004). There is no suitable surface water monitoring point to allow assessment of impacts from this remedial action.

Highway 27 as a Copper Source

Highway runoff is known to be a source of copper (Bannerman et al. 1993). Car brake pads and other components contain copper which can be shed on highway surfaces.

Seventeen soil samples collected along Highway 27 had copper concentrations ranging from 10 to 85 mg/kg (mean = 28 mg/kg) (Foth 2008). Six surface water samples collected from Highway 27 drainage ditches at sites where the highway and roadside area runoff appears to be the primary water source had copper concentrations ranging from 20 to 35 ug/l (mean = 28 ug/l)(Foth and Van Dyke 2006). All but one sampling site in Ladysmith were within 1 mile of the mine site. Samples collected along County Trunk Highway G/P at Doughty Road (about 1 mile northeast of the mine site) had a soil copper concentration of 12 mg/kg and a surface water copper concentration of 8.9 ug/l (Foth 2008).

It is uncertain how much of the copper present along Highway 27 near the mine site is due to normal traffic sources and how much may be due to past mining activities. Deposition of dust generated during active mining is a potential source. Some tracking of mine site soil onto Highway 27 by vehicles is also likely to have occurred. Copper from tracked soil could then be washed onto the shoulders and into the ditches by rainfall runoff.

Other Potential Copper Sources: Wastewater

Household wastewater can contain significant copper concentrations, primarily due to corrosion of copper pipes and brass plumbing fixtures. There are several residential homes along Highway 27. One of the homes is located in the drainage area of site SEB-11 (Figure 1). Site SEB-11 had copper concentrations ranging from 6 to 15 ug/l which exceeded ATC values. This site appears to be influenced by household wastewater. The site had high conductivity (257 umhos/cm) on one date when all other sites did not. It had a high chloride concentration (67 mg/l) and a high fecal coliform concentration (550 per 100ml). It also sustained surface flows when similar small drainage areas were dry. A holding tank for wastewater is reportedly present at the rented residence (Murphy 2011), but the evidence strongly indicates that some of the wastewater is being discharged to surface drainage. The holding tank is probably leaking. Wastewater discharges to surface drainage from other residences in the area are also possible.

Trends in Copper Concentrations

Copper concentrations have declined over time at several monitoring sites (Appendix 2). Declines in copper concentrations at some of the surface water monitoring sites in the Stream C watershed are probably a response to remedial actions that reduced copper sources.

Declines in copper concentrations may also be occurring as copper in soil is gradually mobilized and transported through the surface water drainage system. Two surface water monitoring sites are located upgradient of any remedial actions and show significant trends of declining copper concentrations (SW-C8 (DNR C8-2), $R^2 = 0.59$, $p = 0.0005$; and SW-C3, $R^2 = 0.62$, $p = 0.001$)(Figure 6). This indicates that a past source, quite possibly mining activities, deposited copper in the drainage areas of these sites. It also suggests higher copper concentrations may have been present prior to 2004 when monitoring began at these sites. If the copper concentrations at these sites were due solely to naturally occurring background sources, one would expect the concentrations to remain fairly stable over time.

Site SW-C8 (DNR C8-2) has had surface water copper concentrations ranging from 9 to390 ug/l (Appendix 2). The site is located in the west ditch of Highway 27 (Figure 1). It drains an area of 9.7 acres that is a mix of woods, grassland, and wetland. It is also receives runoff from Highway 27 and includes an area that had exposed soil during mining activities (Type II stockpile). The potential for having received direct runoff from the former sulfide stockpile area is low since the area was lined with a geomembrane and all contact water was routed to the wastewater treatment facility. Deposition of windblown dust from the former stockpile, as well as vehicle tracked mine site soil washed from the highway by rainfall, are more likely potential sources. The H and H building (Figure 4) where elevated soil copper concentrations have been found, is at the north edge of the drainage area. Soil sample copper concentrations in the Highway 27 ditch in this area ranged from 14 to 180 mg/kg (Foth 2008). FMC has scheduled construction of an infiltration basin in spring 2012 that will capture and infiltrate the runoff from the SW-C8 drainage area (Foth 2011). This is likely to help reduce copper concentrations in Stream C.

Site SW-C3 (Figure 1) has had surface water copper concentrations ranging from 6 to18 ug/l (Appendix 2). The site is located on the north side of the rail spur (Figure 4), upgradient of the segment where ballast was removed. Losses of fine particulate ore and ore oxidation products from rail cars in this area could have been a potential copper source. Deposition of dust generated during active mining is a second potential source.

Zinc

Potential Sources of Zinc

Zinc content of the supergene enriched ore body was generally less than 0.05% and lead was rarely detectable (May and Dinkowitz 1996). Based on the removal of 1.8 million tons or ore, no more than approximately 900 tons of zinc were extracted during the life of the mine. Like copper, some of the zinc present may have been redistributed during mining activities by windblown dust, vehicle tracking of mine site soil, and losses of fine particulate ore and ore oxidation products from rail cars. The low zinc concentrations in the ore suggest such contributions would have been relatively minor.

There are also other potential sources of zinc in surface waters. Zinc is used to galvanize steel surfaces. Galvanized building materials, especially roofing materials are known to contribute zinc to stormwater runoff (Bannerman et al. 1993). Galvanized steel drainage culverts can also contribute zinc to surface waters. Most power line post hardware and support cables are galvanized. Some highway sign posts and most sign post hardware is galvanized. Chain link fences and fence posts are galvanized. White paint and some lubricants contain zinc. Car tires and some other vehicle parts contain zinc which is shed onto road surfaces, and can then be carried by runoff.

Stream Background Zinc Concentrations

Surface water zinc concentrations for all monitoring sites are shown in Appendix 2. Mean zinc concentrations are listed in Table 2.

Zinc concentrations in most area streams sampled are fairly low. Intermittent streams A and B, the intermittent reference stream, and two sites on the Flambeau River had mean zinc concentrations < 8 ug/l, which appear to be representative of local background conditions for streams not significantly influenced by localized zinc sources. Two samples collected from Meadow Brook had zinc concentrations of 12 and 67 ug/l, so some additional zinc sources may be present in that stream's watershed.

Soil Zinc Concentrations

Results of most soil tests made by FMC provided copper concentrations, but not zinc concentrations. Eight soil samples collected along Highway 27 were tested for zinc. They had higher zinc concentrations (mean = 171 mg/kg) than copper concentrations (mean = 28 mg/kg) (Foth and Van Dyke 2006). These sites may be influenced by highway pavement runoff, runoff from residential structures, and galvanized surfaces on culverts, power poles, and road signs. No soil samples collected by FMC were found that might be representative of background soil zinc concentrations.

Stream C Watershed Zinc Concentrations

Zinc concentrations in Stream C just below Copper Park Lane (SW-C1 / C1-5) (37 – 78 ug/l) exceeded ATC's on all 13 dates sampled between 2002 and 2011 (Appendix 2). The frequency of ATC exceedences from zinc are less than those from copper in the Stream C watershed. Monitoring sites in the Stream C watershed had zinc concentrations exceeding ATC's 46% of the time, on average. Copper concentrations exceeded ATC's 92% of the time, on average.

The severity of ATC exceedences from zinc are also less than those from copper in the Stream C watershed. At the site just below Copper Park Lane (SW-C1 /C1-5) zinc concentrations as a percent of ATC's ranged from 105 to 241% (mean = 183%). Copper concentrations as a percent of ATC's ranged from 264 to 1,516% (mean = 670%).

The monitoring site in the Stream C watershed with the highest mean zinc concentration (233 ug/l) is SW-C7 (Figure 3) is located on Stream C upstream of the biofilter pond outlet. One sample had a zinc concentration of 600 ug/l. Even without this sample, the mean zinc concentration is 111 ug/l. Corrosion of zinc in culverts might be contributing to the high concentrations at this site. The site is located shortly below two galvanized steel culverts that conduct Stream C under the rail spur. The two culverts are four feet in diameter and 165 feet long. The culvert surfaces below the waterline are rusted, indicating the zinc coating has been completely lost. Stream C is pooled below and into the lower ends of the culverts, creating a depositional area where corroded zinc might accumulate during low flows, and then be resuspended during high flows. The culverts are scheduled for removal in 2012 as part of the FMC's current stormwater management work plan (Foth 2011). Losses of ore material from rail cars on the rail spur may also have influenced this site, although the low zinc content of the ore suggests that the zinc contribution from spillage would be relatively minor.

