Michigan Department of Environment, Great Lakes, and Energy
Water Resources Division

Two Total Maximum Daily Loads for Total Copper for the Owl Creek Watershed Keweenaw County, Michigan

INTRODUCTION

Section 303(d) of the federal Clean Water Act and the United States Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (Title 40 of the Code of Federal Regulations, Part 130) require states to develop Total Maximum Daily Loads (TMDL) for water bodies that are not meeting Water Quality Standards (WQS). The TMDL process establishes the allowable loadings of a pollutant to a water body based on the relationship between pollutant sources and in-stream water quality conditions. TMDLs provide a basis for determining the pollutant reduction necessary from point and/or nonpoint sources to restore and/or maintain water quality.

The purpose of this TMDL is to identify allowable levels of total copper that will result in the attainment of the applicable WQS in the Owl Creek watershed located in Keweenaw County, Michigan.

PROBLEM STATEMENT

For the Owl Creek watershed, the reaches identified in the 2020 Section 303(d) list (Goodwin, 2020) as not meeting the Other Indigenous Aquatic Life and Wildlife designated use due to total copper are as follows:

Water body name: Unnamed Tributary to Owl Creek
AUID: 040201030405-09
Impaired designated use: Other Indigenous Aquatic Life and Wildlife
Cause: Copper
Source: Mine Tailings
Size: **0.95** Miles
Location Description: Owl Creek Tributary from coordinates 47.442, -88.203 upstream to the end of the reach at coordinates 47.437, -88.196.
TMDL Year(s): 2022

Water body name: Owl Creek
AUID: 040201030405-10
Impaired designated use: Other Indigenous Aquatic Life and Wildlife
Cause: Copper
Source: Mine Tailings
Size: **1.68** Miles
Location Description: Owl Creek from coordinates 47.437, -88.199 upstream to Owl Lake.
TMDL Year(s): 2022

AUID stands for Assessment Unit Identifier. Michigan uses the National Hydrography Database coding scheme (1:24,000 resolution) to georeference water bodies when generating the Sections 305(b) and 303(d) lists. The 12-digit Hydrologic Unit Code (HUC) is used as a default when listing streams and rivers to facilitate record keeping and mapping. Each 12-digit HUC base assessment unit may be split into multiple assessment units if site-specific information supports a smaller assessment unit. These smaller assessment units are identified by a dash and number (i.e., -06) after the 12-digit HUC. An assessment unit may consist of all water bodies in a 12-digit HUC (as a maximum) or specific stream segments or lakes in a 12-digit HUC (Goodwin, 2020).

The Keweenaw Peninsula is in the northwestern portion of Michigan's Upper Peninsula and is known locally as "copper country" due to the extensive elemental, mass copper deposits ("native copper") throughout the area. By the late 1880s, mining operations deforested most of the Keweenaw Peninsula and numerous stamp mills were constructed in the headwaters of several Keweenaw Peninsula streams for processing copper ore. The byproduct of the stamp mills' rock crushing activities was a coarse, dark aggregate called stamp sand. Extensive copper stamp sand piles are found throughout the woods, along streambeds, and the Lake Superior shoreline (Figure 1). As a result of the stamp sand deposits, copper concentrations in several water bodies in the Upper Peninsula exceed WQS for the Other Indigenous Aquatic Life and Wildlife designated use and therefore require TMDL development.

Figure 1. Stamp sands in the Owl Creek watershed.

The entire Owl Creek watershed (4.7 miles) was originally listed on the 2010 Section 303(d) list as follows based on water chemistry monitoring results indicating total copper concentrations exceeded WQS.

Water body name: Owl Creek
AUID: 040201030405-06
Impaired designated use: Other Indigenous Aquatic Life and Wildlife
Cause: Copper
Source: Mine Tailings
Size: 4.7 Miles
Location Description: Tributary to Lake Superior, between Great Sand Bay and Cat Harbor
TMDL Year(s): 2011

A TMDL was originally scheduled for 2011 but was postponed allowing for additional data collection and development of site-specific WQS. Subsequent monitoring of the watershed in 2011 and development of site-specific WQS resulted in the division of Owl Creek into three reaches (AUID 040201030405-06, 040201030405-09, and 040201030405-10). AUID 040201030405-06 is not exceeding WQS for total copper.

This document addresses the two impaired reaches in the Owl Creek watershed. AUID 040201030405-09 will be referred to as Reach A for the remainder of the document and AUID 040201030405-10 will be referred to as Reach B. Owl Creek is located southwest of the village of Eagle Harbor. The headwaters of this small watershed originate near Owl Lake on a large bluff known as Petherick Hill. Owl Creek flows downhill for approximately 0.7 miles where it reaches a waterfall known as Copper Falls. The flow here is very minimal (Station 420164; Figure 2). Where it flows beyond this point is unclear. According to National Hydrography data, Owl Creek continues to flow 0.7 miles until it reaches and flows through a large (approximately 48 acres) stamp sand deposit. The stream was observed in the stamp sand area but was only a series of pools (Bill Taft, Michigan Department of Environment, Great Lakes, and Energy [EGLE], personal communication). Owl Creek then discharges to a large (approximately 48 acres) wetland complex. Another tributary with a much higher volume of flow was sampled at Stations 420143 and 420137. It is thought that this water may be coming from the nearly one-mile long Owl Creek adit, which is a historic horizontal mine shaft that most likely drains water from several mining areas on Penthrick Hill (Copper County Media [CCM], 2012). This tributary flows through the large stamp sand area and then to a sand dune wetland complex. Water from this wetland complex eventually discharges to Lake Superior. National Hydrography maps estimate that Owl Creek discharges at the northeast side of Great Sand Bay. Station 420133 is located here.

