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Technical Memorandum #2
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Review: Copper toxicity and development of a Site-Specific Water Quality Objective for Williams Creek – Are the right questions being asked?

Introduction:
The Water Resources Branch (WRB) has undertaken a review of Western Copper Corporation's (WCC or the Applicant) Type A Water License Application for the Carmacks Copper Project. The mine footprint will be in the upper Williams Creek basin that drains eastward 7.5 km's (from the mine site) to the Yukon River. The project, along with other adjacent properties (Minto, Casino), is situated in a mineralized zone where copper is a principal constituent. Considerable attention has been given to copper levels in the small receiving water tributaries because of the known toxicity of this element to aquatic life.

Receiving Environment:
WRB agrees with the company's position that only the first kilometer of Williams Creek has significant habitat for fish. The channel upstream has steeper gradient and does not permit fish passage; aquatic life values (benthos, algae) would still be present, but likely are not of sufficient importance to afford full protection. WRB also agrees with the WCC's proposal that Station W12 (and downstream) is the receiving environment that should not be adversely impacted by mine effluents. This can be accomplished by establishing water quality objectives at this location using generic or derived (site-specific) limits that can be accepted as protective, and back-calculating (dilution modeling) the in-stream objectives to create discharge standards at the last points of control for waste discharge at the mine site.

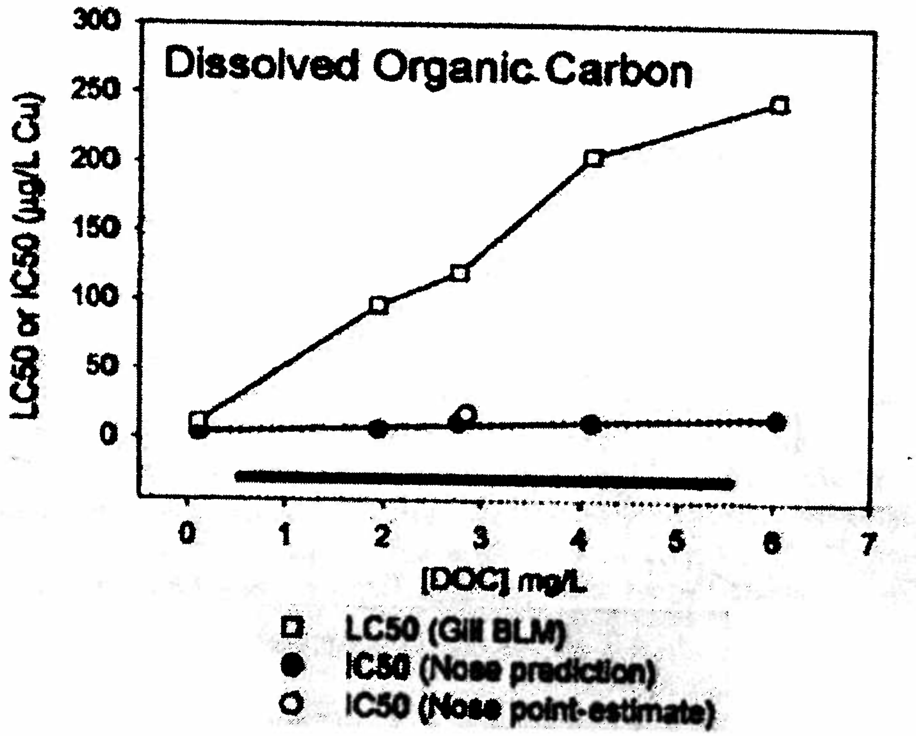
WCC's consultant Minnow Environmental reviewed company data for 2005-2007 and determined that the baseline copper level in lower Williams Creek was approximately 0.004 mg/L (mean). By comparison, Yukon River water carries 0.002 mg/L copper. The concentration in this portion of Williams Creek is already equal to the upper range of the Canadian Council of Ministers of Environment (CCME) water quality criteria for the protection of aquatic life for copper in hard water. Note that the CCME Canadian Environmental Quality Guidelines (2005) represents the primary water quality guidance used by WRB and similarly by the Applicant. The CCME criteria for copper are hardness dependant within three ranges (more hardness equaling less toxicity for an equivalent amount of copper). Williams creek borders on the medium-hard designation of hardness (i.e., on either side of 180 mg/L Hardness as $CaCO_3$). While the background copper concentrations already appear to be near the limit for the protection of aquatic life, other constituents in the water can modify the bioavailability and thus lethal and sub-lethal toxicity of copper.

Copper Toxicity and Toxicity Modifiers:
This section will focus primarily on the toxicity of copper to fish, and in particular, those species/genera that are known to be present in Williams Creek - Chinook salmon and Arctic grayling.

Salmon
Copper is known to disrupt osmoregulation by interfering with sodium uptake in fish gills and cause direct lethality at higher copper concentrations. Published LC_{50} values for freshwater salmonids vary considerably. For example, Taub (2004) reported acute lethalities for rainbow trout (0.250-0.680 mg/L) and Coho salmon (0.06-0.074 mg/L) – a 10 fold difference.