Site SW-C5, which is shortly below site SW-C7 and below the biofilter pond outlet, had a mean zinc concentration of 57 ug/l. The biofilter pond outlet (BFSW-C2 / BO-1) had a mean zinc concentration of 10 ug/l. Dilution of Stream C water with biofilter pond outlet water contributes to zinc concentration declines between SW-C7 and SW-C5. The Stream C course between these sites is wide and contains a dense stand of reed canary grass. Adsorption of zinc by organic matter in the channel, uptake by live grass, or entrapment of particulate bound zinc might also have an influence.

The biofilter pond inlet (BFSW-C1) had the second highest mean zinc concentration (99 ug/l) in the Stream C watershed. This mean is based on all samples collected, both before and after upgradient remedial actions were taken. Before remedial actions, zinc concentrations in biofilter pond inlet samples averaged 149 ug/l. After remedial actions, zinc concentrations averaged 28 ug/l. Zinc concentrations in biofilter pond inlet samples were 14 to 15% of copper concentrations, both before and after remedial actions.

Site CP-4 (Copper Park Lane north ditch, east of Stream C) had the third highest mean zinc concentration (95.3 ug/l) in the Stream C watershed. Tracking of mine site soil onto Copper Park Lane and deposition of dust during mining operations are possible sources for this zinc, but again, the low zinc content of the ore suggests it was a minor potential source. There is also one small galvanized steel culvert in the ditch and a galvanized chain link fence in the drainage area.

Correlation of mean copper and zinc concentrations at sites in the Stream C watershed is fairly low, with an R^2 of 0.27. This suggests copper and zinc sources are not uniform at the monitoring sites. Zinc sources unrelated to mining activities are probably more significant than copper sources unrelated to mining activities. Actions taken to reduce copper concentrations are likely to also reduce zinc concentrations in some, but possibly not all locations. Remedial actions taken upgradient of the biofilter pond did reduce both copper and zinc concentrations. Remedial actions there reduced copper concentrations by 95% and zinc concentrations by 81%.

Trends in Zinc Concentrations

Like copper, declines in zinc concentrations over time at some of the surface water monitoring sites in the Stream C watershed are probably a response to remedial actions that reduced zinc sources. Declines in zinc concentrations may also occur as zinc is gradually mobilized and transported through surface water drainage. Two surface water monitoring sites are located upgradient of any remedial actions and show significant trends of declining zinc concentrations (SW-C8 (DNR C8-2), $R^2 = 0.33$, $p = 0.012$; and SW-C3, $R^2 = 0.34$, $p = 0.046$)(Figure 7). This indicates that a past source, possibly associated with past mining activities, could have deposited zinc in the drainage areas for these sites. It also suggests higher zinc concentrations may have been present prior to 2004 when monitoring began at these sites. If the zinc concentrations at these sites were due solely to naturally occurring background sources, one would expect the concentrations to remain fairly stable over time.

Rates of concentration decline and R^2 values are lower for zinc than for copper. Less enrichment of zinc than copper, and the presence of more zinc sources not related to mining activity may account for this. Slower mobilization of deposited zinc is another possibility.

Site SW-C8 has had surface water zinc concentrations ranging from 15 to100 ug/l. Site SW-C3 has had surface water zinc concentrations ranging from 6.4 to 56 ug/l (one outlier removed). Potential mine related zinc sources are the same as those identified for copper at these sites.

Acute and Chronic Toxicity Test Results

There was no significant acute or chronic toxicity found in the June 19, 2011 samples collected from Stream C and the reference stream. The acute toxicity test exposed 10 day old fathead minnows (*Pimephales promlas*) and water fleas (*Ceriodaphnia dubia*) to stream water and lab control water for 48 to 96 hours. No significant mortality was found.

The chronic toxicity test observes fathead minnow growth and survival, and water flea reproduction and survival over about 7 days. None of these measures showed any significant chronic toxicity effects. The chronic toxicity test also measures the growth of an algae (*Selenastrum capricornutum*) over the same time period. Algae growth in the Stream C water was significantly lower (20% reduction) than in the lab control water. However, standard testing protocols require a growth reduction of greater than 50% before chronic toxicity is verified.

The June 19, 2011 sample from Stream C had a copper concentration of 23 ug/l that was 4.1 times higher than the ATC. It had a zinc concentration of 41 ug/l that was 1.05 times higher than the ATC. The lack of observed toxicity in the lab indicates other factors have influence. Copper toxicity is known to be reduced by the presence of dissolved organic matter (Erickson et al. 1996, De Schamphelaere et al. 2004). Copper will attach to dissolved organic matter, which reduces its availability for uptake by aquatic organisms. The Stream C sample had a moderately high dissolved organic carbon (DOC) concentration (11 mg/l), which is an indicator of dissolved organic matter. Wetlands in the Stream C watershed are probably the main source of the DOC. For comparison, the reference stream, with less wetland influence had a DOC concentration of 3.3 mg/l. The degree to which dissolved organic matter reduces copper toxicity varies with the type of dissolved organic matter that is present. Site specific information is generally needed to quantify this effect.

Further testing would be needed to reach more definitive conclusions regarding the biological effects of the observed concentrations of copper and zinc. In the tests conducted on the June 19, 2011 samples only two to three organisms were tested using water from a single point in time. ATC's are based on a broader and varied group of aquatic organisms and are meant to be protective of a full range of aquatic life thoughout their life cycles. For example, the water flea, *Ceriodaphnia dubia*, used in the lab tests is 10 times more tolerant of copper than another water flea, *Daphnia magna* (Johnson, et al. 2008) Some fish species are present in Stream C, but it is unknown if they can successfully reproduce. Fish eggs or newly hatched larval fish may be more sensitive to copper and zinc concentrations than adults.

SEDIMENT MONITORING RESULTS

DNR sediment monitoring results are listed in Table 3. Site locations are shown in Figures 4 and 2. Metal concentrations in sediment can be assessed using consensus-based sediment quality guidelines (DNR 2003). Threshold effect concentrations (TEC's) are sediment metal concentrations, below which toxicity to benthic dwelling organisms is unlikely. Probable effect concentrations (PEC's) are sediment metal concentrations, above which toxicity to benthic dwelling organisms is probable.

Metals concentrations were highest in the biofilter pond sediments. Only cadmium and lead concentrations were less than TEC's. Arsenic, chromium, iron, manganese, mercury, nickel, and zinc concentrations were above TEC's, but less than PEC's, suggesting marginal levels of toxicity from these metals may be occurring. Copper concentrations were 10 to 16 times higher than the PEC (up to 2,450 mg/kg), indicating toxicity to benthic organisms from copper is highly likely. Biofilter pond sediment samples collected by FMC showed similar levels of metals, with sediment furthest from the inlet tending to have lower levels (Foth and Van Dyke 2006, Foth 2008). Biofilter pond sediments are scheduled to be removed and placed in a landfill in spring of 2012 (Foth 2011).

Stream sediment samples from Stream C and the reference stream had concentrations of nearly all metals less than TEC's. Only manganese concentrations exceeded TEC's at two sites on Stream

C. None of the stream sediment samples collected by DNR had metals concentrations exceeding PEC's.

Sediment samples collected from Stream C were similar to samples collected from the reference stream except for copper and zinc concentrations. Copper concentrations in Stream C sediment (mean = 13.7 mg/kg) were 2.5 times higher than in the reference stream sediment (mean = 5.4 mg/kg). Zinc concentrations in Stream C sediment (49 mg/kg) were 1.8 times higher than the reference stream sediment (27 mg/kg).

One of two Stream C sediment samples collected by FMC had higher metal concentrations than found in samples collected by DNR (Foth 2008). The sampling site was just below Copper Park Lane. The stream bed was dry at the time of sample collection. The copper concentration was 180 mg/kg, which exceeds the PEC. The zinc concentration was 320 mg/kg, which exceeds the TEC, but is below the PEC. Since the stream was dry, the sample may have contained finer-grained or organically enriched material deposited during an earlier period of declining stream flow. These materials tend to have higher copper and zinc concentrations. Close proximity to Copper Park Lane where high soil concentrations of copper and zinc have been found may also be a factor.

FMC also collected six sediment samples from the constructed wetland pond near the mouth of Stream B (Foth 2008). Copper concentrations ranged from 28 to 71 mg/kg (mean = 44 mg/kg). Zinc concentrations ranged from 51 to 69 mg/kg (mean = 60 mg/kg). Five of the six samples exceeded the copper TEC, but all were below the copper PEC. All zinc samples were below the zinc TEC.