Most of the land use in the Owl Creek watershed consists of forest (63%) and wetlands (32%) (Table 1) (United States Geological Survey [USGS], 2006). The land use for Reach B could not be calculated due to its small size and the lack of flow accumulation information that is necessary to use the watershed tool in ArcGIS. The entire Owl Creek watershed is within Eagle Harbor Township.

Table 1. Land use within the Owl Creek watershed (USGS catchment information, 2006).

Landuse Classification	Entire Watershed	Reach A	Reach B
Open Water	2.4%	1.6%	N/A[1]
Developed, Open Space	2.6%	2.4%	N/A
Developed, Low Intensity	0.1%	0.0%	N/A
Deciduous Forest	13.3%	24.2%	N/A
Evergreen Forest	30.7%	24.5%	N/A
Mixed Forest	19.2%	31.8%	N/A
Shrub/Scrub	0.1%	0.2%	N/A
Woody Wetlands	22.8%	11.1%	N/A
Emergent Herbaceous Wetlands	8.9%	4.2%	N/A
TOTAL	**100.0%**	**100.0%**	N/A

NUMERIC TARGET

The impaired designated use addressed by this TMDL is "Other Indigenous Aquatic Life and Wildlife." At a minimum, all surface waters of the state are protected for all of the following designated uses: agriculture, navigation, industrial water supply, warmwater fishery, other indigenous aquatic life and wildlife, partial body contact recreation, and fish consumption (Rule 100 [R 323.1100], Designated Use, of the Part 4 rules, WQS, promulgated under Part 31,

[1] N/A = Not Available

Water Resources Protection, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended [NREPA]). Rule 57 (R 323.1057), Toxic Substances, of the Part 4 rules, states that toxic substances shall not be present in the surface waters of the state at levels that are or may become injurious to the public health, safety, or welfare; plant and animal life; or the designated uses of the waters.

Modification of aquatic life criteria values to reflect local environmental conditions is permitted under Subrule r(ii) of R 323.1057. Under this subrule, site-specific aquatic life values may be derived using a recalculation, water effect ratio (WER), or resident species procedures. A WER procedure accounts for the effects of water quality variables such as hardness or dissolved organic carbon (DOC) on metal bioavailability. EGLE staff conducted a regional study in Michigan's Upper Peninsula to develop a procedure for calculating WER that could be used to develop site-specific WQS for copper (Michigan Department of Environmental Quality [MDEQ], 2007). Details of this procedure are included in the document "Development of Site-Specific Aquatic Life Values for Total Copper for Water Bodies in the Upper Peninsula of Michigan" (Lipsey, 2013) which was reviewed and approved by the USEPA.

There are two approved site-specific WQS for the Owl Creek watershed. These WQS are the numeric targets for the TMDLs. The first TMDL target applies to Reach A, which is the portion of Owl Creek from the Owl Lake outlet downstream to the base of Pentherick Hill where the sand dune complex begins (bold blue reach, Figure 2). A site-specific WQS of 12 micrograms per liter (µg/L) was calculated for Reach A. The second TMDL target applies to Reach B, which is the second tributary likely flowing out of the Owl Creek adit, through the stamp sands, and to the wetland complex (purple Reach, Figure 2). A site-specific WQS of 22 µg/L was calculated for Reach B. For both TMDLs the target is equal to the site-specific Final Chronic Value (FCV) because it is the most conservative value of the applicable WQS.

Decision criteria for use in determining the extent (distance of stream reach included) to which a site-specific WQS was applied is detailed in the site-specific criteria document (Lipsey, 2013) and includes availability of water quality data (hardness, DOC, copper, and total organic carbon [TOC]) and landscape feature considerations.

DATA DISCUSSION

Water Sampling Data

A total of 34 water samples were taken at 5 stations (4 stream stations and 1 wetland station) throughout the Owl Creek watershed (Figure 2; Table 2; Appendix A) from October 2003-September 2011. Stations 420164, 420143, and 420137 were sampled monthly from June-September 2011. Total Copper, TOC, DOC, and Total Hardness as measured by total calcium and total magnesium ions were collected at each station. Water samples were collected and analyzed according to USEPA approved methods.

Table 2. Station locations for water quality sampling in the Owl Creek watershed.

STORET Station #	Location	Latitude	Longitude
420164	Downstream of Copper Falls	47.4298	-88.1960
420143	Upstream edge of stamp sands	47.4378	-88.1967
420137	In middle of stamp sands	47.4387	-88.1994
420133	Lake Superior confluence	47.4456	-88.2166
420172	Marsh area downstream of stamp sands	47.4430	-88.2004

As noted above, two site-specific WQS were calculated for the Owl Creek watershed.

A site-specific WQS of 12 µg/L was calculated for Reach A (Figure 2; Table 3). The geometric mean of the copper data collected at Station 420164 was 20 µg/L and thus exceeded the site-specific WQS.

A site-specific WQS of 22 µg/L was calculated for Reach B (Figure 2; Table 3). The geometric mean of the copper data collected at Station 420143 was 103 µg/L and at Station 420137 was 108 µg/L and thus exceeded the site-specific WQS. DOC data were collected at both stations. Total hardness and DOC values were similar between these two stations and thus the most conservative site-specific WQS was chosen.

