ANALYSIS OF EFFECTS OF MINE SITE REMEDIATION ON TOTAL COPPER CONCENTRATIONS IN THE TSOLUM RIVER AND SOME OF ITS TRIBUTARIES

Prepared for:

Ministry of Environment

Nanaimo, B.C.

Prepared by:

BWP Consulting Inc.

Kamloops, B.C.

January, 2011

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report analyzes total copper concentrations in the Tsolum River and a number of its tributaries, before and after a site remediation project conducted in 2009. An abandoned copper mine on Mt Washington has been a significant source of copper which has affected water quality in the Tsolum River and a few of its tributaries. While earlier reclamation work at the mine site is thought to have reduced the copper loadings to the Tsolum substantially, further improvements in water quality were needed. The recent work at the mine site involved covering the site with a thick geomembrane (resembling a heavy roofing material), and then covering the geomembrane with a substantial layer of glacial till to protect it from the elements.

Included in this report are an assessment of changes in total copper concentrations near the minesite, in Pyrrhotite Creek (the tributary adjacent to the minesite), and in Tsolum River, as well as an assessment of objectives attainment in the Tsolum River on both a monthly and seasonal basis. All of these analyses are based on data collected between 2007 and 2010.

Total copper was measured at three long term locations draining the mine and a new location created in response to the remediation work. Concentrations at each of the sites decreased in both the spring and fall when comparing data collected between 2007 and 2009 with data collected in 2010. The decrease in concentrations was least pronounced at the outlet of Weir #1 and most pronounced at the outlet of Weir #3.

Total copper concentrations in Pyrrhotite Creek near the Branch 1200 Road remained similar between seasons from 2007 through 2009 before decreasing considerably in 2010 for both the spring and fall periods. A comparison of spring and fall total copper concentrations from each year between 2007 and 2009 with total copper concentrations measured in 2010 showed a significant decrease between each of the years (*i.e.* 2007 vs. 2010, 2008 vs. 2010 and 2009 vs. 2010), as well as for the overall period of 2007-2009 vs. 2010. Total spring copper loadings to Pyrrhotite Creek were similar in 2007 and 2008 before decreasing somewhat in 2009 (due to decreased snowpack) and then decreased considerably more in the spring of 2010.

Total copper concentrations were also measured at five sites on the Tsolum River (one background site, upstream from Murex Creek, and four impacted sites between Murex Creek and the Puntledge River). Both maximum and average total copper (calculated using a minimum of five samples collected within a 30-day period) concentrations remained similar between 2007 and 2009 before decreasing considerably at all of the impacted sites in 2010. In general, the number of samples exceeding either the maximum or average objective for the Tsolum River decreased between 2009 and 2010, with the exception of average total copper concentrations measured at the site upstream from Headquarters Creek. However, there were insufficient data collected at this site prior to 2010 to make an accurate comparison, and it appears that, overall, average total copper concentrations decreased here as well.

1.0 INTRODUCTION

The Tsolum River originates on Mount Washington and flows southeast about 30 km before joining the Puntledge River just before it enters Comox Harbour and the Strait of Georgia (see Figure 1). Pyrrhotite, McKay and Murex creeks are the tributaries that drain the Mt. Washington mine to the Tsolum River (Figure 1).

The river is licensed for domestic and irrigation water supply. In the past, the river supported large populations of steelhead and resident rainbow trout, sea-run cutthroat trout, and coho, pink and to a lesser extent, chum salmon. The fisheries resource is believed to have declined in the basin predominantly because of the acid mine drainage from an abandoned copper mine on Mt. Washington. Other factors such as the reduction of summer low flows by irrigation withdrawals, over-fishing, logging and gravel extraction may have also played a role in decreasing the populations of certain species. The neighbouring Puntledge River has continued to support strong salmonid populations, despite similar human disturbances. In any case, the Tsolum River has the potential to support an extensive fishery, with or without an enhancement program.

The Mt Washington copper mine has been a significant source of copper which has affected the downstream waters of the Tsolum River. While extensive reclamation work conducted at the mine site in the late 1980's reduced the copper levels in the river, further improvement was needed. To protect the fisheries resource of the Tsolum River from the impacts of the mine site, a partnership approach was taken. The partnership has grown to include the Tsolum River Restoration Society, Timber West, the Pacific Salmon Foundation, the Department of Fisheries and Oceans, Environment Canada, Ministry of Natural Resource Operations, Mining Association of B.C., Natural Resources Canada, Breakwater Resources and the Ministry of Environment. The partnership brought together resources to reroute Pyrrhotite Creek through the Spectacle Wetland in 2003, which further improved water quality in the Tsolum River. However, the wetland project was only a short term solution, as the wetlands ability to remove copper is finite. A long term remediation plan was needed.

The Tsolum River partnership hired SRK Consultants in 2006 to determine the best remediation option for the mine site. In 2007, SRK completed the detailed design and cost estimates to complete the work. In April 2008, the Province of BC announced $4.5 million in funding to complete the needed work.

Lead by Quantum Murray (with SRK Consultants and Stantec), the remediation work had largely been completed by October 2010, with minor work scheduled for summer 2011 to complete the project. The work at the mine site involved covering the site with a thick geomembrane, resembling a heavy roofing material. The material was laid down in large rolls through the summer of 2009. Since that time, the geomembrane has been covered with a substantial layer of glacial till to protect it from the elements. The till layer has largely been covered with an additional layer of organic soil and large woody debris in preparation for revegetation. The intent of the project is to minimize the amount of precipitation and groundwater flowing through the minesite. It is expected that the benefits of the project will be immediate, although the overall effectiveness of the work will increase over the next several years.

The purpose of this report is to assess the initial effectiveness of the remediation work in reducing the copper loadings from the mine site and improving water quality in the Tsolum River.

2.0 MINE SITE WATER QUALITY

Water quality was measured at three long term locations draining the mine and a new location created in response to the remediation work (see Figure 2). Samples were collected either during the spring freshet (early April through mid-July) or during the fall (late September through early November).

Weir #3 was installed in the late 1980's, collecting surface runoff from the majority of the mine site. The remediation work is anticipated to substantially reduce the copper concentrations and loadings at this site. The geomembrane cover was designed to transport all of the surface runoff to Weir #3, preventing water from flowing through the mine site.

Weir #2 was installed in the late 1980's, collecting runoff from Weir# 3, the manhole near Weir #3, and some additional surface drainage in the area. The remediation work is anticipated to substantially reduce both the copper concentrations and loadings at this site.

Weir #1 was installed in the late 1980's, collecting groundwater travelling through the mine site. The remediation work is anticipated to reduce the flow through this site but may not reduce the copper concentrations.

Manhole near Weir#3 is a new site installed in 2009, designed to collect subsurface flows moving through the minesite, beneath the geomembrane cover. It is anticipated that copper loadings will be limited at this site. At each of the three long term sites (Weirs #1, #2, #3), total copper concentrations were higher during the spring freshet than in the fall (Table 1). Comparing spring samples collected between 2007 and 2009 with samples collected in the spring of 2010, total copper concentrations decreased significantly ($p<0.005$ for 1-sided t-test assuming equal variance) at each of the three sites. The decrease was least-pronounced at the outlet of Weir #1 (average total concentrations decreased from 12.7 mg/L in the spring between 2007 and 2009 to 7.4 mg/L in the spring of 2010), and most pronounced at the outlet of Weir #3, where average total copper concentrations dropped from 10.74 mg/L in the spring of 2007-2009 to only 0.046 mg/L in the spring of 2010, a decrease of over 200 times.

Through the fall, conditions at the mine site typically gradually shift from near drought to much wetter conditions as the fall/winter rains develop. As a result, fall concentrations can vary considerably due to rain events. The installation of the geomembrane has exaggerated the minesite's response to rain, as it is designed to shed water immediately. As the site is revegetated in 2011, vegetation, soil and till covering the geomembrane will soften the response time, allowing the site to shed water more slowly.

Average fall total copper concentrations decreased substantially at Weirs #2 and #3, post-treatment, from 2.1 mg/L to 1.2 mg/L at Weir #2, and from 3.07 mg/L to 0.06 mg/L at Weir #3. At Weir #1, the average concentration decreased only slightly, from 9.9 mg/L to 9.2 mg/L. However, only the decrease at Weir #1 was statistically significant (p=0.03), due to the high degree of variability in total copper concentrations at the other sites.

Table 1. Summary of average total copper concentrations (mg/L) measured at three surface water and one groundwater site near the mine, pre- and post-treatment.