FISH SURVEY RESULTS

Fish survey results are summarized in Table 4. Comparisons of fish populations in the reference stream and Stream C are limited by physical differences between the streams. Both streams are intermittent and have similar watershed sizes, but the reference stream has a higher gradient, less meanders, and more cobble/boulder substrate. This results in the reference stream having a much smaller volume of water present in its channel. Total stream volume in the reference stream appeared to be only about 25% or less of stream volume in Stream C. The larger stream volume in Stream C gives it a greater potential to support fish.

Stream C had more fish species than the reference stream in both fall (6 and 3, respectively) and spring (6 and 4, respectively). The reference stream had more fish per 100 meters of stream length than Stream C in both fall (28 and 6, respectively) and spring (19 and 16, respectively). A larger percentage of the fish in Stream C than in the reference stream were species tolerant of low dissolved oxygen concentrations (42 – 65% in Stream C; 2 – 14% in the reference stream). Brook stickleback, central mudminnows, and fathead minnows are the low oxygen tolerant species present. Stream C is more influenced by wetland drainage that can result in low dissolved oxygen concentrations at times.

Brook sticklebacks full of eggs and creek chubs with spawning coloration were noted in Stream C, indicating these fish were prepared to spawn. The reference stream contained mostly juvenile fish and is probably not large enough to support much fish spawning.

Intermittent streams commonly support fish populations seasonally. A fish-based index of biotic integrity has been developed for intermittent streams in Wisconsin (Lyons 2006). Application of the index requires a fish population > 25 fish per 100 meters. Intermittent streams like Stream C and the reference stream, with watershed areas less than 1.5 mi^2, often do not support a population of this density.

Eleven fish were captured along 200 feet of shoreline in the biofilter pond near the outlet. Species captured were fathead minnows, central mudminnows, and a brook stickleback. The fish appeared to be in good condition.

MACROINVERTEBRATE SAMPLING RESULTS

A detailed report on the fall macroinvertebrate sample results was prepared by Jeff Dimick of the Aquatic Entomology Laboratory at the University of Wisconsin, Stevens Point.
The report is contained in Appendix 3. Biotic index values and number of species for samples is listed in Table 5.

The fall Stream C sample was dominated by chironomids (82%) and contained 27 species of macroinvertebrates. Several genera of chironomids found in Stream C are known to be tolerant to metals. The short life cycles of many chironomids allow them to survive in streams with intermittent flow. The riffle site sampled on Stream C was more subject to seasonal flow loss than the riffle site sampled on the reference stream.

The fall reference stream sample was dominated by isopods and amphipods (89%) and contained 13 species of macroinvertebrates. Isopods and amphipods are known to be especially sensitive to copper. Spring samples from the reference stream and Stream C both contained seventeen species of macroinvertebrates.

The macroinvertebrate index of biotic integrity (MIBI) is generally not sensitive to stream metals concentrations. In northern Wisconsin the MIBI reflects impairments to streams due to land use, bank erosion, embedded substrate, lack of buffer strips, and lack of habitat diversity. The Hilsenhoff biotic index is also generally not sensitive to stream metals concentrations. It responds primarily to organic pollution that results in lowered dissolved oxygen concentrations.

There were no indications of metals influence in the Flambeau River samples. Differences noted in these samples are probably mostly due to differences in fine sediment deposition and periphyton growth that caused shifts in the dominant mayfly species. Hilsenhoff biotic index (HBI) values were poorer below Stream C than above Stream C. Deposition of sediment below Stream C would be expected.

HBI values were better below the reference stream than above the reference stream. The Flambeau River sampling sites below the reference stream were more affected by scouring and had noticeably less fine sediment present than the sites above the reference stream. Further investigation would be needed to more definitively identify the reasons for the observed differences in the macroinvertebrate communities at the Flambeau River sites.

SUMMARY OF FINDINGS

- With the exception of Stream C, streams in the reclaimed areas of the Flambeau mine site (Stream A and B watersheds) exhibit low copper and zinc concentrations similar to a nearby reference stream (RS-10) uninfluenced by past mining activities.

- Monitoring of the Flambeau River before, during, and after mining activities has not shown any significant changes in copper and zinc concentrations. The Flambeau River has a very high dilutional capacity and fairly substantial inputs of copper and zinc would be needed to produce significant changes.

- The Stream C watershed includes the Industrial Outlot area at the southeast corner of the mine site, and a section of the rail spur used to transport ore. This area was not completely stripped of surface soils and revegetated as initially proposed in the Reclamation Plan, since the City of Ladysmith requested that the buildings and infrastructure be maintained and re-used.

- Surface water copper and zinc concentrations at multiple sites in the Stream C watershed exceed the acute toxicity criteria on a frequent basis.

- 1.8 million tons of ore containing approximately 181,000 tons of copper and no more than 900 tons of zinc were extracted from the mine. The copper sulfide ore was stored and loaded in the Industrial Outlot area and along the rail spur. Copper and zinc could potentially have been redistributed during mining activities in this area by wind transported dust, losses of fine particulate ore from rail car spillage, and tracking of copper rich soil and dust by vehicles.

- Soil sampling in the Industrial Outlot area and along the rail spur found multiple sites with elevated copper concentrations.

- Areas with elevated soil copper concentrations were generally correlated with elevated runoff water copper concentrations.

- Past remedial actions taken by FMC to remove or cap soils with elevated copper concentrations have been effective at reducing copper concentrations in runoff water. For the one remedial action where zinc data is available, zinc concentrations in runoff water were also reduced.

- Other potential sources of copper to Stream C include highway runoff and residential wastewater (in the case of one apparently leaking holding tank).

- The zinc content of the ore (0.05% or less) was much less than the approximate copper content (10.1%). Other potential sources of zinc include highway runoff and zinc galvanized surfaces on culverts, buildings, fences, signs and power line posts. White paint and some lubricants also contain zinc.

- At two sites in the Stream C watershed (SW-C3 and SW-C8) unaffected by any past remedial actions, copper and zinc concentrations show significant declining trends over time. This suggests that past deposition of copper and zinc occurred in the drainage areas for these sites, and that the metals are gradually being mobilized from the soils and transported by runoff. If the copper and zinc concentrations at these sites were due solely to naturally occurring background sources, one would expect the concentrations to remain fairly stable over time.

- FMC is currently pursuing additional remedial actions that are likely to result in noticeable reductions in copper and zinc concentrations in Stream C. In Fall of 2011 an infiltration basin was constructed at the west end of the Industrial Outlot and drainage modifications were made to divert more runoff to the basin. Actions scheduled for Spring 2012 include removal of the geomembrane liner and overlying sediment in the biofilter pond. The sediment will be landfilled and the biofilter pond will be converted to an infiltration basin. A third infiltration basin that captures the drainage from the SW-C8 drainage area will also be constructed. The remaining rail spur bed in the Industrial Outlot area will be removed along with the two large culverts currently passing beneath the rail spur bed.

- There was no significant acute or chronic toxicity found in the June 19, 2011 sample from Stream C. In the chronic toxicity test, algae growth was significantly lower (20% less) in the Stream C sample than in lab control water. However, standard testing protocols require a growth reduction of greater than 50% before toxicity is verified. Dissolved organic matter in Stream C may be reducing the toxicity of copper and zinc. Further testing would be needed to assess toxicity more fully and to determine the influence dissolved organic matter may be having.

- The most heavily contaminated sediment was found in the biofilter pond, with copper being the contaminant of greatest concern. Biofilter pond sediments are scheduled to be removed and placed in a landfill in Spring of 2012.

- Fall and spring fish surveys of Stream C found 6 species of fish present during each survey. Fish densities were lower in Stream C than in a reference stream, even though the volume of habitat in Stream C was considerably greater. About half of the fish present in Stream C were species that are tolerant of low dissolved oxygen concentrations. Wetland drainage in the Stream C watershed probably results in low dissolved oxygen concentrations at times.

- Macroinvertebrate samples from the Flambeau River showed no indications of metals influence. Stream C macroinvertebrate samples showed a good number of species present (17-27). Several genera of chironomids found in Stream C are known to be tolerant to metals.