The wetland area (Station 420172) has been sampled only two times and has high reported total copper concentrations; however, no DOC data are available. DOC concentrations are likely higher due to the organic nature of wetlands. Any remediation activities that take place to bring copper concentrations back into compliance at upstream stations will have a positive impact on the wetland complex and should bring total copper concentrations down to compliance levels. Copper concentrations were also measured at the Lake Superior confluence (Station 420133) and were meeting WQS.

<u>Macroinvertebrate Sampling Data</u>

Macroinvertebrate community and habitat surveys at Stations 420133, 4201037, 420143, and 420164 in the Owl Creek watershed indicate the macroinvertebrate communities are meeting the biological integrity requirements of the Michigan WQS (Kohlhepp et al., 2007 and Noffke, 2012; Table 4).

Table 3. Data summary of current WQS, site-specific WERs, site-specific WQS to be applied, and summary of water quality data in tributaries within the Owl Creek watershed.

STORET #	AUID	Water Body Name	Station Location	Minimum DOC (mg/L[2])	Geomean Hardness all available data (mg/L)	Original WQS (µg/L[3])	SMAV[4] WER based on minimum DOC	WQS with WER (µg/L)	Geomean Copper all available data (µg/L)	n [5]	Site-specific WQS to be applied (µg/L)
420164	040201030405-09	Owl Creek	Copper Falls	4.0	65	9	1.8	12	20	8	**12 (Reach A)**
420143	040201030405-09	Owl Creek	Upstream edge of stamp sands	8.4	49	7	4.4	23	103	8	**22 (Reach B)**
420137	040201030405-10	Owl Creek	in stamp sands	6.8	65	9	3.5	22	108	7	
420172	N/A	Owl Creek	Marsh area downstream of stamp sand deposit	na[6]	57	8	na	na	137	2	**NA**
420133	040201030405-06	Owl Creek	Lake Superior Confluence	na	71	10	na	na	7	5	**NA[7]**

[2] Milligrams per liter
[3] Micrograms per liter
[4] Species Mean Acute Value
[5] Number of hardness and copper values used for geometric mean
[6] Not available
[7] Not applicable

Table 4. Macroinvertebrate data collected from Owl Creek Watershed, Keweenaw County, Michigan.

AUID	Storet	Water Body Name	Station Location	Date Sampled	P-51 Rating and Score	Report #
040201030405-09	420164	Owl Creek	Copper Falls (Loop Road)	6/14/2011	Acceptable (0)	MI/DEQ/WRD-12/018
040201030405-09	420143	Owl Creek	Upstream Stamp sands	6/17/2006	Acceptable (+4)	MI/DEQ/WB-07/080
040201030405-10	420137	Owl Creek	Stamp sands	6/14/2006	Acceptable (-2)	MI/DEQ/WB-07/080
040201030405-06	420133	Owl Creek	Lake Superior (W)	6/17/2006	Acceptable (+1)	MI/DEQ/WB-07/080

SOURCE ASSESSMENT

As noted above, the Keweenaw Peninsula is known locally as “copper country” due to the extensive copper deposits throughout the area. The area has a unique, complex geology that includes a large igneous uplifted fault line that bisects the peninsula. The largest copper mining operations in the world were located along this fault line during the 19th century. Early Native Americans mined copper from small pits along the Keweenaw Fault, and the first systematic copper mining operation started in 1846 near Eagle River, Michigan. By the late 1880s, mining operations deforested most of the Keweenaw Peninsula and numerous stamp mills were constructed in the headwaters of several Keweenaw Peninsula streams for processing copper ore. The byproduct of the stamp mills’ rock crushing activities was a coarse, dark aggregate called stamp sands. Extensive copper stamp sand piles are found throughout the woods, along streambeds, and the Lake Superior shoreline (Figure 1). Stamp sand deposits affect stream biota by burying in-stream habitat and leaching cupric ions into the water column. Groundwater that flows through stamp sands may also be a significant source of copper to surface water because copper ions are released from the stamp sands more readily in the acidic, anoxic conditions underground (Kotke, 2011). When the groundwater reaches surface waters, the dissolved copper remains mobile in the less stable oxygenated surface water conditions, due to DOC complexes and their ability to bind and transport dissolved copper (Ford et al., 2007). There are countless abandoned mines throughout the Keweenaw Peninsula that serve as conduits for venting groundwater that may contain high concentrations of copper.

As a result of the stamp sand deposits, there are increased water column copper concentrations in several water bodies that have low hardness and low pH values. The lower the hardness, the less magnesium and calcium ions are available to bind with copper and make it less available to bind with gills of aquatic organisms. The lower the pH, the more dissolved copper is released into the water column, and dissolved copper contributes to aquatic toxicity. Thus, copper concentrations in several water bodies in the Upper Peninsula exceed WQS for the other indigenous aquatic life and wildlife designated use, thus necessitating TMDL development.

In Reach A (Figure 2) of the Owl Creek watershed, the only known sources of copper are the historic mining activities and lake and groundwater contributions from old mine shafts. For Reach B (Figure 2) the largest possible source of copper is the obvious large historic deposit of stamp sand (48 acres) (gray area on Figure 2). In addition, it is believed that more than a mile of adit and mine workings (shafts, stopes, tram line passages, etc.) from the Copper Falls Mine are being drained by this tributary (CCM, 2012) and are a likely source of copper.