	Weir #1 E207461	Weir #2 E207461	Weir #3 E207856	Manhole near Weir #3 E277469
Spring 2007-2009	12.7	5.06	10.74	N/A
Fall 2007-2009	9.9	2.10	3.07	2.04
Spring 2010	7.4	0.70	0.046	2.32
Fall 2010	9.2	1.17	0.060	1.27
t-test (spring v spring)	< 0.005	< 0.005	< 0.005	N/A
t-test (fall v fall)	0.03	0.10	0.12	0.27

At the recently installed manhole site (the manhole near the outlet of Weir #3, EMS ID E277469), sampling began in fall 2009. However, average fall concentrations decreased from 2.04 mg/L in 2009 to 1.27 mg/L for the fall of 2010. Because of the high variability in the sample concentrations (total copper concentrations increased from 0.0026 mg/L on October 15, 2009 to 7.3 mg/L on October 20, 2009, only five days later), the decrease seen post-treatment was not significant (p=0.27 for 1-sided t-test assuming equal variance).

3.0 PYRRHOTITE CREEK WATER QUALITY

Pyrrhotite Creek at Br1200 is the key monitoring location, located below the mine site, collecting virtually all of the mine site drainage. Water samples were collected, typically once every day or every other day, from Pyrrhotite Creek near the Branch 1200 Road between mid-April and mid-July, as well as between mid-September and mid-November each year between 2007 and 2010. The range of total copper concentrations was similar between seasons from 2007 through 2009 before decreasing considerably in 2010 (Figure 7). Typically, concentrations were highest during the early spring (when the snowpack was melting slowly) and during dry periods, when dilution was lowest. Increased snowmelt and/or rainfall resulted in dilution and generally rapid decreases in total copper concentrations. As mentioned in Section 2.0, lack of ground cover over the geomembrane in 2009 and early 2010 exaggerated the minesite's response to rain, decreasing the residence time.

An analysis of total copper concentrations on a seasonal basis shows average spring concentrations ranged from 2.15 mg/L to 2.90 mg/L in 2007-09, with a sharp decrease to 0.44 mg/L in 2010 (Table 2). Similarly, fall concentrations ranged from an average of 1.87 mg/L in 2009 to 2.94 mg/L in 2008 before decreasing to 0.77 mg/L in 2010. One-sided t-tests (assuming equal variance) comparing average concentrations for each year between 2007 and 2009, as well as the complete data set for 2007-2009, with data collected in 2010 shows a significant decrease for all analyses, both spring and fall ($p<<0.005$).

Table 2. Summary of seasonal total copper concentrations (mg/L) in Pyrrhotite Creek at Branch 1200 Road from 2007 through 2010.

	Spring average	t-test, Spring v 2010	Fall average	t-test, Fall v 2010
2007	2.61	< 0.005	2.60	< 0.005
2008	2.15	< 0.005	2.94	< 0.005
2009	2.90	< 0.005	1.87	< 0.005
2007-09	2.59	< 0.005	2.47	< 0.005
2010	0.44		0.77	

Figure 8 shows a seasonal comparison between years for total copper concentrations in Pyrrhotite Creek at Branch 1200. The general trend of decreasing total copper concentrations through the spring is evident, as are the rapid changes in total copper concentrations in the fall resulting from rainfall events. The substantial decrease in total copper concentrations between 2009 and 2010 are also very evident, especially during the spring.

3.1 Total Copper Loadings to Pyrrhotite Creek

Continuous hydrometric data for Pyrrhotite Creek, coupled with frequent measurements of total copper concentrations, allows a fairly accurate estimate of total copper loadings to the creek (*i.e.* the total mass of copper carried through the stream during a given period). Figure 9 and Table 3 show a comparison of total copper loadings to Pyrrhotite Creek between 2007 and 2010.

Total loadings between 2007 and 2009 were similar for May before decreasing considerably in 2010. Similarly, loadings for June were similar for 2007 and 2008 before dropping to about half of the previous totals in 2009 and dropping by about half again in 2010. The decrease between 2008 and 2009 is primarily a result of the reduced snowpack that year – the monthly snowpack measured at nearby Wolf River (Environment Canada Snow Survey Station 3B18) was about half the average level in 2009. The decreased volume of runoff water therefore decreased the overall loadings, since loadings are calculated by multiplying the total copper concentration by the total volume of water passing through the creek.

Table 3. Comparison of total copper loadings (kg) to Pyrrhotite Creek in May and June between 2007 and 2010.

	2007	2008	2009	2010
May	455	407	395	84
June	291	271	136	65
Total (May and June)	**746**	**678**	**531**	**149**

4.0 TSOLUM RIVER

Water samples were collected at five sites on the Tsolum River between 2007 and 2010. These were: just upstream from Murex Creek (E206513, representing unimpacted, ambient total copper concentrations); 500 m downstream from Murex Creek (E207826, the first Tsolum site impacted by runoff from the mine site); just upstream from Headquarters Creek (E255693); downstream from Headquarters Creek (0127620); and just upstream from the Puntledge River (0127621). It is expected that copper concentrations in the Tsolum River would be highest just downstream from Murex Creek (where the effects of the mine would first appear) and decrease in a downstream direction as dilution from other tributaries increases.

Total copper concentrations measured at each of the five sites on the Tsolum River between 2007 and 2010 are shown in Figure 10 - Figure 14. A summary of the average total copper concentration measured at each site in both spring and fall, for the period before and after the site remediation, is given in Table 4. In some instances, no samples were collected in 2007 and/or 2008, and so averages include only the years where samples were collected. As expected, average total copper concentrations dropped at each of the sites in 2010 compared with concentrations measured at those sites between 2007 and 2009 (with the exception of the ambient site, E206513 (Tsolum River upstream from Murex Creek), where concentrations remained similar between the two periods). However, the decrease from pre-remediation to post-remediation was statistically significant (using 1-sided t-test assuming equal variance) only at site 0127620 (Tsolum River at Farnham Road Bridge) in the spring, due to the high degree of variability in the total copper concentrations at the other sites.

Table 4. Summary of total copper concentrations (mg/L) measured at the five Tsolum River sites, for spring and fall before and after the site remediation project.

E206513	2009	2010	t-test
Spring	0.0010	0.0011	0.11
Fall	0.0012	0.0012	0.47
E207826	2007-2009	2010	t-test
Spring	0.0338	0.0070	0.21
Fall	0.0084	0.0076	0.20
E255693	2009	2010	t-test
Spring	N/A	0.0062	N/A
Fall	0.0047	0.0037	0.23
0127620	2008-09	2010	t-test
Spring	0.0085	0.0057	0.04
Fall	0.0040	0.0031	0.26
0127621	2007-2009	2010	t-test
Spring	0.0052	0.0039	0.11
Fall	0.0022	0.0013	N/A

A comparison of total copper concentrations measured pre- and post-remediation at the five Tsolum River sites with the maximum total copper objective is shown in Table 5. In each instance (with the exception of the ambient site, E206513 at Duncan Main Road, where no change would be expected), post-remediation, the percentage of samples exceeding the objective at each site decreased. The decrease was most significant at E207826 (downstream from Murex Creek), where exceedances decreased from 36% of samples to only 4% of samples from 2007-2009 to 2010.

Of the remaining samples with total copper concentrations that exceeded the objective, it is important to note that the copper objectives for the Tsolum River are based on dissolved copper. Dissolved copper is more closely correlated to bioavailable copper, which is linked to impacts on aquatic life. Using total copper provides a more conservative approach to water quality objectives attainment. However, high flow events can cause increases in turbidity from erosional events or sediment disturbance which result in elevated total copper only. These events can physically impact aquatic life but are not necessarily related to copper from the mine site. For example, the concentration of total copper measured at Site E255693 (upstream from Headquarters Creek) on May 25, 2010 was 0.0115 mg/L (exceeding the objective), but the dissolved copper concentration on that day was only 0.00895 mg/L. In another instance, total copper measured at Site E207826 (downstream from Murex Creek) on October 19, 2010 was 0.0158 mg/L but another sample collected on the same day had a total copper concentration of 0.00315 mg/L, suggesting that there is a high degree of variability even on a given day. Intermittent exceedances of the total objective are much less likely to impact aquatic life than prolonged elevated levels of total copper.

Rolling average total copper concentrations were also calculated whenever samples were collected with sufficient frequency (a minimum of five samples within a 30-day period are required to determine an average value). Each rolling average represents a one-day offset from the previous average, providing there were the requisite minimum of five samples collected during that 30-day period (*i.e.* an average was calculated for all values collected between April 1 and April 30, and then a separate average was calculated for all values between April 2 and May 1, etc.). However, rolling averages were only calculated for the 30-day period preceding each new data point. For example, if data were collected on a daily basis from January 1 to May 1, rolling averages would be calculated for each day beginning January 31 until May 1 for the 30 days prior to each date. Averages could theoretically continue to be calculated until May 25 (until that date, the data set contains at least five samples in the previous 30-day period). However, the last 25 rolling averages would simply be reanalyzing existing data, and no new information would be produced.