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FIGURES

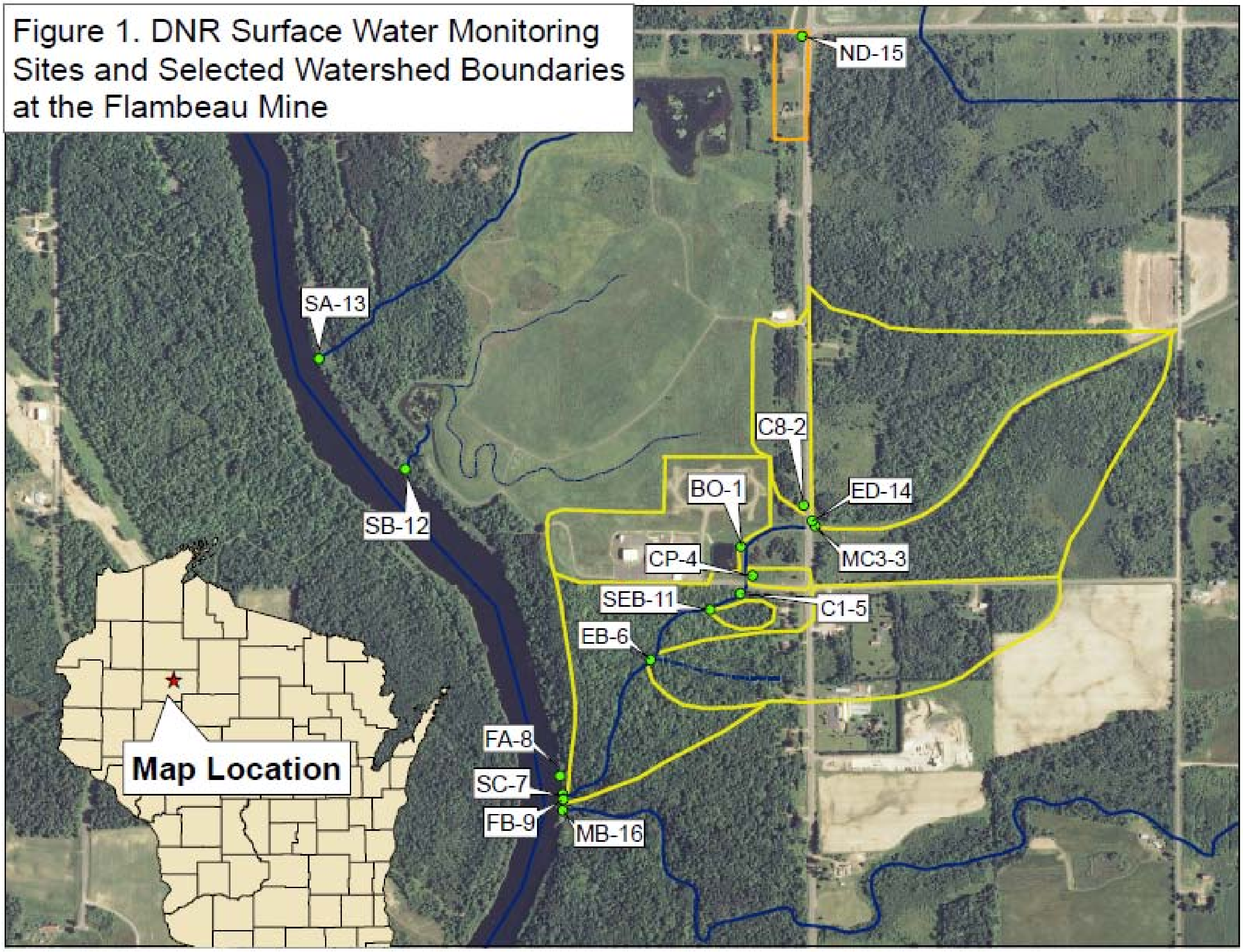


Figure 1. DNR Surface Water Monitoring Sites and Selected Watershed Boundaries at the Flambeau Mine
ND-15
SA-13
C8-2
ED-14
BO-1
SB-12
MC3-3
CP-4
SEB-11
C1-5
EB-6
FA-8
SC-7
FB-9
MB-16
Map Location

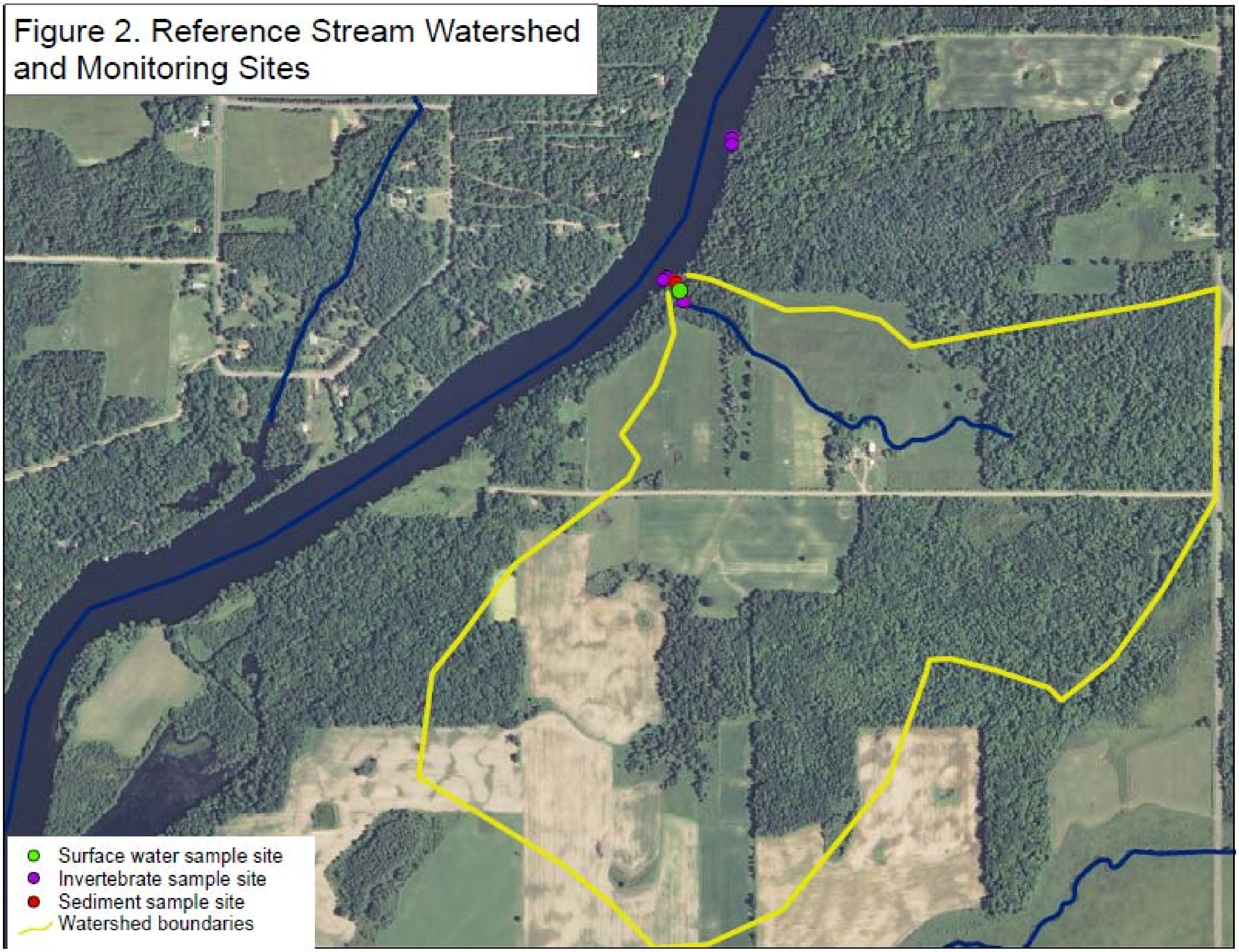


Figure 2. Reference Stream Watershed and Monitoring Sites
Surface water sample site
Invertebrate sample site
Sediment sample site
Watershed boundaries