There are no National Pollutant Discharge Elimination System (NPDES) permits or known point source discharges in the impaired reaches of the Owl Creek watershed (MiWaters, 2020). The only NPDES permit within the entire watershed is the Michigan Department of Transportation statewide Municipal Separate Storm Sewer System permit. This permit would cover storm water discharges associated with any state roads within the watershed. The only state road is M-26, which crosses the outlet of Owl Creek just before its confluence with Lake Superior. It is downstream of both impaired reaches and thus is not included in either TMDL.

As an additional tool in determining potential sources of total copper to the Owl Creek watershed, a load duration curve analysis, as outlined by Cleland (2002), was developed for each sampling station. A load duration curve considers how flow conditions relate to a variety of potential pollutant sources (point and nonpoint sources). The load duration curves for each station sampled in the Owl Creek watershed are included in Appendix B. All historical flows available from the USGS gage on the Trap Rock River near Lake Linden, Michigan (Gage #04043050), and four individual flow measurements taken at Stations 420164 and 420143 in 2011 (Appendix C) were used to develop the load duration curves.

The data indicate that exceedances of the WQS are observed during wet and dry weather events (Appendix B). Note that dots above the curve on the left side of each figure are indicative of total copper WQS exceedances during wet weather conditions (higher flows) and dots above the curve to the right side of the figure indicate total copper WQS exceedances during dry weather conditions (lower flows). Exceedances of the WQS occurred during all flow conditions. This would be expected since the primary source of copper to the watershed is stamp sands within the streambed and through which groundwater flows.

LOADING CAPACITY DEVELOPMENT

The loading capacity (LC) represents the maximum daily loading that can be assimilated by the water body while still achieving WQS. As indicated in the Numeric Target section, the targets for these Owl Creek total copper TMDLs are site-specific aquatic FCV WQS of 12 µg/L for Reach A and 22 µg/L for Reach B (Figure 2; Table 3).

Concurrent with the selection of numeric concentration endpoints, development of the LC requires identification of the critical conditions. The “critical condition” is the set of environmental conditions (e.g., flow) used in developing the TMDL that result in attaining WQS and have an acceptably low frequency of occurrence. The critical conditions for the applicability of WQS in Michigan are given in Rule 90 (R 323.1090). For FCV values, such as for copper, R 323.1090 specifies that WQS shall apply at all flows equal to or exceeding the design flows. The design flow for copper is equal to the lowest of the 12 monthly 95% exceedance flows. The 95% exceedance flow is the flow equal to or exceeded 95% of the time.

The LC is the sum of individual waste load allocations (WLA) for point sources and load allocations (LA) for nonpoint sources and natural background levels to assure WQS are met. In addition, the LC must include a margin of safety (MOS), either implicitly within the WLA or LA, or explicitly, that accounts for uncertainty in the relation between pollutant loads and the quality of the receiving water body. Conceptually, this definition is denoted by Equation 1.

(Equation 1) LC = ∑WLAs + ∑LAs + MOS

EGLE's Hydrologic Studies Unit used flows from USGS gage Station 04043050 on the Trap Rock River near Lake Linden, Michigan, and the rating curve developed using the discharge measurements in Appendix C to estimate a 95% exceedance flow for Owl Creek at Station 420164, of 0.002 cubic feet per second (cfs) (0.001 million gallons per day [mgd]). Using Equation 2, the WQS of .012 mg/L (Table 3), the 95% exceedance flow (mgd), and a conversion factor (8.34), the **LC** for **Reach A** of the Owl Creek watershed was calculated as **0.0001 pounds per day (lbs/day)** of total copper.

(Equation 2) LC (Individual Reach) = WQS (mg/L) x 95% Exceedance Flow (mgd) x 8.34

The Hydrologic Studies Unit used the same USGS gage and the rating curve developed using the discharge measurements in Appendix C to estimate a 95% exceedance flow for Owl Creek at Station 420137, of 0.2 cfs (0.13 mgd). Using Equation 2, the WQS of 0.022 mg/L (Table 3), the 95% exceedance flow (mgd), and a conversion factor (8.34), the **LC** for **Reach B** of the Owl Creek watershed was calculated as **0.02 lbs/day** of total copper.

The next step is to calculate the current load at each of the stations. Using Equation 3 and the geometric mean of all total copper water samples taken at Station 420164 from 2006 to 2011 from Reach A of Owl Creek (0.02 mg/L; Table 3), the estimated 95% exceedance flow of the tributary at Station 420164 (0.001 mgd), and a conversion factor (8.34), it is estimated that the **current total load** of copper at critical conditions in **Reach A is 0.0002 lbs/day**.

(Equation 3) Current Loading at Critical Conditions = Geometric Mean Copper Samples (mg/L) x 95% Exceedance Flow (mgd) x 8.34

Using Equation 3, and the geometric mean of all total copper water samples taken at Station 420137 from 2006 to 2011 in Reach B of Owl Creek (0.108 mg/L; Table 3), the estimated 95% exceedance flow of the tributary at Station 420137 (0.13 mgd), and a conversion factor (8.34) it is estimated that the **current load** of copper at critical conditions in **Reach B is 0.12 lbs/day.**

WLAs

The WLA component of the TMDL defines the fraction of the LC for total copper from point sources. There are no NPDES permitted facilities upstream or within the impaired reaches of the Owl Creek watershed (MiWaters, 2020). No WLA and reduction in loads from point sources are required in this TMDL.