Table 5. Comparison of total copper concentrations measured at the five Tsolum River sites pre- and post-remediation with the maximum total copper objective (0.011 mg/L).

	Number of samples collected	Number of samples exceeding objective	% of samples exceeding objective
E206513			
2009	14	0	0%
2010	20	0	0%
E207826			
2007-2009	291	106	36%
2010	91	4	4%
E255693			
2007-2009	9	1	11%
2010	21	1	5%
0127620			
2008-2009	16	2	13%
2010	24	0	0%
0127621			
2007-2009	22	1	5%
2010	11	0	0%

Rolling 30-day average total copper concentrations for each of the five Tsolum River sites are shown in Figure 15 - Figure 19. Decreases in average total copper concentrations were seen at most sites in 2010 compared with previous years. The exception to this was site E255693 (upstream from Headquarters Creek), where four rolling average values measured in the spring of 2010 exceeded the objective, and no rolling average values exceeded the objective in 2009. However, there were insufficient samples collected in the spring of 2009 at that site to calculate any rolling averages. As decreases were seen in rolling averages in the fall from 2009 to 2010 at this site, it is likely that similar decreases occurred in the spring as well. Table 6 contains a summary of average 30-day rolling average values calculated for each of the five sites, and shows that there was a significant decrease in average concentrations for each of the four sites downstream from Murex Creek when there were sufficient data to calculate t-tests (1-sided t-test assuming equal variance).

Table 6. Average of 30-day rolling average total copper concentrations at each of the five Tsolum River sites for spring and fall, before and after site remediation.

E206513	2009	2010	t-test
Spring	N/A	0.0011	N/A
Fall	0.0012	0.0014	0.06
E207826	2007-2009	2010	t-test
Spring	0.0112	0.0069	< 0.005
Fall	0.0085	0.0076	0.01
E255693	2009	2010	t-test
Spring	N/A	0.0067	N/A
Fall	0.0055	0.0037	0.01
0127620	2008-09	2010	t-test
Spring	N/A	0.0058	N/A
Fall	0.0051	0.0032	0.01
0127621	2007-2009	2010	t-test
Spring	0.0085	0.0039	N/A
Fall	N/A	N/A	N/A

A summary of the total number of rolling averages calculated for each of the five Tsolum River sites both before and after the remediation project, as well as the number of times that the objective was exceeded pre- and post-remediation, is included in Table 7. With the exception of site E255693 (discussed above), only site E207826 (downstream from Murex Creek) had rolling averages that exceeded the objective in some instances. However, the degree to which the averages exceeded the objective decreased considerably – the average amount by which rolling averages exceeded the objective decreased from 0.0046 mg/L between 2007 and 2009 to only 0.0006 mg/L. That is, in those instances where the average objective was exceeded, the average amount of the exceedance dropped by more than a factor of seven, from 4.6 µg/L to 0.6 µg/L, above the actual objective.

Table 7. Comparison of total number of rolling averages calculated for the period before and after remediation, as well as the number of times that the objective was exceeded for each of the five Tsolum River sites.

	Number of 30-day rolling averages calculated	Number of averages exceeding objective	% of averages exceeding objective
E206513			
2009	5	0	0%
2010	6	0	0%
E207826			
2007-2009	239	192	80%
2010	73	46	63%
E255693			
2009	5	0	0%
2010	11	4	36%
0127620			
2009	5	0	0%
2010	11	0	0%
0127621			
2007	1	1	100%
2010	4	0	0%

5.0 SUMMARY

In conclusion, both maximum total copper and average total copper concentrations have decreased downstream from the mine site after the installation of the geomembrane in 2009. Total copper concentrations measured at three long-term and one new water quality monitoring sites on the mine property show considerable decreases in total copper concentrations in 2010 compared with previous years. Similarly, copper concentrations and loadings in Pyrrhotite Creek have also decreased substantially. Finally, objectives compliance within the Tsolum River has improved, and in those instances where objectives continue to be exceeded, the degree to which they are exceeded has decreased considerably. As the reclamation work associated with covering and revegetating the area over the geomembrane is completed in 2011 and the benefits of the remediation reach full potential, it is expected that copper levels will decrease further. It is anticipated that in the near future, objectives for copper in the Tsolum River will be met consistently, and continued increases in salmonid escapements will be observed.

Figure 1. Map of Tsolum River watershed and Comox Valley showing location of minesite and sampling locations.

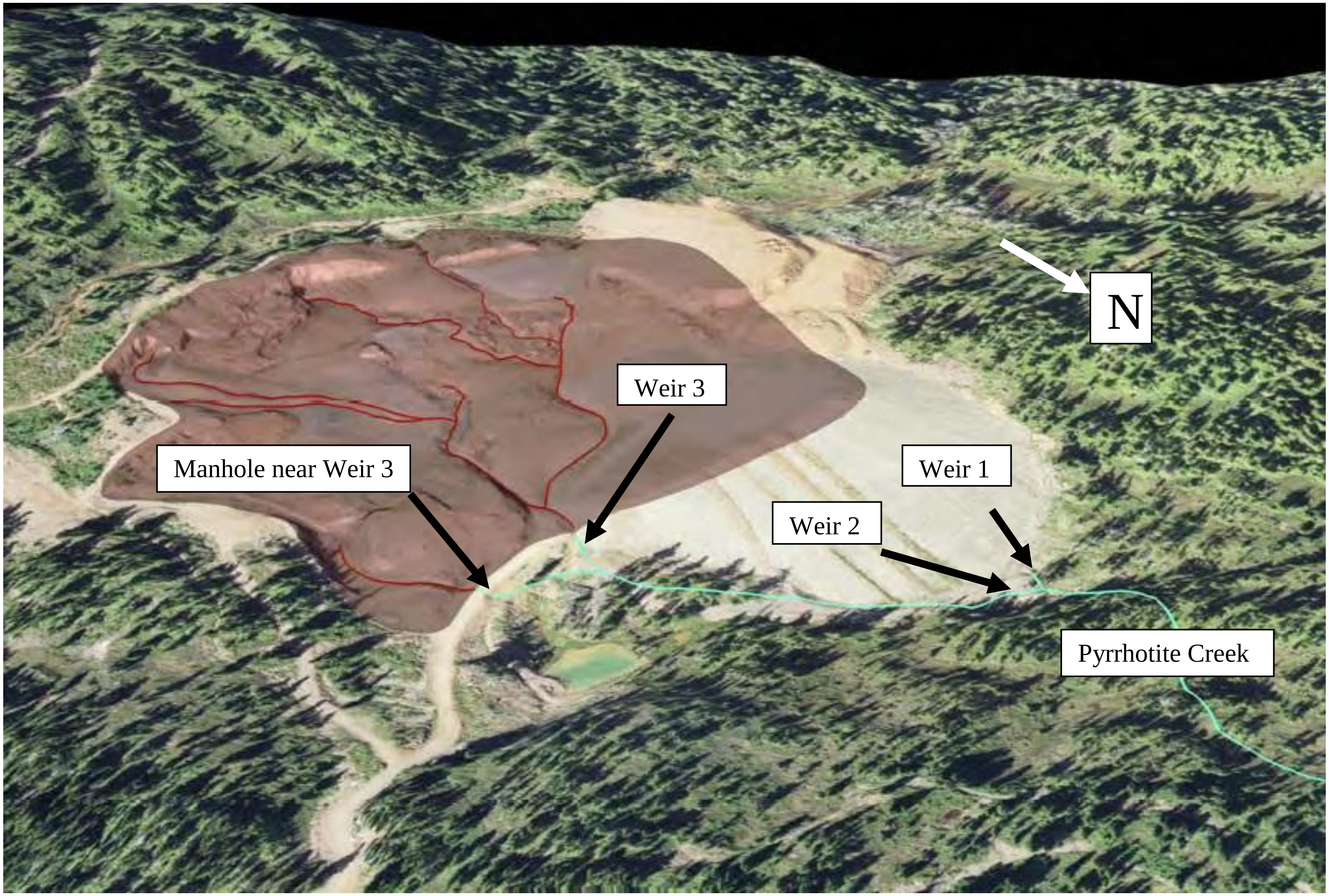

Figure 2. Artist's rendition of Mt Washington mine site (supplied by SRK Consultants) showing location of sampling sites.