The most sensitive attribute of migratory fish (salmon) appears to be related to neurobehavioural toxicity that can be indirectly related to lethality. This concerns the proper functioning of the olfactory nervous system, that directly influences a salmon's migratory sense and ability to avoid predation. These affects have been well-documented to occur at very low copper concentrations, though metal bioavailability considerations are important. As noted, a hardness scale is commonly cited with copper water quality criteria as a modifier since this relationship is well-established (see Singleton (1998), for BC; CCME). Similarly, higher pH, alkalinity and dissolved organic carbon (DOC) are known to reduce toxicity, though apparently not predictable enough for modifier relationships to be developed. These constituents reduce toxicity by competing for binding sites (ligands) at the gill as well as complexing copper in the water column and making it unavailable for other reactions.

McIntyre et al (2008) exposed juvenile coho salmon to 0.02 mg/L copper for 30 minutes under different water chemistry regimes to discern which components were most influential. The researchers noted that while toxicity at the gill is a widely utilized biotic ligand model (BLM) test approved by the USEPA, the model's utility may not extend to sublethal neurobehavioural toxicity effects on the olfactory system. The study compared the effects of modifiers on median lethal copper concentrations (LC_{50}s) and secondly, on median inhibitory concentrations (IC_{50}s) on chemosensory capacity. The former investigation was found to have much greater sensitivity to chemical modifiers. For example, DOC was 20x more influential in the case of lethality at the gill relative to the nose, which indicated that the ligands in both structures are distinctly different and likely have different affinities for copper. As this work was done in the Pacific Northwest, the tested DOC levels were lower than those found in Williams Creek (6 mg/L versus 16 mg/L respectively). However, the slope of the relationship shown below is informative and suggests that the protection from DOC at the nose is gradual through low copper concentrations and vastly different from lethality at the gill:



The authors concluded that olfactory toxicity of copper may be only partially reduced in surface waters that have a high DOC content. The bottom solid black line in the above figure denotes the typically low DOC levels in west coast U.S. streams. The form of carbon complexes varies regionally and the relationship of considerably higher levels of DOC with copper in Yukon's waters cannot be reliably extrapolated from this research.

Comment: The protection provided to migratory salmonids by DOC during lethality testing related to gills cannot be extrapolated to the olfactory system and its concomitant role in prey avoidance and migration

Limited research is available for **Chinook salmon** behavioural studies, however Hansen et al (1999) compared responses of Chinook and Rainbow trout exposed to copper. They had two important findings. Chinook did not avoid higher dissolved copper concentrations following acclimation to a nominal 0.002 mg/L Cu concentration, while rainbow trout consistently avoided copper above 0.0016 mg/L. Of more interest, the addition of DOC at 4 and 8 mg/L did not appreciably affect the avoidance response of Chinook salmon, whereas this same lab treatment did elicit avoidance by rainbow trout at low copper concentrations. The team concluded that Chinook salmon may experience chronic physiological effects (behavioural) at relatively low copper concentrations and were observed to be 'intoxicated'. As with the work by McIntyre, et al, the olfactory system is likely of most concern.

Comment: The protection afforded by DOC to rainbow trout , a non-migratory salmonid, cannot be inferred on migratory salmon such as Chinook salmon. The two species appear to have different avoidance capacities and the Chinook salmon olfactory sense may be overwhelmed quickly.

Arctic Grayling

Little research appears to have been done on the toxicity of copper to **Arctic Grayling,** although Buhl and Hamilton (1990) report LC_{50} values for two age classes. The lethal limit for the swim-up (very young) stage was given as 0.00265 mg/L and for fry, 0.0096 mg/L. The presence or influence of toxicity modifiers during the testing is unknown. Grayling can be expected to both spawn and rear in lower Williams Creek, and the lethal concentrations identified by these researchers are exceptionally low for young grayling.

WCC's Derivation of a Site-Specific Water Quality Objective (SSWQO) for Copper at W12:

Minnow Environmental (Minnow) has conducted several rounds of testing to develop a SSWQO for copper in Williams Creek (Minnow, 2008; Minnow, 2009). They noted that the rationale for using the Water Effect Ratio procedure is to take account of the relatively high concentration of DOC in Williams Creek and the associated reduction in bioavailability/toxicity of copper. Lab-based toxicity testing (LC_{50}s, IC_{50}s) was carried out for various organisms in Williams Creek water spiked with copper (the only fish used were rainbow trout and fathead minnows). The resultant ratios between measured responses in lab water and site water were then multiplied by generic (CCME) water quality criteria to arrive at SSWQOs.

Date	**Method**	**SSWQO Cu (mg/L)**
2007	Water Effects Ratio (WER) 5.4 (fathead minnow) 6.5 (rainbow trout)	(based on lowest WER x generic CCME of 0.003) **0.016**
Spring 2008	Background Concentration	**0.003**
Spring 2008	WER 6.4 (rainbow trout) 10.5 (invertebrate)	(based on mean of two lowest WERs – 8.2) **0.025**
Summer 2008	WER 15.8 (rainbow trout) 11.5-14.6 (invertebrate)	(based on mean of spring and summer WER results-10.5) **0.032** medium hard water **0.042** hard water

Three different manipulations have been used above – lowest WER, mean of two lowest WER and geometric mean of all 2008 WER results).