LAs

The LA component of the TMDL defines the fraction of the LC for total copper from nonpoint sources. For Reach A of the Owl Creek watershed, a reduction in total copper loading at critical conditions from nonpoint sources equal to 0.0001 lbs/day is necessary to meet the TMDL (Table 5). For Reach B of the Owl Creek watershed, a reduction in total copper loading at critical conditions from nonpoint sources equal to 0.10 lbs/day is necessary to meet the TMDL (Table 5).

Table 5. Summary of the WLAs and LAs for Total Copper at critical conditions in the Owl Creek watershed.

Source Category	Reach A Current Total Copper Estimated Load (lbs/day)	Reach A Target Total Copper Load (lbs/day)	Reach B Current Total Copper Estimated Load (lbs/day)	Reach B Target Total Copper Load (lbs/day)
WLA Components				
NPDES Individual Permits	0	0	0	0
WLA Subtotal	0	0	0	0
LA Components				
Forested, Wetland, Developed Open Space, Low Intensity Development, Open Water	0.0002	0.00009	0.12	0.018
LA Subtotal	0.0002	0.00009	0.12	0.018
MOS		0.00001		0.002
LC Total	**0.0002**	**0.0001**	**0.12**	**0.02**

MOS

The MOS accounts for any uncertainty or lack of knowledge concerning the relationship between pollutant loading and water quality, including the pollutant decay rate if applicable. The MOS can be either implicit (i.e., incorporated into the WLA or LA through conservative assumptions) or explicit (i.e., expressed in the TMDL as a portion of the loadings). For this Total Copper TMDL an implicit and explicit MOS was used. An implicit MOS applies because conservative assumptions were made in the development of site-specific WQS. The minimum DOC value of the four samples analyzed from each station sampled in the Owl Creek watershed during 2011 was used for development of the Species Mean Acute Value (SMAV) WER using Equation 1. The lower the DOC value, the lower the resultant WER will be, resulting in a more conservative site-specific WER. In addition, if two of the four samples had the minimum DOC value, we chose the sample that had the minimum hardness value. This would be the most conservative approach since the FCV increases as hardness increases.

We were also conservative when applying a site-specific WQS to a reach of stream. If DOC data were collected at two sampling stations within the same watershed and total hardness and DOC values were similar between these two stations, the most conservative site-specific WQS was chosen to be applied to that reach.

We also incorporated an explicit MOS. Because of the limited data set (4 samples within one year) of DOC data available to develop site-specific WQS, we set aside 10% of the LC of each reach as the MOS, to ensure that the allocations of this TMDL are protective (Table 5).

SEASONALITY

Seasonality in this TMDL is addressed using a numeric target that is equal to the WQS, which applies throughout the year. The WQS is targeted to be met at flows greater than or equal to the 95% exceedance flow, which should occur 95% of the time. In addition, the load duration curves included in Appendix B (explained in the source assessment section) indicate that water was collected during most flow conditions, except for very high flows.

MONITORING

Future monitoring by EGLE of the Owl Creek macroinvertebrate community and water quality will take place as resources allow as part of the five-year rotating basin monitoring and/or if restoration activities take place to remediate sources of copper.

REASONABLE ASSURANCE

Currently, the Owl Creek watershed does not have an active watershed group and there is no watershed management plan. This area is rather remote and future development is not expected within the watershed. If future growth does occur, copper inputs are not expected to increase since sources of copper are due to historic mining activities. Currently, no remediation activities are planned for the known sources of copper in the Owl Creek watershed. As resources allow, EGLE will continue to investigate site-specific sources of copper from past mining practices in the watershed and evaluate whether remediation of the stamp sands is feasible.