APPENDIX I. FIGURES AND TABLES.

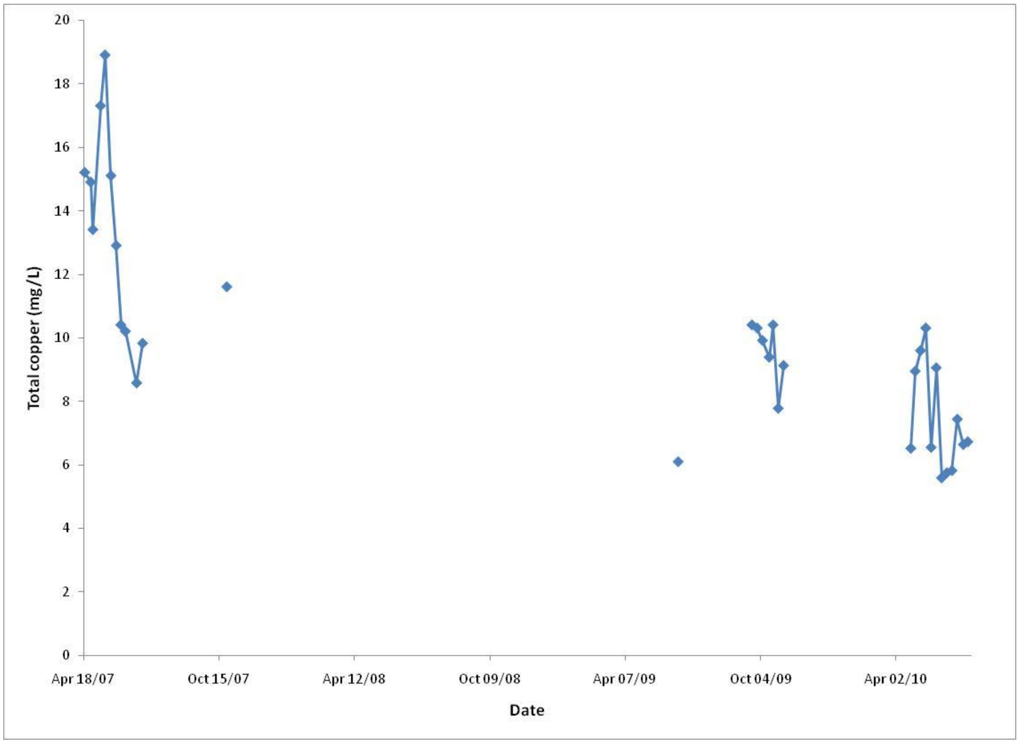

Figure 3. Total copper concentrations measured at Weir #1 near the mine site.

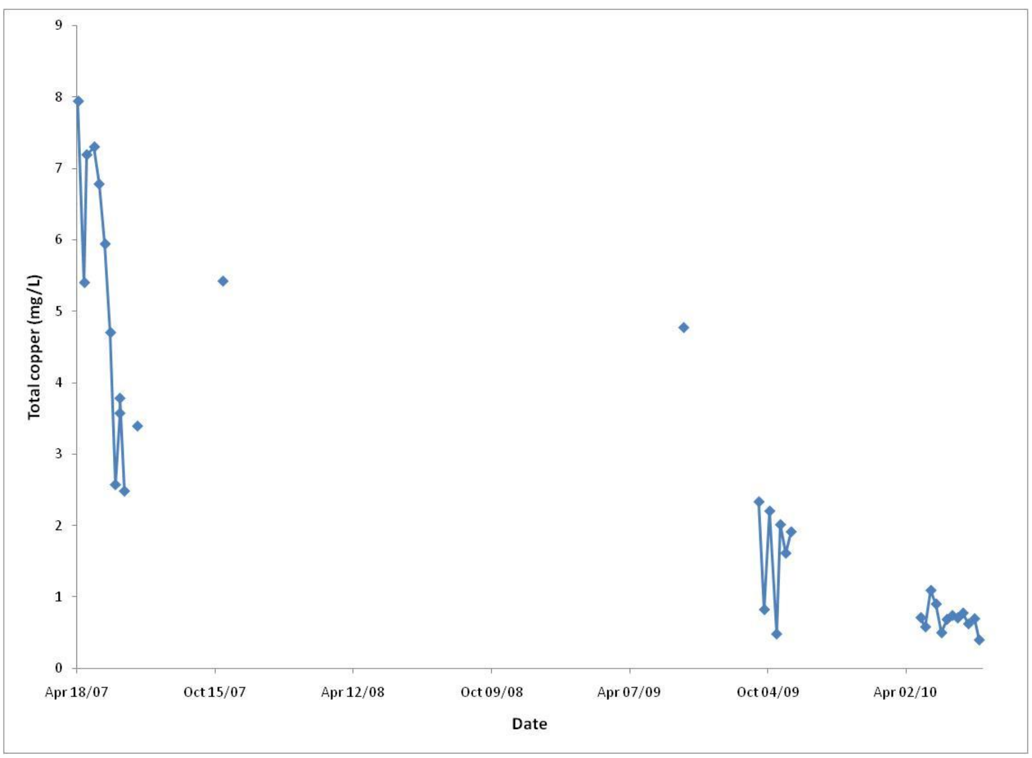

Figure 4. Total copper concentrations measured at Weir #2 near the mine site.

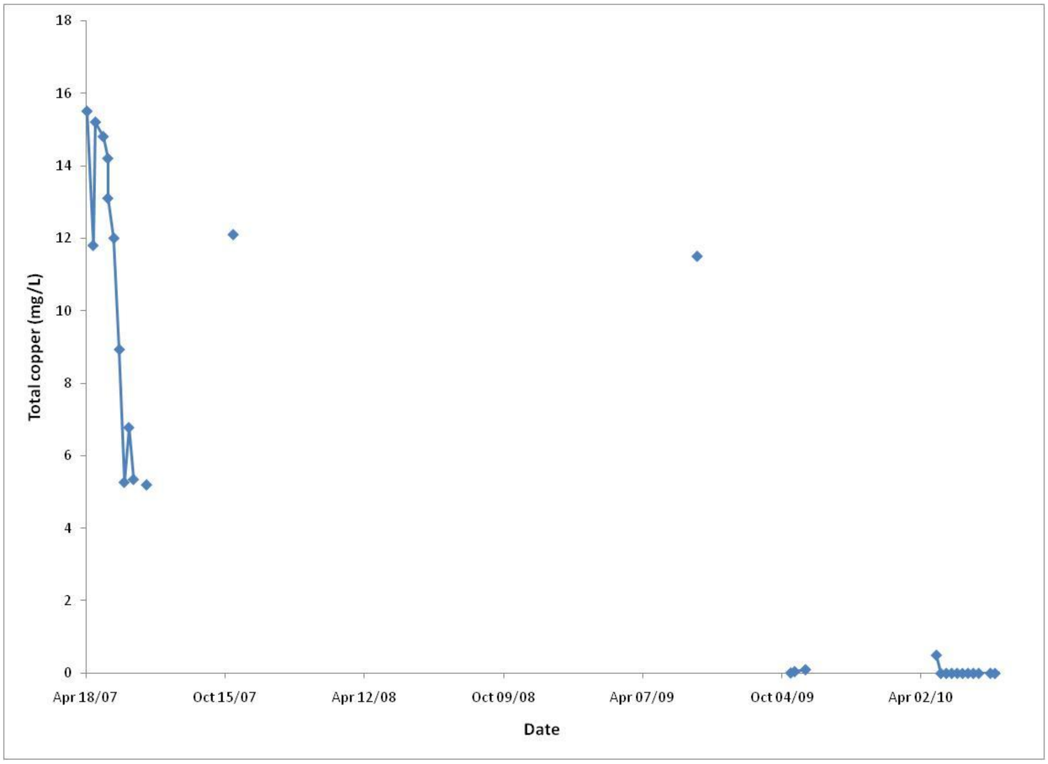

Figure 5. Total copper concentrations measured at Weir #3 near the mine site.