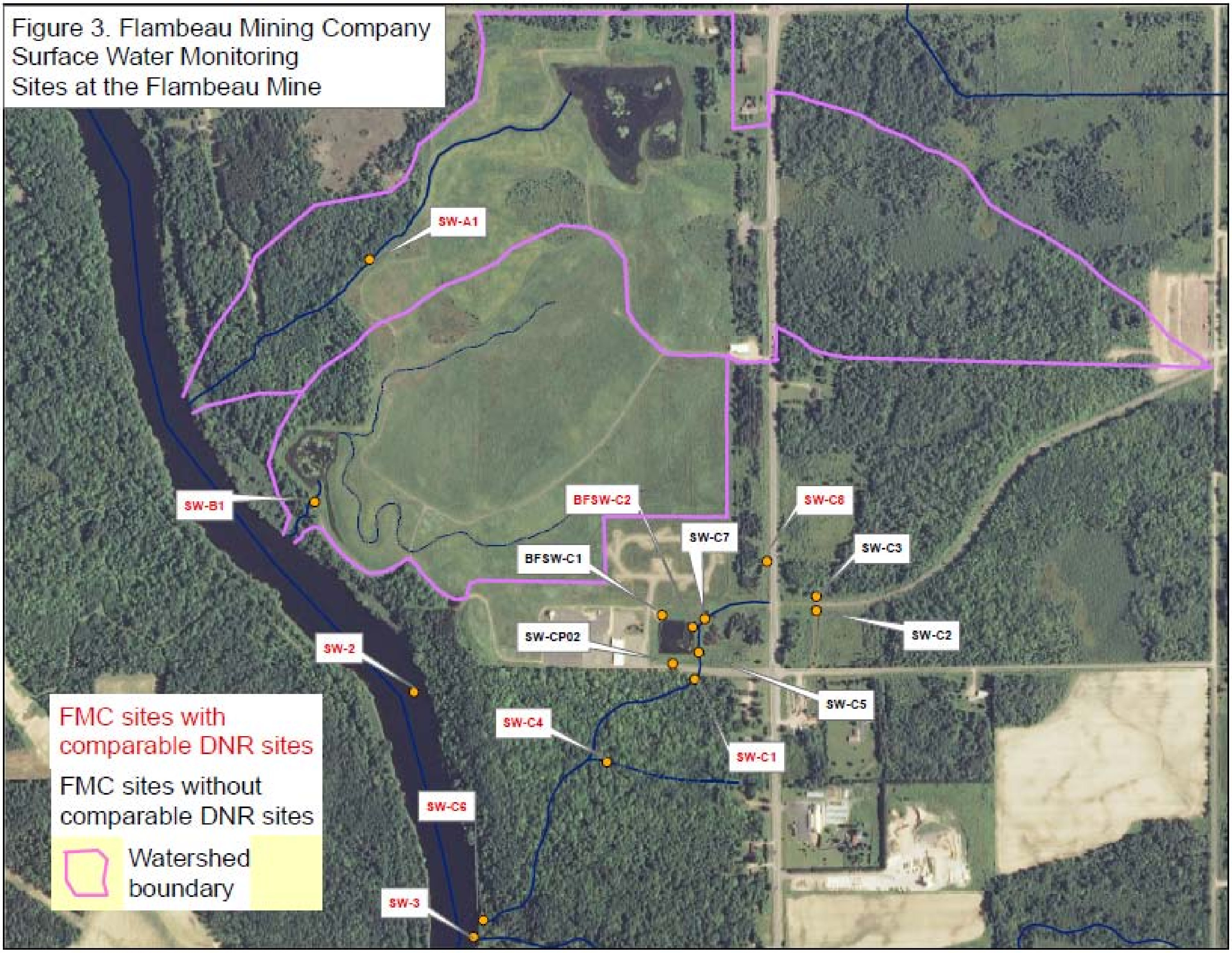


Figure 3. Flambeau Mining Company
Surface Water Monitoring
Sites at the Flambeau Mine
SW-A1
SW-B1
BFSW-C2
SW-C8
SW-C7
SW-C3
BFSW-C1
SW-CP02
SW-C2
SW-2
SW-C5
SW-C4
SW-C1
SW-C6
SW-3
FMC sites with
comparable DNR sites
FMC sites without
comparable DNR sites
Watershed
boundary

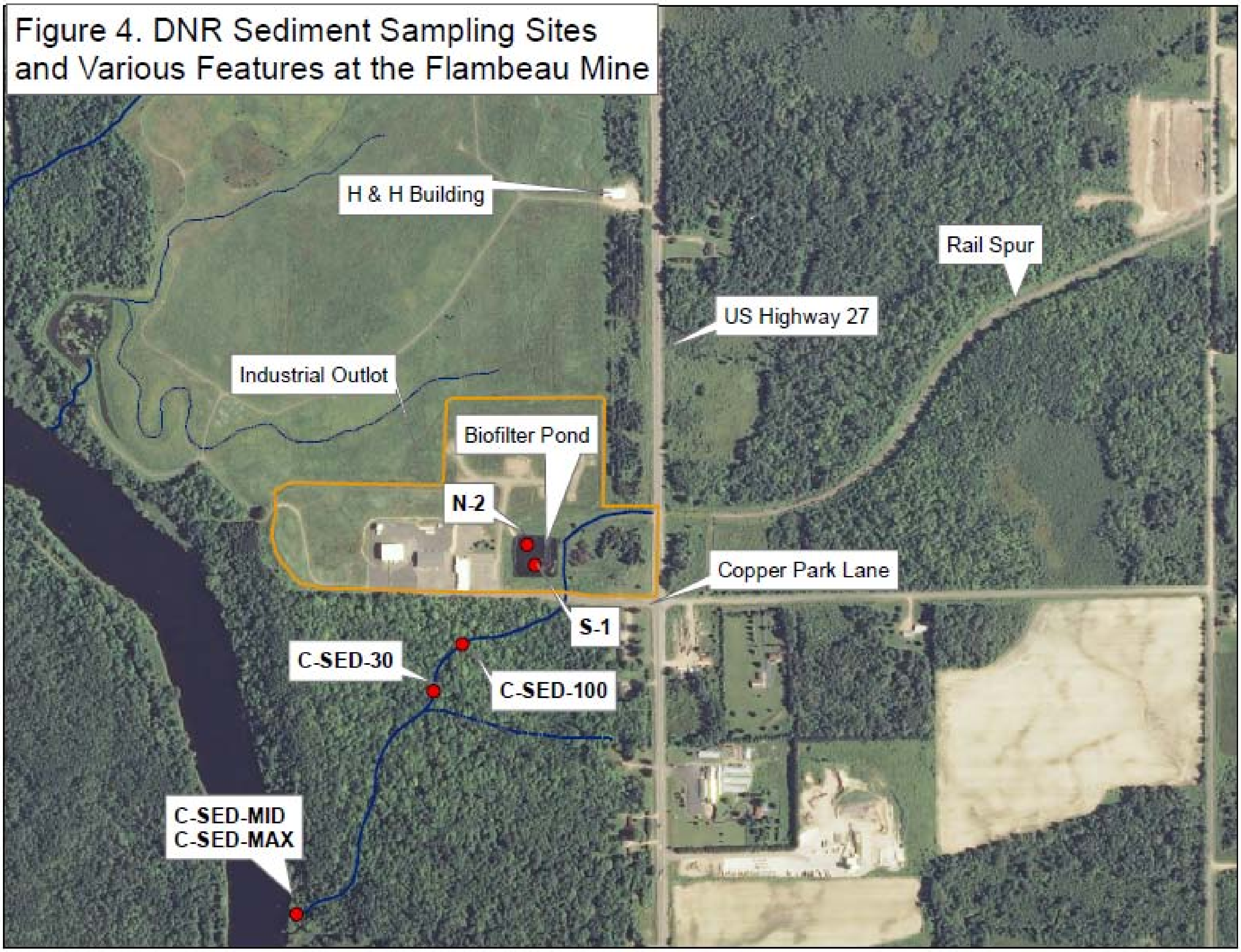


Figure 4. DNR Sediment Sampling Sites
and Various Features at the Flambeau Mine
H & H Building
Rail Spur
US Highway 27
Industrial Outlot
Biofilter Pond
N-2
Copper Park Lane
S-1
C-SED-30
C-SED-100
C-SED-MID
C-SED-MAX