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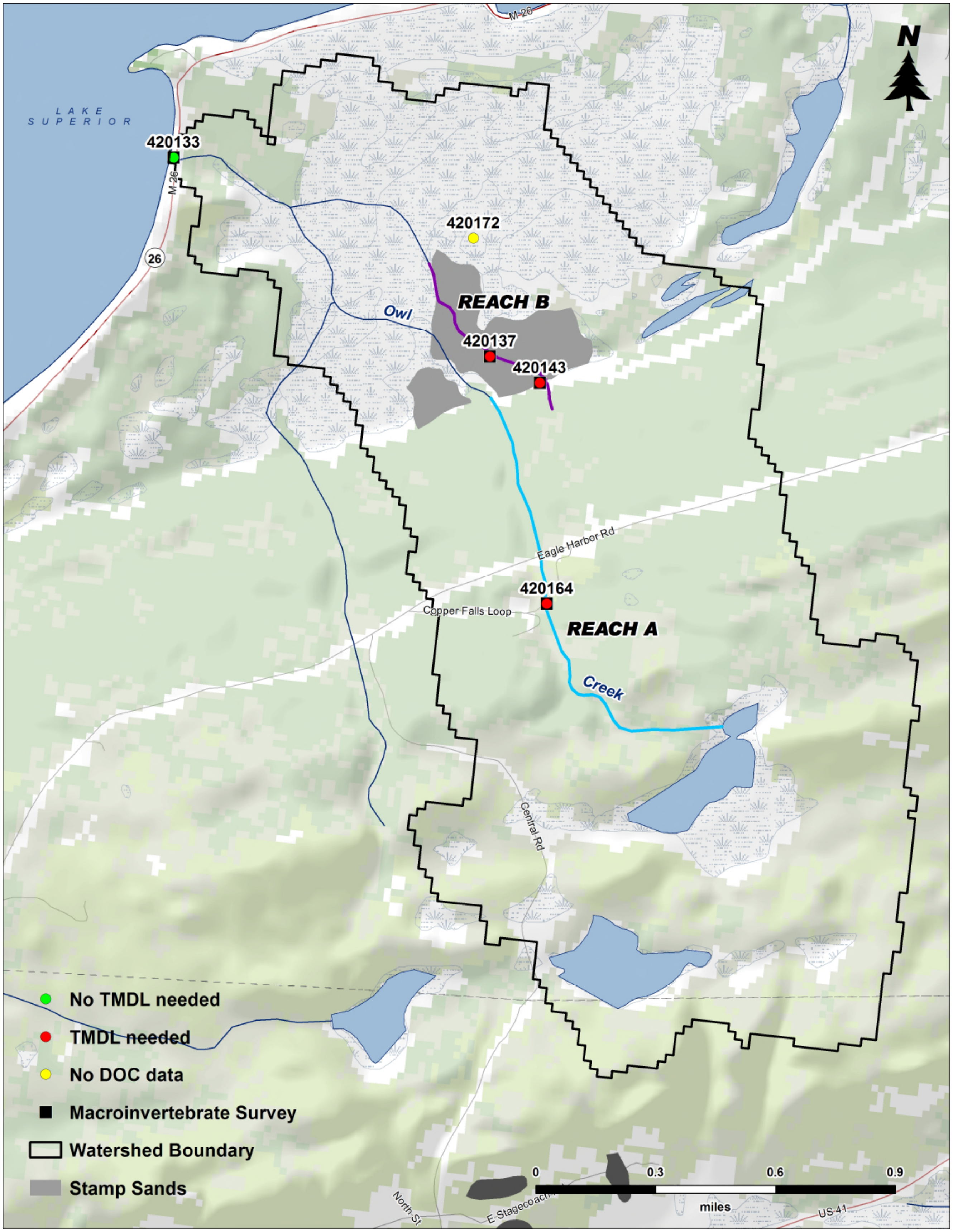

Figure 2. Owl Creek watershed sampling stations, Keweenaw County, Michigan.

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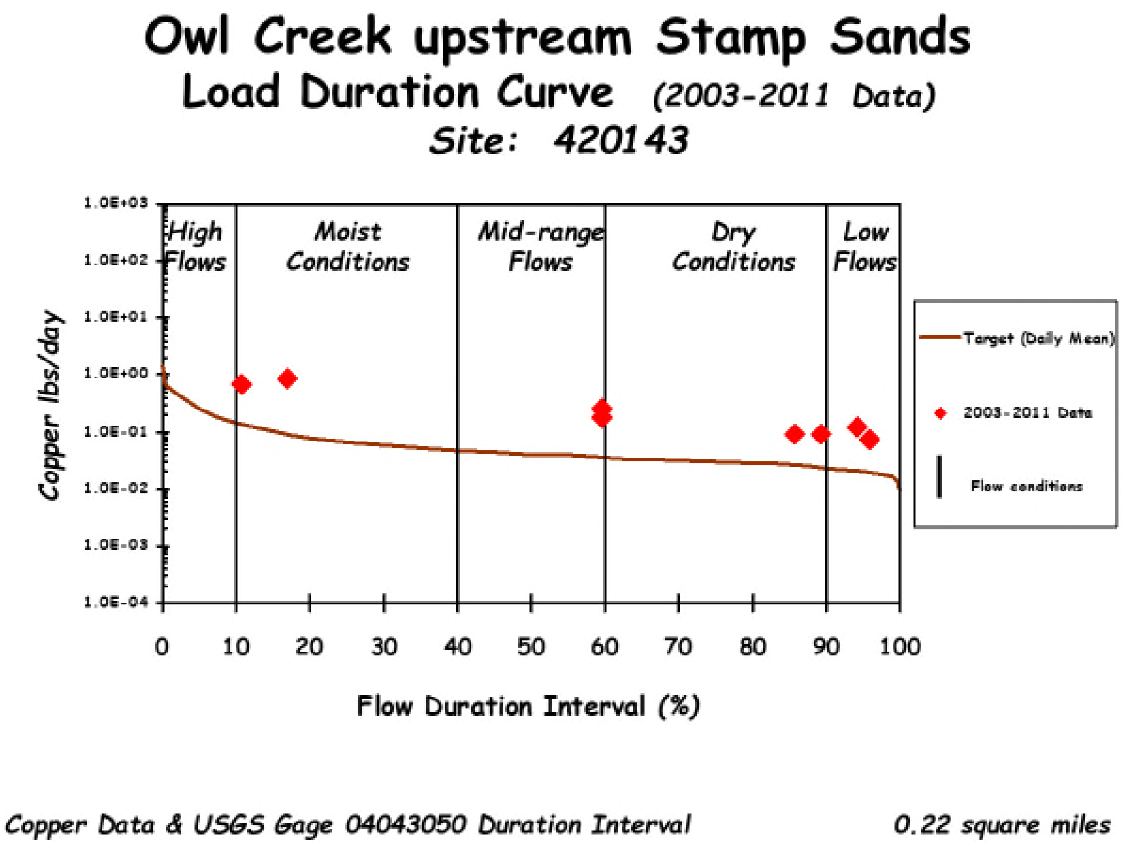
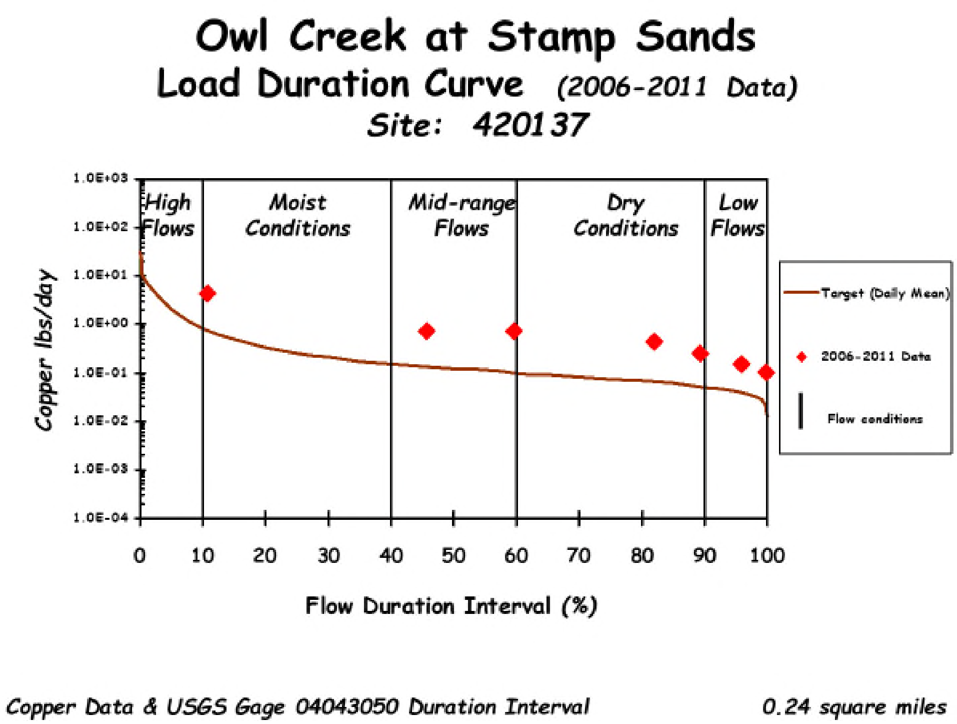
Appendix A. Analytical results for water samples collected from the Owl Creek watershed, Keweenaw County, Michigan.