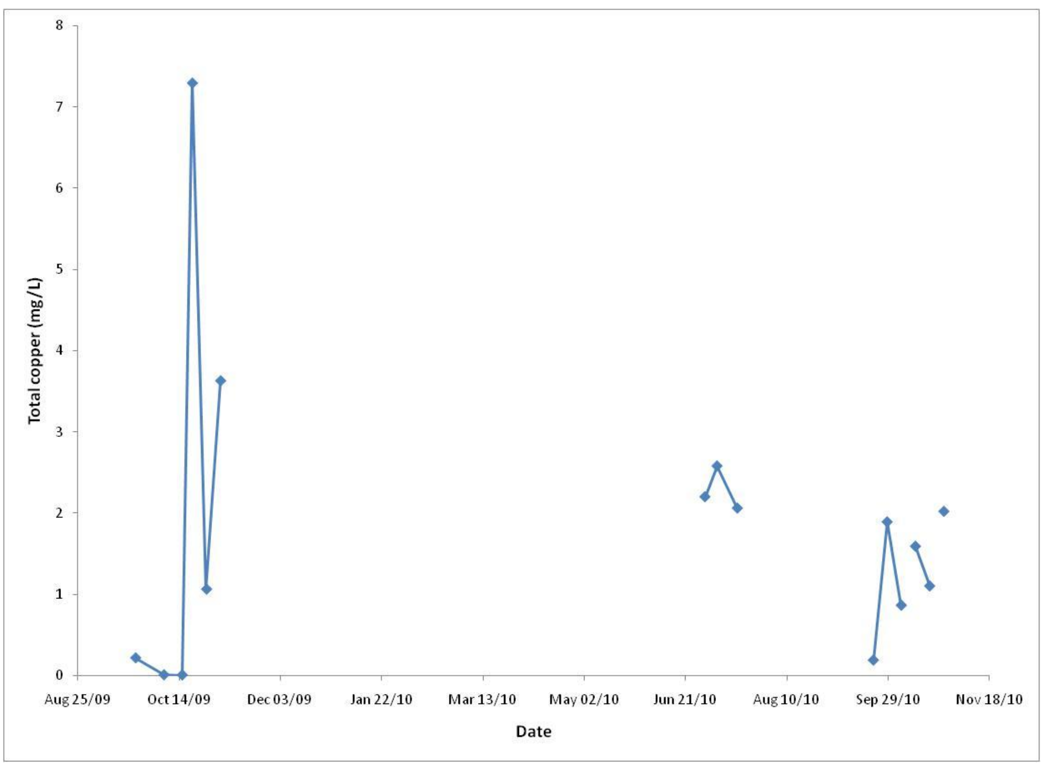

Figure 6. Total copper concentrations measured at manhole near Weir #3.

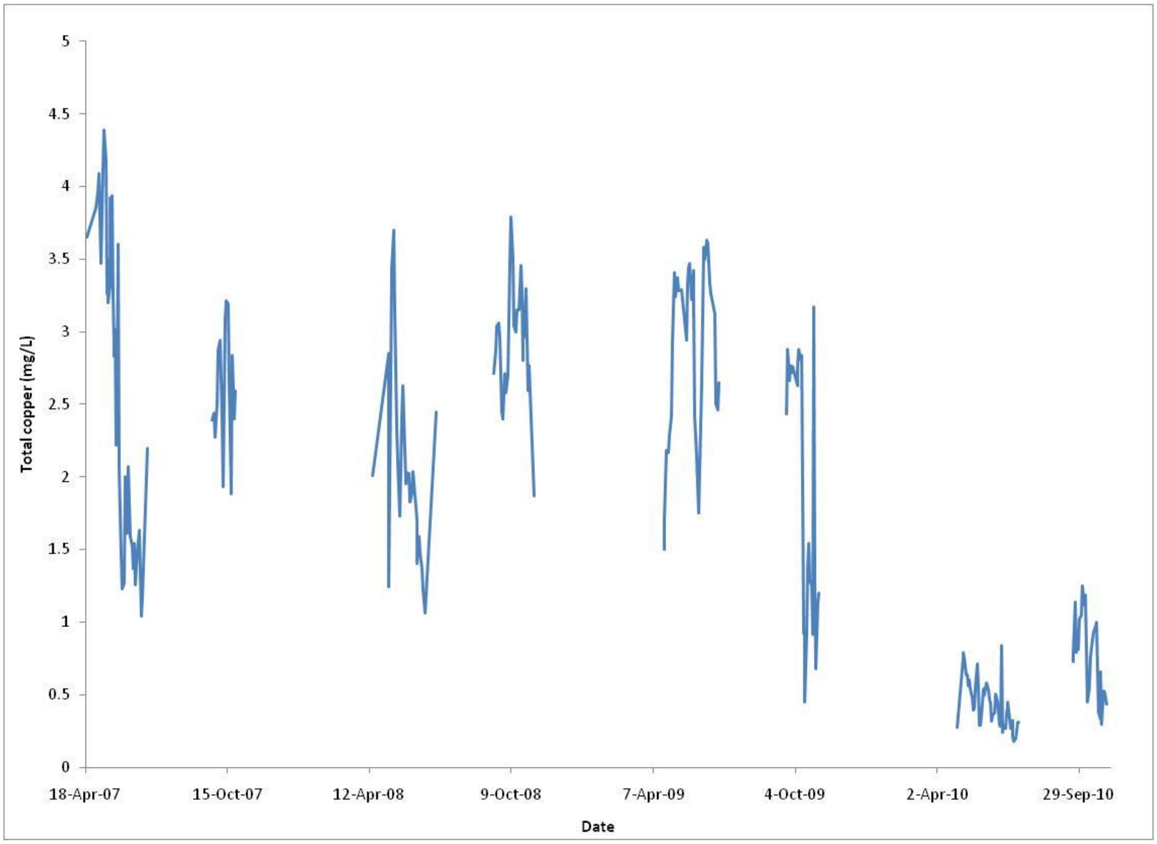

Figure 7. Total copper concentrations measured at Pyrrhotite Creek at Branch 1200 Road between 2007 and 2010.

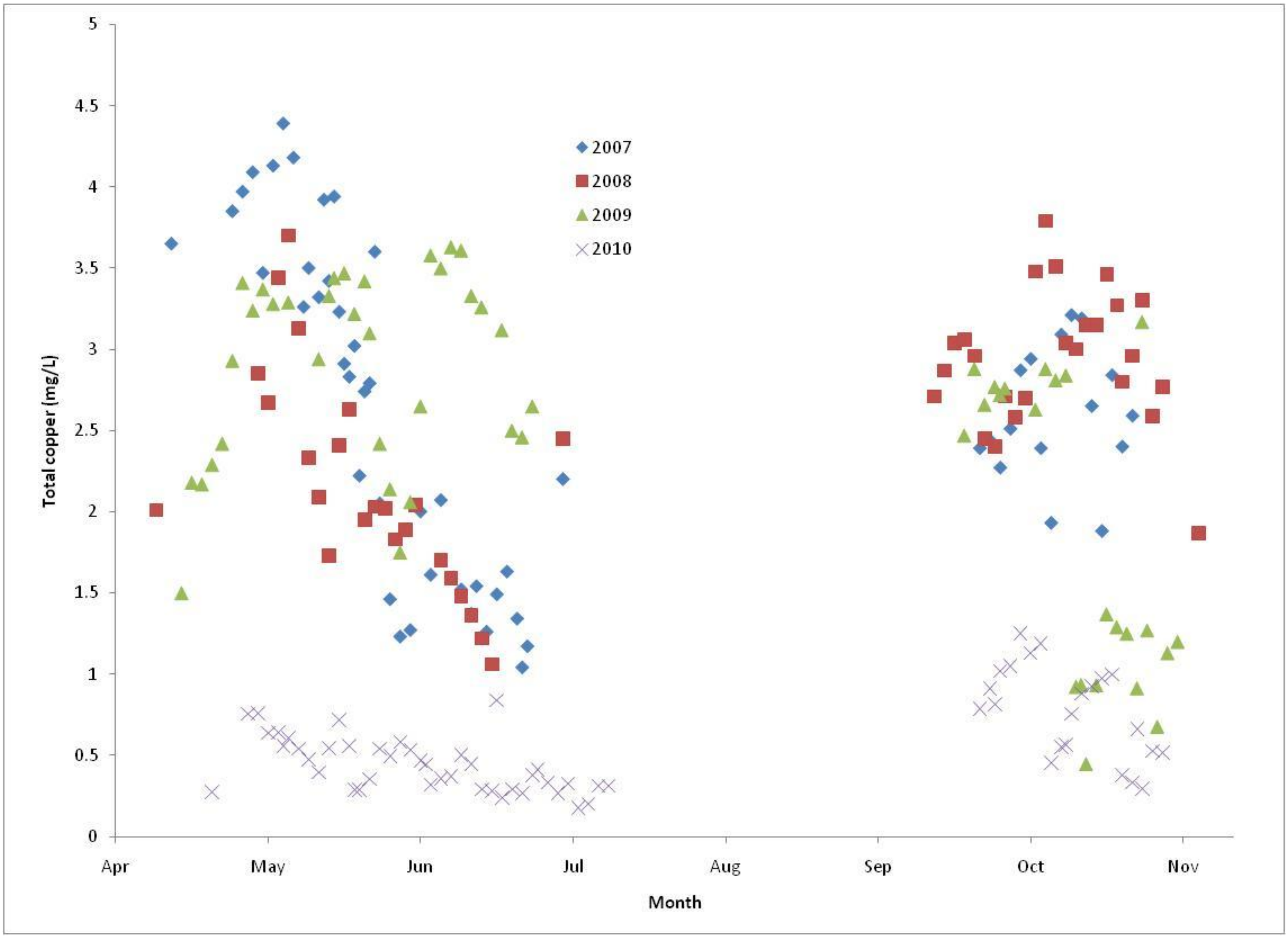

Figure 8. Comparison of spring and fall total copper concentrations measured in Pyrrhotite Creek at Branch 1200 Road between 2007 and 2010.