Comment: WER calculations above encompass a considerable range, and final objectives calculations are a product of how the groupings are handled.

Minnow noted also that while WERs for copper were generally supported by application of the Biotic Ligand Model to the parallel tests with lab water, toxicity in Williams Creek water was moderately under-predicted – possibly due to other unaccounted for constituents in the site water affecting toxicity. It is known for example that copper and zinc can act together and result in higher toxicity through additive or synergistic effects. Other limitations of the WER method have been described by the CCME and include: it may not reflect temporal/chemical variability of the site (e.g., Minnow had done testing in June and September, but not the low flow month of October); related to this, it may be difficult to duplicate confounding factors such as acidity, alkalinity, Ca:Mg ratios between site water and lab water; and, the procedure does provide exacting numbers that must be scaled up or down such that small inconsistencies can literally be multiplied many times.

Copper Objectives/Criteria of Interest:
It is useful to consider a range of copper criteria and site specific objectives (with modifiers if available) to assess the levels being recommended for Williams Creek:

	Cu Criteria/SSWQO mg/L	Methodology
CCME	0.002-0.004*	Research compilation – no observed effect level
B.C. Environment	0.007**	As above
Water Resources - Yukon	0.007	Background concentration at W12 + 2x Standard Deviation
Capstone (Minto Creek)	0.013***	Previously a WER resulting in 0.017, and now a Background Concentration in consideration of olfactory impairment of salmon
Western Copper Corp. (Williams Creek)	0.021, 0.032, 0.042*	WER

*hardness dependant
**hardness dependant (criterion for chronic toxicity, hardness 175 mg/L)
***newest proposed limit, reduced from 0.017 mg/L Cu, recognizing olfaction concerns

The site-specific water quality objective for copper, submitted by WCC, has been developed through considerable effort following approved protocols, but questions and uncertainties remain about the details of the procedures. In summary:

- Tested fish species are not resident in Williams Creek
- Research suggests non-lethal, neurobehavioural responses may differ between migratory (Chinook salmon) and non-migratory (Rainbow trout) salmonids under the same DOC regime.
- Typical WER tests are directed at acute lethality endpoints at the gill, which is not the most sensitive or suitable endpoint for anadramous salmon where sensory system health is of particular importance; recall that McIntyre et al observed a 20x lower response to the protective influence of DOC at the fish nose, relative to the gill of juvenile Coho salmon.

- WER testing demonstrated that there may be additive or synergistic affects of metals or other contaminants that couldn't be accounted for. This is a concern that accompanies most all water quality criteria and site-specific objectives due to the myriad of contaminant complexes (and resultant toxicities) that cannot realistically be defined or predicted – hence the rationale for a precautionary and more conservative approach.
- Demonstrated WER testing (by Minnow Environmental) has considerable variability – which is expected when a variety of different biological taxa are involved, raising the question: which do you choose as being the most representative and applicable to actual site conditions? It appears some of the final calculations have been somewhat arbitrary though satisfying the minimum requirements of the procedure. There is uncertainty about making extrapolations of test results to species of most interest that have not been tested.

Recommendation and Path Forward:
Notwithstanding the stated concerns of the SSWQO work thus, Water Resources is not trying to be dismissive of the WER procedure. We share the opinion of the company that it should be a consideration for management of copper in Williams Creek and that the ameliorating influence of dissolved organic carbon can be significant – there is much supportive science elsewhere for this. After careful review of the literature on DOC-Cu related toxicity, the sequence of Background Concentration Procedure and Water Effect Ratio testing that has been presented by WCC, and another SSWQO for copper being proposed in a nearby drainage, our principal concern is that the proposed result is not sufficiently conservative given the uncertainties discussed here.

Also to be taken into consideration is the mixing and assimilation zone from the point of discharge to station W12. This allows substantial dilution flow over several kilometers of stream length as well as the input from Nancy Lee Creek, an adjoining tributary to the Williams Creek mainstem (and similar sized drainage area). In light of this, and in attempting to achieve an acceptable balance, we are suggesting a water quality objective that has a higher degree of certainty to prevent lethal and sub-lethal effects to the aquatic resources downstream of W12.

Summary: In the absence of WER testing with Chinook salmon that provides information on the sub-lethal affects of copper on the olfactory system, Water Resources recommends that a more conservative, site-specific objective based on background levels should be utilized in calculating effluent discharge standards (example presented below).

	Baseline (mean)	W12 SSWQO Mean + 2 Standard Deviations	Recommended Discharge Limit[1] (operations)
Cu mg/L (Total)	0.004	0.007	0.01

[1]Based on Williams Ck baseline flow of 0.050 m3/s and discharge of 0.026

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