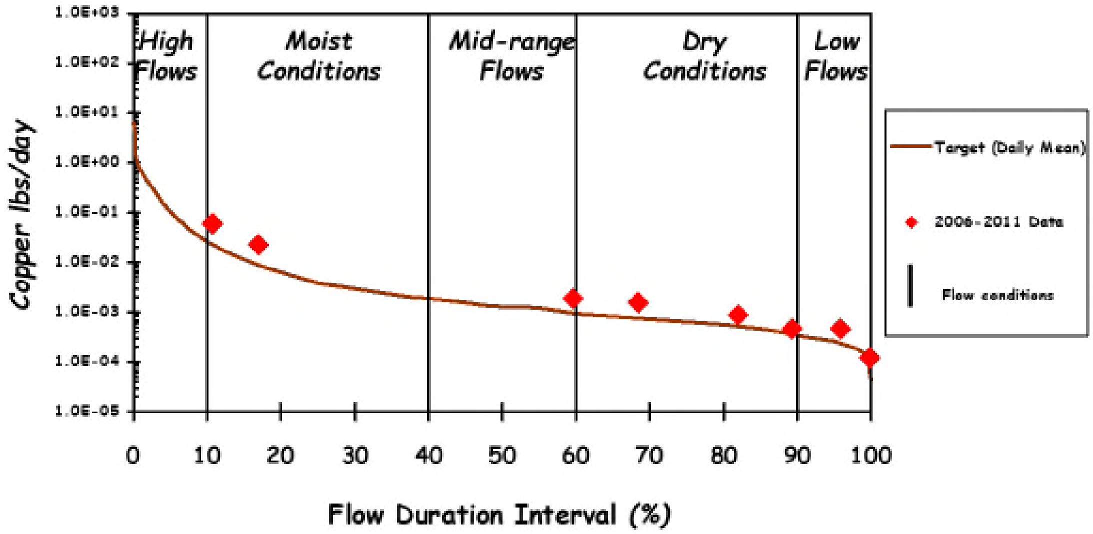
STORET #	AUID	Water Body	Station Location	Latitude	Longitude	County	Date	Total Hardness (mg/L)	DOC (mg/L)	TOC (mg/L)	Total Copper (µg/L)
420133	040201030405-06	Owl Creek	Lake Superior (W)	47.4456	-88.2166	Keweenaw	10/23/2003	86	na		2
420133	040201030405-06	Owl Creek	Lake Superior (W)	47.4456	-88.2166	Keweenaw	6/17/2006	76	na	11	9.6
420133	040201030405-06	Owl Creek	Lake Superior (W)	47.4456	-88.2166	Keweenaw	6/11/2007	67	na	8.4	13
420133	040201030405-06	Owl Creek	Lake Superior (W)	47.4456	-88.2166	Keweenaw	8/3/2007	80	na	7.7	2
420133	040201030405-06	Owl Creek	Lake Superior (W)	47.4456	-88.2166	Keweenaw	10/26/2007	52	na	11	28
420137	040201030405-06	Owl Creek	stamp sands	47.4387	-88.1994	Keweenaw	6/14/2006	49	na	9.3	110
420137	040201030405-06	Owl Creek	stamp sands	47.4387	-88.1994	Keweenaw	6/11/2007	47	na	10	130
420137	040201030405-06	Owl Creek	stamp sands	47.4387	-88.1994	Keweenaw	8/3/2007	99	na	6.4	99
420137	040201030405-06	Owl Creek	stamp sands	47.4387	-88.1994	Keweenaw	6/20/2011	58.4	9.4	10	115
420137	040201030405-06	Owl Creek	stamp sands	47.4387	-88.1994	Keweenaw	7/20/2011	59.8	10	10	140
420137	040201030405-06	Owl Creek	stamp sands	47.4387	-88.1994	Keweenaw	8/15/2011	90.7	7.4	7.4	92.9
420137	040201030405-06	Owl Creek	stamp sands	47.4387	-88.1994	Keweenaw	9/14/2011	71.2	6.8	6.5	80
420143	040201030405-06	Owl Creek	u/s Stamp sands	47.4378	-88.1967	Keweenaw	10/23/2003	52	na		72
420143	040201030405-06	Owl Creek	u/s Stamp sands	47.4378	-88.1967	Keweenaw	6/17/2006	41	na	10	98
420143	040201030405-06	Owl Creek	u/s Stamp sands	47.4378	-88.1967	Keweenaw	6/15/2007	45	na	10	120
420143	040201030405-06	Owl Creek	u/s Stamp sands	47.4378	-88.1967	Keweenaw	10/26/2007	39	na	15	190
420143	040201030405-06	Owl Creek	u/s Stamp sands	47.4378	-88.1967	Keweenaw	6/20/2011	49.6	9.9	11	106
420143	040201030405-06	Owl Creek	u/s Stamp sands	47.4378	-88.1967	Keweenaw	7/20/2011	49.6	11	11	135
420143	040201030405-06	Owl Creek	u/s Stamp sands	47.4378	-88.1967	Keweenaw	8/15/2011	73.9	8.6	8.5	76.4
420143	040201030405-06	Owl Creek	u/s Stamp sands	47.4378	-88.1967	Keweenaw	9/14/2011	51.6	8.4	7.7	73.3
420164	040201030405-06	Owl Creek	Copper Falls-(W)	47.4298	-88.196	Keweenaw	6/16/2006	52	na	5.2	21
420164	040201030405-06	Owl Creek	Copper Falls-(W)	47.4298	-88.196	Keweenaw	6/11/2007	59	na	3.4	17
420164	040201030405-06	Owl Creek	Copper Falls-(W)	47.4298	-88.196	Keweenaw	8/3/2007	90	na	4	15
420164	040201030405-06	Owl Creek	Copper Falls-(W)	47.4298	-88.196	Keweenaw	10/26/2007	44	na	5.9	28
420164	040201030405-06	Owl Creek	Copper Falls-(W)	47.4298	-88.196	Keweenaw	6/20/2011	71.8	4.2	4.4	28.2
420164	040201030405-06	Owl Creek	Copper Falls-(W)	47.4298	-88.196	Keweenaw	7/20/2011	61.6	4.4	4.1	19.2
420164	040201030405-06	Owl Creek	Copper Falls-(W)	47.4298	-88.196	Keweenaw	8/15/2011	88.2	4	3.7	12.7
420164	040201030405-06	Owl Creek	Copper Falls-(W)	47.4298	-88.196	Keweenaw	9/14/2011	65.9	4.6	4.2	21.4
420172	NA	Owl Creek	Sand dune Marsh Area d/s Stamp Sand deposit	47.44298	-88.20046	Keweenaw	6/11/07	76	na	12	110
420172	NA	Owl Creek	Sand dune Marsh Area d/s Stamp Sand deposit	47.44298	-88.20046	Keweenaw	10/26/07	43	na	13	170