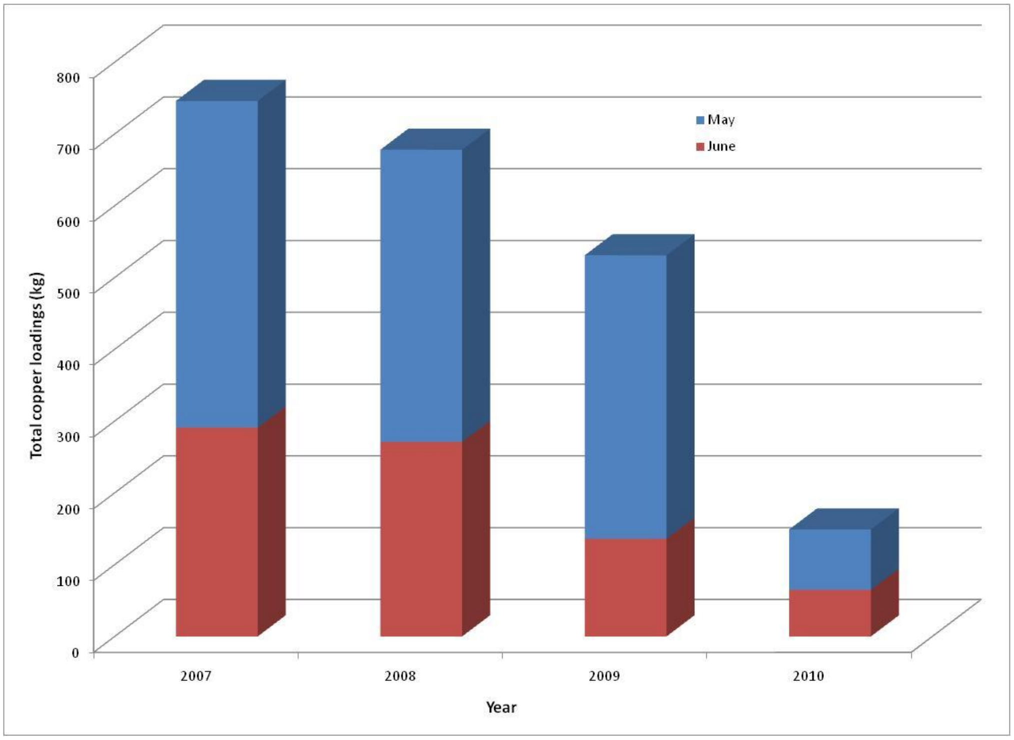

Figure 9. Comparison of total copper loadings to Pyrrhotite Creek for May and June between 2007 and 2010.

Figure 10. Total copper concentrations measured at E206513, Tsolum River at Duncan Main Road (upstream from Murex Creek), 2009 – 2010.

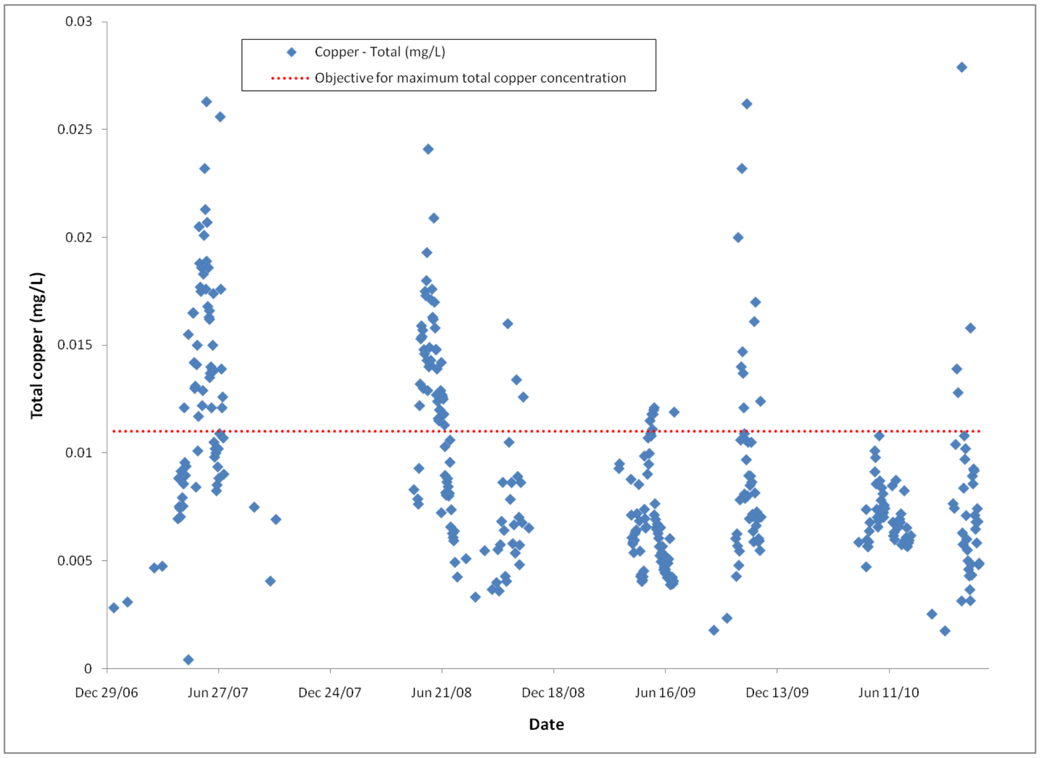

Figure 11. Total copper concentrations measured at E207826, Tsolum River 500 m downstream from Murex Creek, 2007 – 2010.

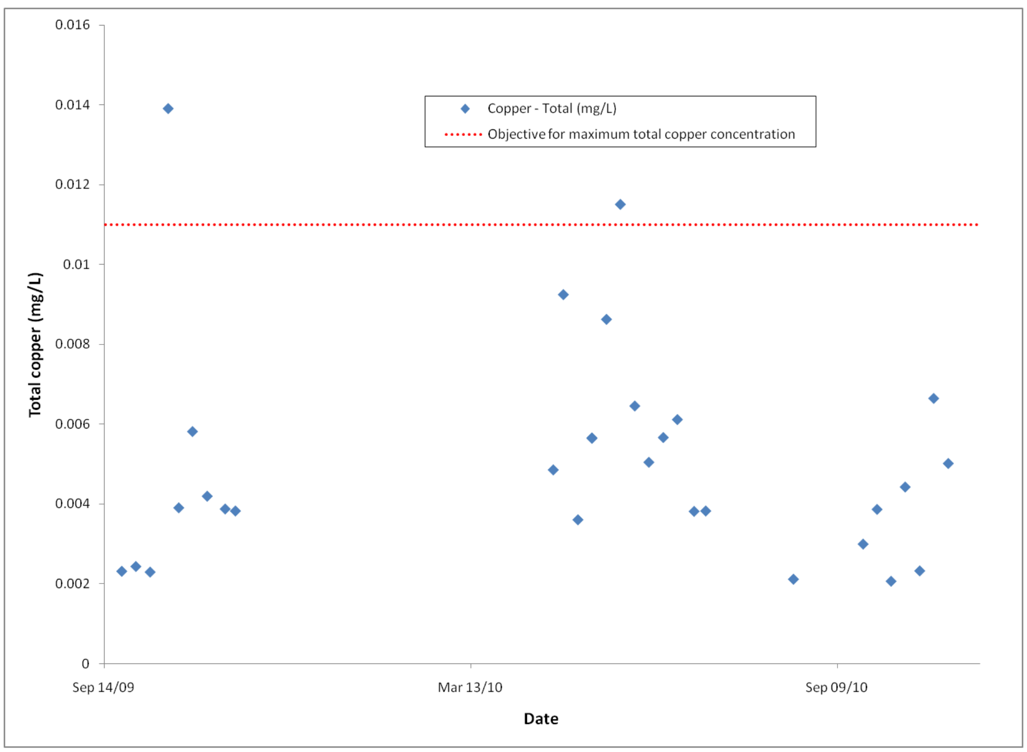

Figure 12. Total copper concentrations measured at E255693, Tsolum River upstream from Headquarters Creek, 2009 – 2010.