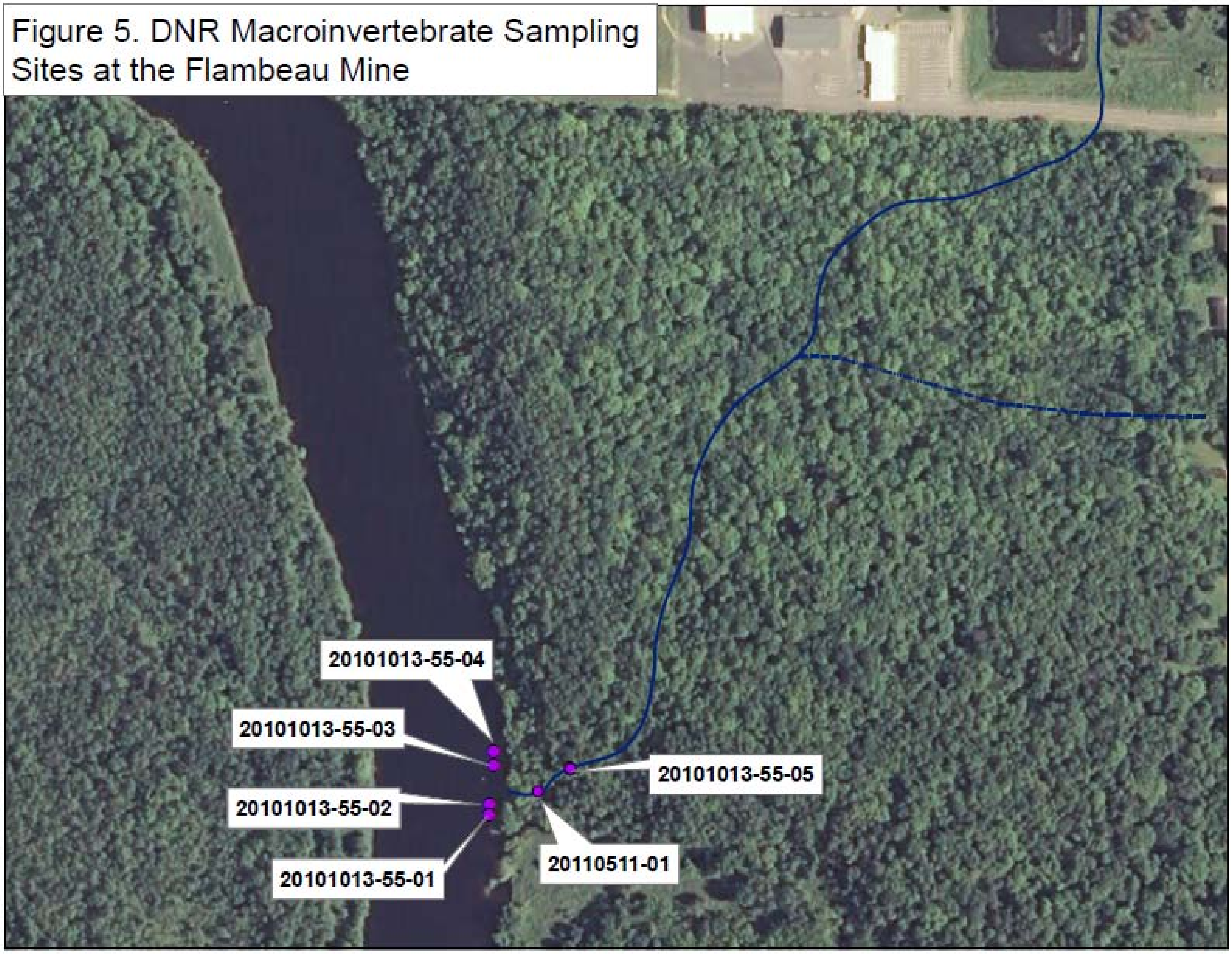
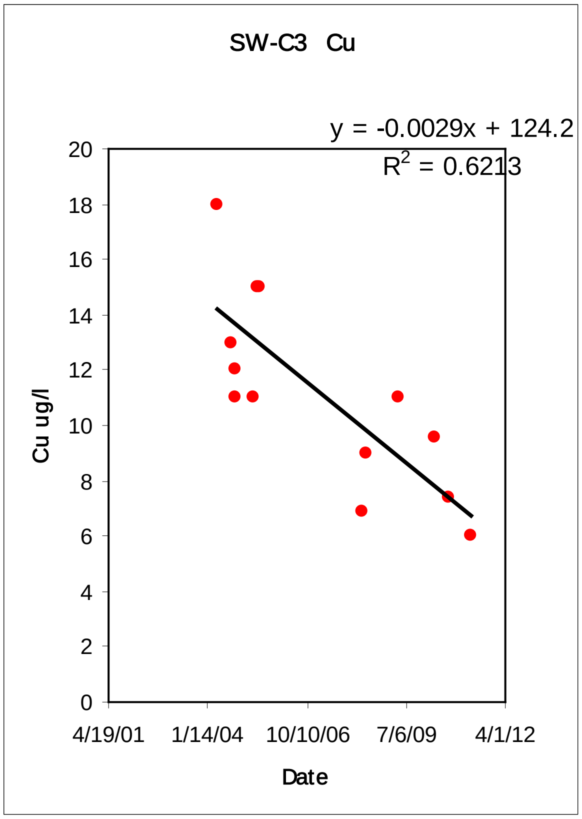


Figure 5. DNR Macroinvertebrate Sampling Sites at the Flambeau Mine

Figure 6. Copper Concentration Trends at Sites SW-C3 and SW-C8



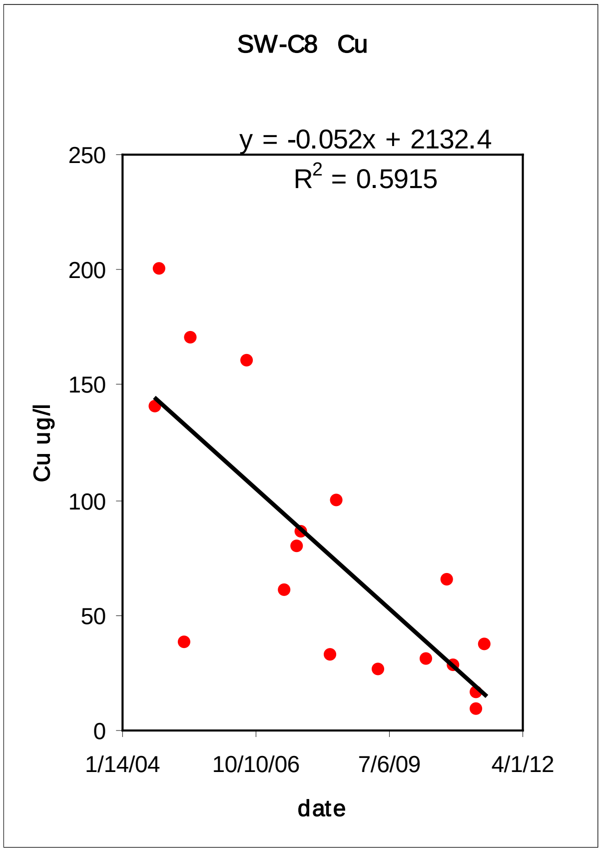
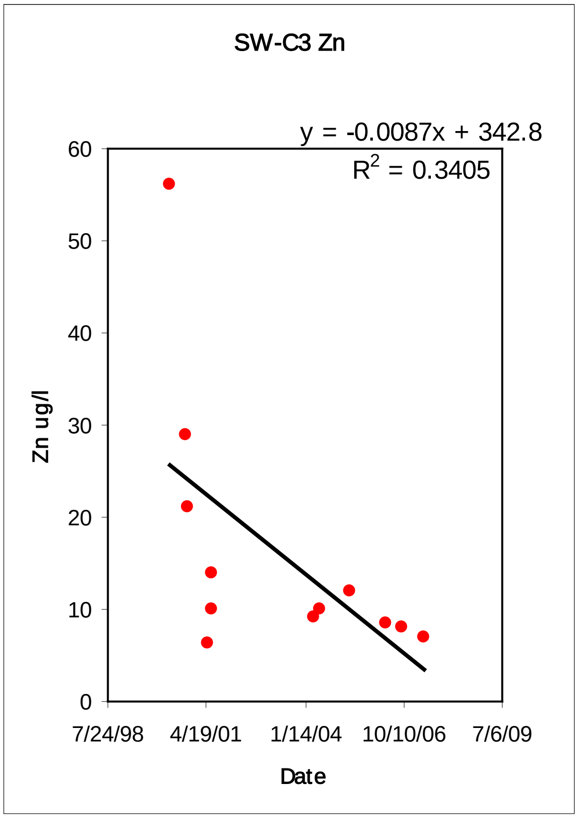
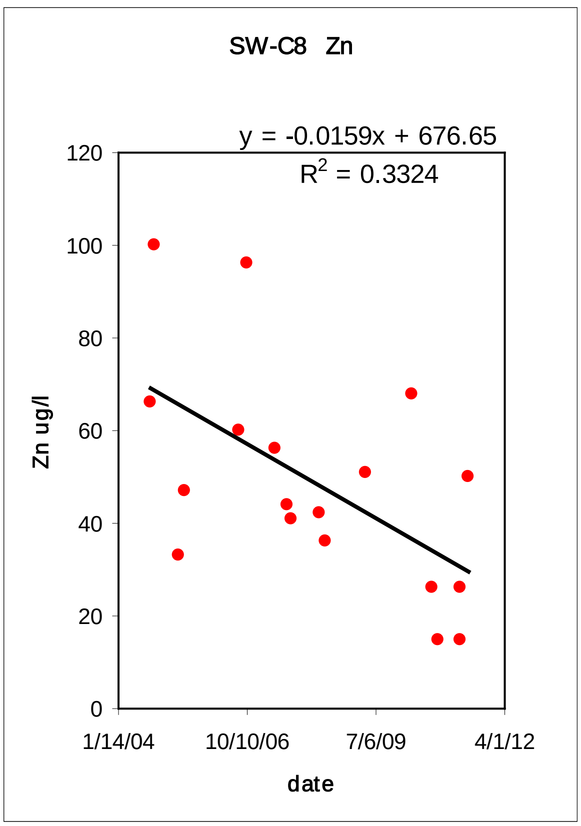