Appendix B. Total copper load duration curves for selected stations in the Owl Creek watershed, Keweenaw County, Michigan.





Owl Creek at Copper Falls
Load Duration Curve *(2006-2011 Data)*
Site: 420164



Copper Data & USGS Gage 04043050 Duration Interval *1.0 square miles*

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Appendix C. Tape down measurements used to develop flow rating curves for development of load duration curves for the Owl Creek watershed.

STREAM NAME	STORET	DATE	TIME (ET)	TAPE DOWN (feet, inches)	TAPE DOWN (inches)	DISCHARGE (cfs)
Owl Creek	420137	06/20/11	0925	3’ 7.25”	43.25	2.07
		07/20/11	0835	3’ 7.50”	43.50	1.81
		08/15/11	0855	3’ 9.00”	45.00	0.15
		09/14/11	0835	3’ 9.50”	45.50	0.26
Owl Creek	420143	06/20/11	1010	1’ 11.25”	23.25	0.78
		07/20/11	1130	1’ 11.50”	23.50	0.57
		08/15/11	0930	2’ 1.00”	25.00	0.17
		09/14/11	0849	2’ 1.00”	25.00	0.14
Owl Creek	420164	06/20/11	1055	3’ 6.50”	42.50	0.12
		07/20/11	1111	3’ 6.75”	42.75	0.04
		08/15/11	1000	3’ 7.25”	43.25	0.02
		09/14/11	0908	3’ 11.50”	47.50	0.001