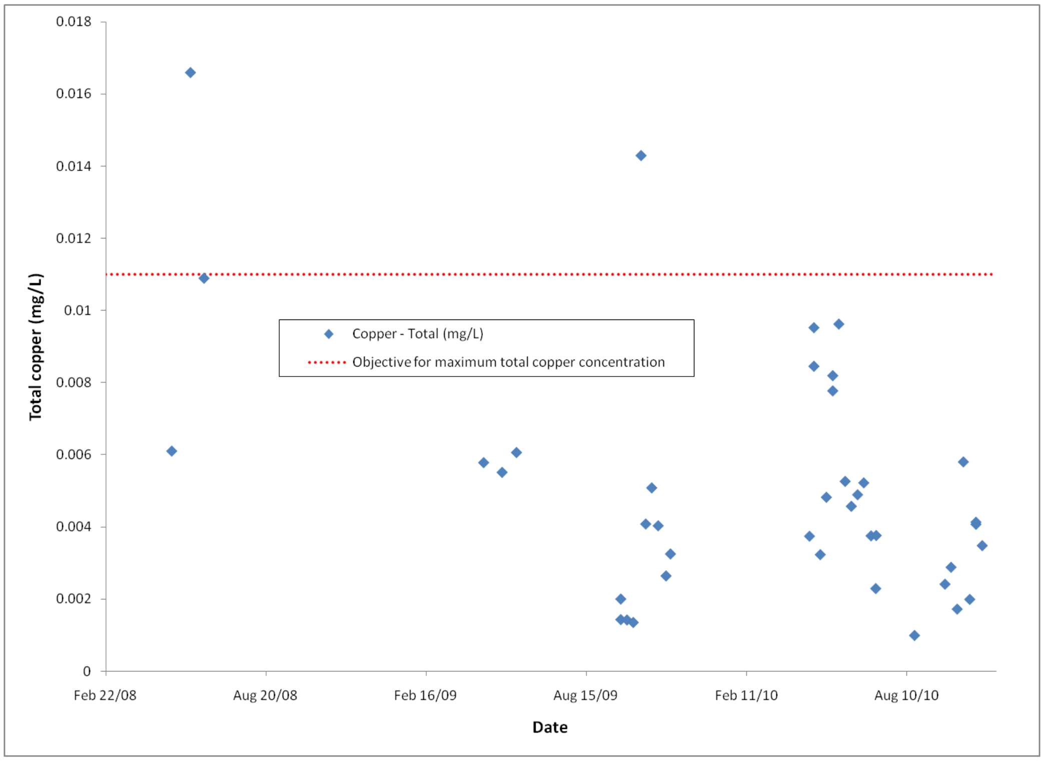

Figure 13. Total copper concentrations measured at 0127620, Tsolum River at Farnham Road bridge, 2008 – 2010.

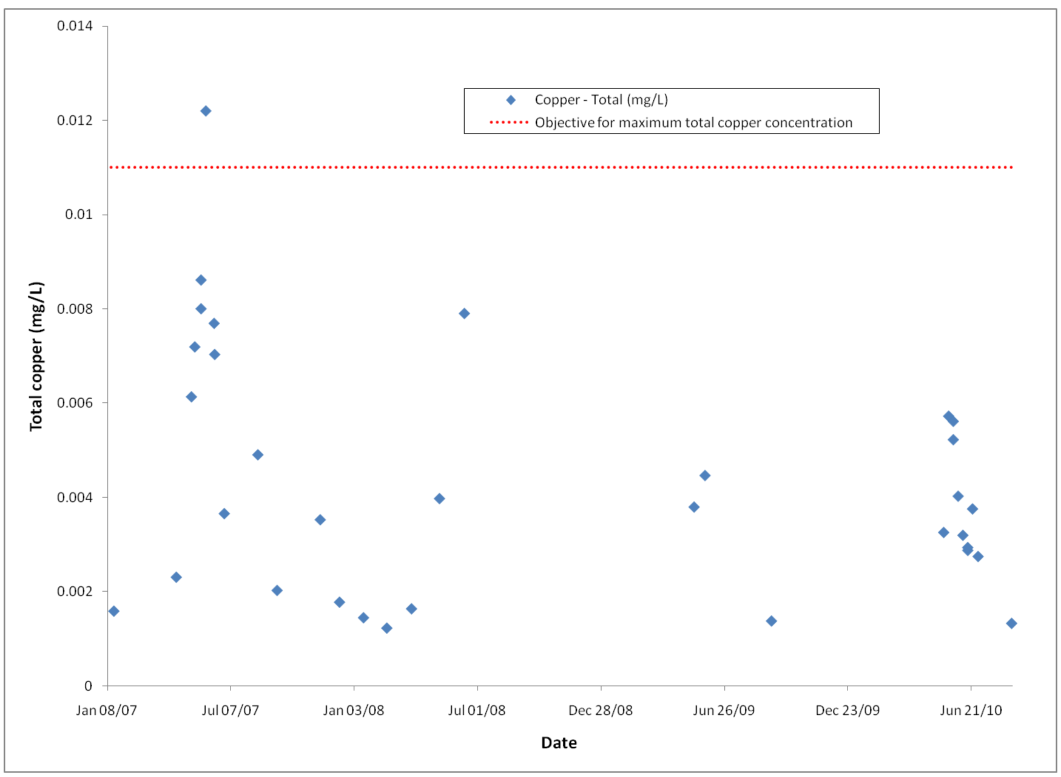

Figure 14. Total copper concentrations measured at 0127620, Tsolum River upstream from Puntledge River, 2007 – 2010.

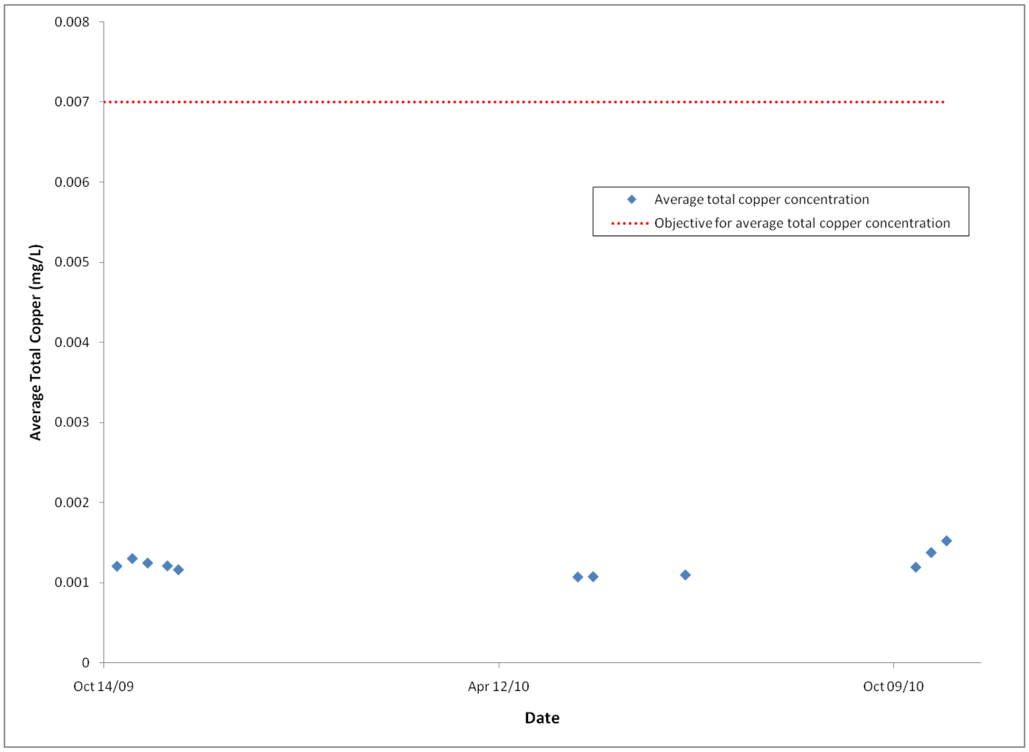

Figure 15. Rolling 30-day average total copper concentrations measured at E206513, Tsolum River at Duncan Main Road (upstream from Murex Creek), 2009 – 2010.