Figure 7. Zinc Concentration Trends at Sites SW-C3 and SW-C8





TABLES

TABLE 1. SURFACE WATER CONCENTRATION MEANS FOR THE FLAMBEAU MINE

Based on combined DNR and FMC data

***DNR monitoring site**

	Site mean values							
Stream C Watershed Sites	Copper ug/l	Zinc ug/l	Hardness mg/l CaCO3	Conductivity umhos/cm	Sulfate mg/l	Iron mg/l	Manganese ug/l	pH s.u.
SW-C3	11	27	16.8	45.9	7.7	0.93	134	6.6
SW-C2	12	47	10.6	29	2.5	0.19	11	6.2
MC3-3*	8	14	11.1	30.7	9.1	1.3	48	5.8
SW-C8 / C8-2*	93	48	20	356	7.2	1.77	153	6.4
SW-C7	26	233	25	128	9.6			6.7
BFSW-C1	651	99	51	220	38	0.32	168	6.7
BFSW-C2 / BO-1*	30	10	26	167	5.7	0.9	92	6.8
SW-C5	28	57	18.5	129	5.2	0.77	36	6.5
SW-CP-02	162	36	134	529	21	2.6	215	6.95
CP-4*	144	95	8	155	15.8	2.2	35	6.4
SW-C1/ C1-5*	27	52	19.7	123	6.7	1.2	62	6.6
SW-C4 / EB-6*	6.9	13	15.1	120	9	0.75	106	6.7
SW-C6 / SC-7*	19	34	36.5	142	9.4	1.42	101	6.6
SEB-11*	10	8.7	33.1	306	10.2	0.97	48	6.1
ED-14*	13	19	38.4	179	17.5	1.35	206	5.4
Stream C Watershed Site Means =	82.7	52.8	30.9	177.3	11.6	1.2	101.1	6.4
Other Sites								
SW-B1 / SB-12*	3	3.3	19.5	53	3.4	0.88	58	6.7
SW-A1 / SA-13*	2.7	4.8	25.5	72	6.1	0.75	43	6.8
SW-3 / FB-9*	2.7	7.3	42	108	7.2	0.88	93	7.2
SW-2 / FA-8*	1.5	4.6	40.5	98	6.6	0.64	76	7.3
RS-10*	2.2	6.4	42.7	90	8.3	1.24	110	6.5
ND-15*	20	32	9.6	158	11.6	1	63	5.6
MB-16*	4.6	40	56.2	119	10.1	1.33	250	7.3

TABLE 2. SUMMARIZED TOTAL RECOVERABLE COPPER AND ZINC CONCENTRATIONS FOR FLAMBEAU MINE SURFACE WATER MONITORING SITES

Arranged from lowest to highest mean copper concentrations

*DNR sites

**Concentrations below detection limits were assumed to be 1/2 of the detection limit for mean calculations

		Copper Concentrations (ug/l)			Zinc Concentrations (ug/l)		
Site	Description	Range	Mean**	No. of Samples	Range	Mean**	No. of Samples
SW-2 / FA-8*	Flambeau R. above Stream C	0.32 - 4	1.5	22	<2 - 8.8	4.6	22
RS-10*	Reference stream, 2 1/2 mi. SW of Stream C	<2 - 4	2.2	5	<3 - 13	6.4	5
SW-3 / FB-9*	Flambeau R. below Stream C	<1.3 - 5.6	2.7	10	<5 - 11	7.3	10
SW-A1 / SA-13*	Stream A at the Flambeau mine site	<1.3 - 5	2.7	7	<3 - 10	4.8	7
SW-B1 / SB-12*	Stream B at the Flambeau mine site	<1.3 - 5.9	3.0	9	<3 - 7.8	3.3	9
MB-16*	Meadow Brook	4.2 - 5	4.6	2	12 - 67	39.5	2
SW-C4 / EB-6*	East tributary to Stream C; enters below Copper Pk. Ln.	3.1 - 9	6.9	5	11 - 15	13	5
MC3-3*	Drainage from mostly S of rail spur, E of hwy. 27	2 - 15	8	3	11 - 17	14	3
SEB-11*	Smaller east tributary to Stream C; enters below Copper Pk. Ln.	6 - 15	10	3	6 - 11	8.7	3
SW-C2	Drainage along south side of rail spur	12 - 12	12	2	36 - 58	47	2
SW-C3	Drainage along north side of rail spur	6 - 18	12.4	13	6.4 - 160	27	13
ED-14*	Drainage from N of rail spur, east of hwy. 27	5 - 21	13	2	4 - 34	19	2
SW-C6 / SC-7*	Stream C near mouth	8 - 36	19.1	10	20 - 70	34	10
ND-15*	Hwy 27 ditch at Blackberry Ln	11 - 29	20	2	32 - 33	32.5	2
SW-C7	Stream C above biofilter outlet	14 - 41	25.8	4	38 - 600	233	4
SW-C1 / C1-5*	Stream C below Copper Pk Ln	9 - 77	27.5	13	37 - 78	52	13
SW-C5	Stream C below biofilter outlet, above Copper Pk. Ln.	9.1 - 74	28	19	32 - 100	57	19
BFSW-C2 / BO-1*	Biofilter outlet	4.8 - 67	30.2	19	<3 - 53	10	18
SW-C8 / C8-2*	Drainage along west side of hwy 27, just north of Stream C	9 - 390	92.8	18	15 - 100	48.4	18
CP-4*	Ditch along N side of Copper Pk Ln, east of Stream C	57 - 266	144	3	47 - 127	95.3	3
SW-CP-02	Ditch along N side of Copper Pk Ln, west of Stream C	56 - 340	162	4	31 - 41	36	2
BFSW-C1	Biofilter inlet	15 - 2000	651	18	4.7 - 365	99	17

TABLE 3. FLAMBEAU MINE DNR SEDIMENT SAMPLE DATA

BIOFILTRATION POND SEDIMENT DATA

		TEC/PEC's*:	9.8/33	0.99/5	43/110	32/150	20,000/40,000	36/130	460/1,100	0.18/1.1	23/49	120/460					
	SWIMS		arsenic	cadmium	chromium	copper	iron	lead	manganese	mercury	nickel	zinc	solids	solids	solids	solids	solids
Site	Sta. No.	Date	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	%	% volatile	%clay	%sand	%silt
S-1	10032169	12/22/2010	21	0.1	43.9	1,550	32,700	23	598	0.153	30	189	11.3	21.8	12	55	33
N-2	10032170	12/22/2010	25	< 0.1	46.5	2,450	33,400	26	487	0.186	33	186	27.9	12.3	17	41	42

Site	Latitude	Longitude	Description
S-1	45.43703	-91.11333	3 ft. water depth; 4.5 in. of dark brown fines with Nitella (an algae) at surface, underlain by 1.5 in. brown sandy layer, underlain by clayey layer
N-2	45.4372	-91.11337	5 ft. water depth; 4.5 in. of dark brown fines, unerlain by clayey layer

Samples were collected with stainless steel Eckmann dredge. Top 4 in. of sediment was sampled.

STREAM SEDIMENT DATA

		TEC/PEC's*:	9.8/33	0.99/5	43/110	32/150	20,000/40,000	36/130	460/1,100	0.18/1.1	23/49	120/460					
	SWIMS		arsenic	cadmium	chromium	copper	iron	lead	manganese	mercury	nickel	zinc	solids	solids	solids	solids	solids
Site	Sta. No.	Date	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	%	% volatile	%clay	%sand	%silt
CSED-MID	10031970	05/11/2011	3	<0.1	9.6	14.1	8630	6	419	0.018	6	50	66.9	3.1	0	90	10
CSED-MAX	10031970	05/11/2011	5	<0.1	10.2	10.5	15500	5	481	0.02	9	46	73.8	2.6	5	89	6
CSED -30	10033614	05/11/2011	4	<0.1	10.7	13.1	12400	5	225	<0.015	7	45	72.6	2.4	5	78	17
CSED-100	10033615	05/11/2011	3	<0.1	18.9	17	7770	4	483	<0.015	7	55	36.4	10.9	1	80	19
RSED-MID	10031973	05/11/2011	4	<0.1	8.4	5.1	11000	3	258	<0.015	6	24	71	1.9	3	94	3
RSED-MAX	10031973	05/11/2011	4	<0.1	9.3	5.7	13700	4	391	<0.015	7	30	53.1	5.3	5	89	6

Site	Latitude	Longitude	Description
CSED-MID	45.43235	-91.1178	10 m upstream of stream C mouth; 0.5 ft. water depth; medium brown sandy sediment, with some organic debris
CSED-MAX	45.43235	-91.1178	10 m upstream of stream C mouth; 1 ft. water depth; medium brown sandy sediment
CSED -30	45.43525	-91.11511	30 m upstream of horse bridge on stream C; 0.5 ft. water depth; medium brown sandy sediment

TABLE 3. FLAMBEAU MINE DNR SEDIMENT SAMPLE DATA (Cont.)

Site	Latitude	Longitude	Description
CSED-100	45.4358	-91.11533	100 m upstream of horse bridge on stream C; 0.8 ft. water depth; medium brown sandy sediment with decaying leaves
RSED-MID	45.42125	-91.16392	15 m upstream of reference stream mouth; 0.7 ft. water depth; medium brown sandy sediment
RSED-MAX	45.42125	-91.16392	16 m upstream of reference stream mouth; 1.2 ft. water depth; medium brown sandy sediment with some decaying leaves

Samples were collected with a stainless steel trowel. Top 0.2 ft. of sediment was sampled.

*TEC's are threshold effect concentrations at which toxicity to benthic dwelling organisms is unlikely.
PEC's are probable effect concentrations a which toxicity to benthic dwelling organisms is probable. (DNR, 2003)

TABLE 4. FLAMBEAU MINE FISH SURVEYS, 2010-2011

FLAMBEAU MINE STREAM C AND REFERENCE STREAM FISH SURVEY DATA, 09-27-2010

Single upstream pass with backpack shocker used.

Stream	Segment End Points	Segment length (m)	Number of fish	Number of rusty crayfish	No. fish per 100 m	No. crayfish per 100 m	No. of fish species
Stream C flow 0.26 cfs Temp 7.7C, D.O. 7.9 mg/l	mouth to Copper Park Lane culvert @ 45.43644 91.1127	912	57	7	6	0.8	6
Reference stream flow 0.21 cfs Temp 10.1C, D.O. 5.0 mg/l	30 m above mouth* to start of grass swale @ 45.4203 91.16227	165	46	6	28	3.6	3

*high water in Flambeau River prevented start at mouth

Stream C fish species	Number captured
brook stickleback	23
creek chub	18
central mudminnow	10
fathead minnow	4
pumpkinseed	1
yellow perch	1
Total	57

Reference stream fish species	Number captured
white sucker	23
creek chub	22
fathead minnow	1
Total	46

TABLE 4. FLAMBEAU MINE FISH SURVEYS, 2010-2011 (Cont.)

FLAMBEAU MINE STREAM C AND REFERENCE STREAM FISH SURVEY DATA, 05-06-2011

Single upstream pass with backpack shocker used.

Stream	Segment End Points	Segment length (m)	Number of fish	Number of rusty crayfish	No. fish per 100 m	No. crayfish per 100 m	No. of fish species
Stream C	mouth to Copper Park	912	146	1	16	0.1	6
flow 0.21 cfs	Lane culvert @						
Temp 6.7C, D.O. 11.8 mg/l	45.43644						
	91.1127						
Reference stream	mouth to	195	37	1	19	0.5	4
	start of grass swale						
flow 0.12 cfs	@						
Temp 13.2 C, D.O. 8.7 mg/l	45.4203						
	91.16227						

Stream C fish species	Number captured
creek chub	75
brook stickleback	32
fathead minnow	19
central mudminnow	11
white sucker	8
nothern red bellied dace	1
Total	146

Reference stream fish species	Number captured
creek chub	25
white sucker	7
fathead minnow	4
central mudminnow	1
Total	37

FLAMBEAU MINE BIOFILTER POND FISH SURVEY, 10-05-2010

Backpack shocker used along 200 ft. of shoreline at northeast corner of pond.
Abundant filamentous algae and cattails limited capture efficiency.

Fish species	Number captured	Lengths in inches			
fathead minnow	8	1.8, 1.3,	1.1, 1.2,	1.5, 1.6, 1.3,	1.3
central mudminnow	2	3.5, 3.3			
brook stickleback	1	1.2			

TABLE 5. FLAMBEAU MINE STREAM MACROINVERTEBRATE INDICES

SWIMS Station No.	Site Description	October 13, 2010 samples Macroinvertebrate IBI	Value Description	Hilsenhoff BI	Value Description	No. of Species
10032094	Flambeau R. 5m UST of stream C mouth	3.65	fair	2.60	excellent	14
10032095	Flambeau R. 10m UST of stream C mouth	4.69	fair	2.90	excellent	19
10032092	Flambeau R. 6m DST of stream C mouth	6.38	good	3.90	very good	22
10032093	Flambeau R. 10m DST of stream C mouth	8.01	excellent	3.57	very good	22
10032099	Flambeau R. 279m UST of ref. stream mouth	5.59	good	3.81	very good	15
10032100	Flambeau R. 278m UST of ref. stream mouth	6.20	good	3.73	very good	18
10032097	Flambeau R. 12m DST of ref. stream mouth	3.54	fair	2.40	excellent	21
10032098	Flambeau R. 16m DST of ref. stream mouth	3.84	fair	2.32	excellent	23
10032096	Stream C 70m UST of mouth	8.74	excellent	6.98	fairly poor	27
10032101	Ref. stream 33m UST of mouth	4.26	fair	7.45	fairly poor	13

		May 11, 2011 samples Macroinvertebrate IBI	Value Description	Hilsenhoff BI	Value Description	No. of Species
10031970	Stream C 35m UST of mouth	7.01	good	4.63	fair	17
10031973	Ref. stream 40m UST of mouth	1.17	poor	4.51	fair	17

TABLE 6. MACROINVERTEBRATE SAMPLING SITE DESCRIPTIONS FOR THE FLAMBEAU MINE

FIELD NO.	SITE DESCRIPTION	LATITUDE	LONGITUDE	SWIMS ID NO.	WBIC
20101013-55-01	Flambeau R. 10m downstream of stream C mouth	45.43236	91.11788	10032092	2225000
20101013-55-02	Flambeau R. 6m downstream of stream C mouth	45.43235	91.11787	10032093	2225000
20101013-55-03	Flambeau R. 5m upstream of stream C mouth	45.43246	91.11776	10032094	2225000
20101013-55-04	Flambeau R. 10m upstream of stream C mouth	45.43275	91.11784	10032095	2225000
20101013-55-05	Stream C 70m upstream of mouth	45.43245	91.11732	10032096	
20101013-55-06	Flambeau R. 12m downstream of reference stream mouth	45.42142	91.16415	10032097	2225000
20101013-55-07	Flambeau R. 16m downstream of reference stream mouth	45.42141	91.16415	10032098	2225000
20101013-55-08	Flambeau R. 279m upstream of reference stream mouth	45.42362	91.16265	10032099	2225000
20101013-55-09	Flambeau R. 278m upstream of reference stream mouth	45.42361	91.16265	10032100	2225000
20101013-55-10	Reference stream 33m upstream of mouth	45.42105	91.16393	10032101	5006202
20110511-55-01	Stream C 35m upstream of mouth	45.43242	91.11746	10031970	
20110511-55-02	Reference stream 40m upstream of mouth	45.42109	91.16393	10031973	5006202