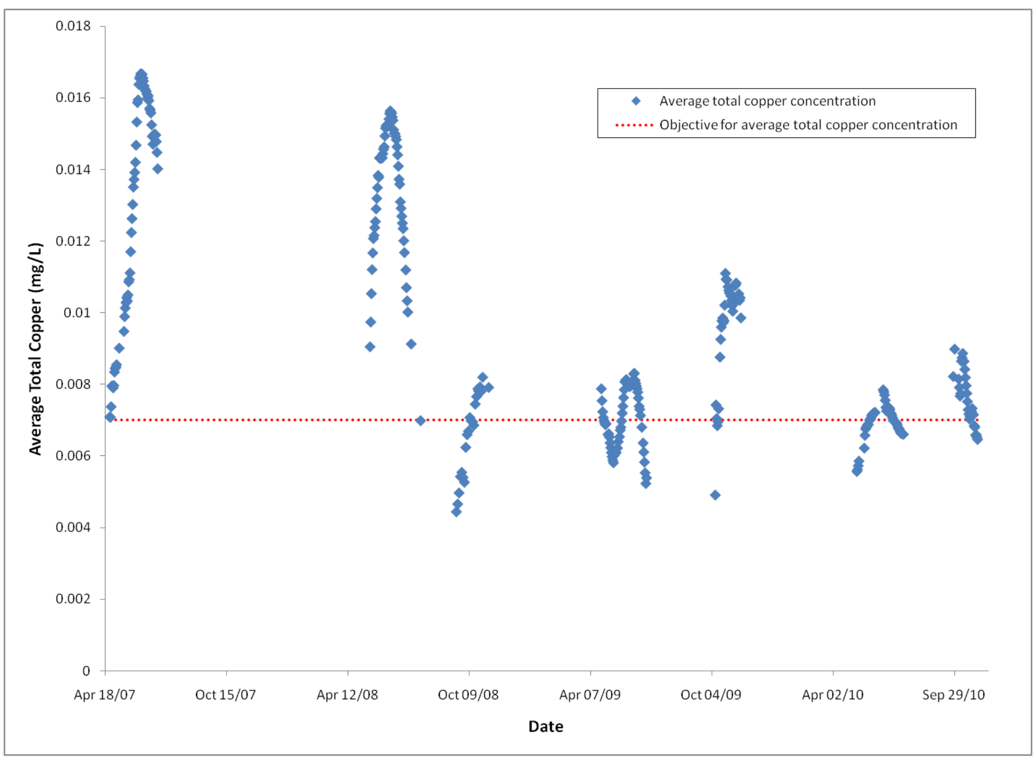

Figure 16. Rolling 30-day average total copper concentrations measured at E207826, Tsolum River 500 m downstream from Murex Creek, 2007 – 2010.

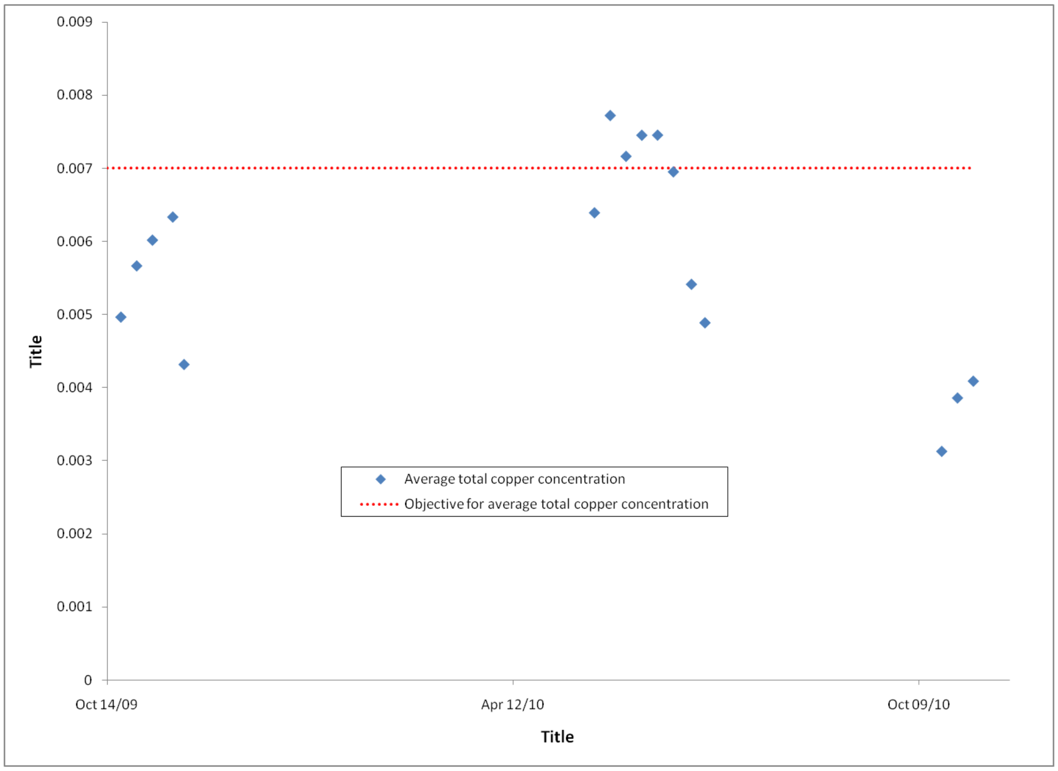

Figure 17. Rolling 30-day average total copper concentrations measured at E255693, Tsolum River upstream from Headquarters Creek, 2009 – 2010.

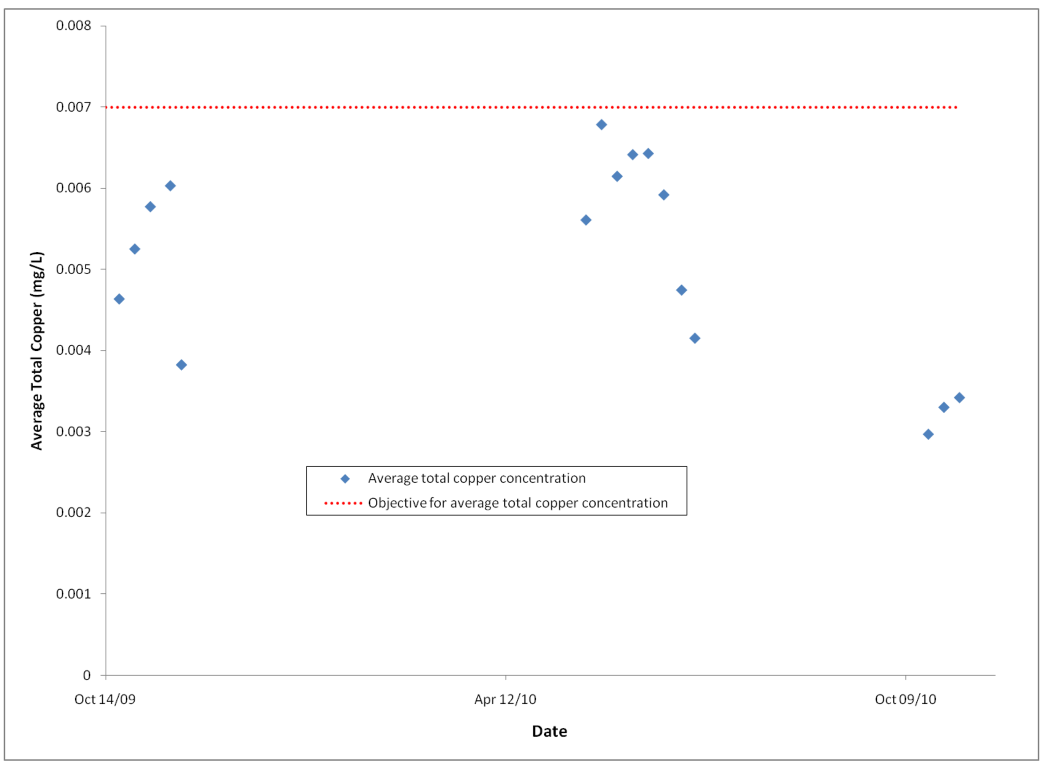

Figure 18. Rolling 30-day average total copper concentrations measured at 0127620, Tsolum River at Farnham Road bridge, 2008 – 2010.

Figure 19. Rolling 30-day average total copper concentrations measured at 0127620, Tsolum River upstream from Puntledge River, 2007 – 2010.