



**Western Copper  
Corporation**

**Project Proposal  
Carmacks Copper Project  
Yukon Territory**

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**Appendix Q**

**Williams Creek Geochemistry  
(September 2006)**

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# Report

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## **Williams Creek Geochemistry September 3, 2006**

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**Submitted to Access Consulting Group**

Summary:

A series of analyses and simulations were conducted on water quality and streamflow data from Williams Creek, Y.T. for the purposes of determining the potential impacts of a copper mining operation within the watershed. The analyses and simulations were comprised of bulk geochemical equilibrium and attenuation calculations and advanced 2-dimensional hydrologic flow simulations. The results and discussion of these exercises are found in the following sections attached below:

I. Williams Creek Chemical Condition Assessment Bulk Analysis

II. Williams Creek Hydrologic Simulation and Chemical Condition Assessment

The general findings of these analyses and simulations indicate the following:

- 1.) Williams Creek is a well buffered natural stream with geochemistry and flows ample and adequate to assimilate, dilute and attenuate treated effluent from the proposed mining operation.
- 2.) Williams Creek already transports relatively high concentrations of naturally occurring total dissolved copper. However, given its high alkalinity, the natural total dissolved copper is likely not present as toxic free copper, but rather as non-toxic chelates of carbonates and hydroxyl groups. Soluble copper added through treated waste streams will likely take the same soluble forms and not impact aquatic life forms to any significant degree.
- 3.) The Creek is also sufficiently buffered with adequate flows to be able to assimilate limited accidental discharges of acidic copper solutions as well as controlled discharges of treated excess process solution without significant harm to downstream aquatic life forms.

Model runs for the Williams Creek chemical condition assessment bulk analysis and hydrologic simulation and chemical condition assessment are available on CD.

## **I. Williams Creek Chemical Condition Assessment Bulk Analysis**

### Background Conditions and Water Quality Genesis

The natural conditions of the water quality of Williams Creek were determined through direct sampling and analysis from 1989 to 2005 by Access Consulting. During that sampling period, the creek was consistently well buffered throughout the year with alkalinity ranging from ~40-250 mg/l as CaCO<sub>3</sub> and pH levels in the ranging from ~7.3 to 7.7. Buffering capacity was typically well above 100 mg/l as CaCO<sub>3</sub> with the lowest values noted during one early spring. Periodic springtime alkalinity depressions are not unusual as variations in the timing and amount of snow and ice accumulations and melting within the watershed may short-circuit shallow groundwater and/or hyporheic (stream bank and stream bottom) flow paths. In these instances, melt water with low dissolved solids dilutes down the alkalinity of the base flow of the creek.

The natural chemistry of the creek is likely derived primarily from the dissolution of dolomitic calcites within the soils and aquifer materials. Chemical simulations of natural rainwater (377ppm CO<sub>2</sub>; pH ~5.64) reacting with an unlimited supply of ordered and amorphous dolomites and calcites yields almost exactly the observed amounts of dissolved calcium, magnesium and alkalinity found in solution within Williams Creek. The only difference between simulated and actual conditions in this instance was that the pH was higher under the simulated case (about 0.5 pH unit). This is not surprising, since dissolved organic material, which is comprised of humic and fulvic acids were not measured in the field and not included in the simulation. Naturally occurring dissolved organic acids will reduce the overall pH of stream waters, but also add valuable ligands which chelate and remove dissolved metals from solution.

While the aquatic chemistry of Williams Creek is very likely controlled by reaction of runoff with Ca/Mg carbonate materials, what is unknown is to what degree runoff entering the length of the creek contacts dolomitic calcites or whether the water chemistry was initially poised by contact with a fixed/finite amount of carbonates in the headwaters. Since the composition of the creek water is very close to being in equilibrium with common Ca- and Mg- based carbonates, it is difficult to determine the degree to which alkalinity may be recharged in the system. This distinction is important when considering the range of impacts from the discharge of dissolved copper and/or mineral acids into the creek. Therefore, the most effective means to consider possible mine drainage impact is to simulate the creek water assuming continual contact with dolomitic calcites and assuming creek water not in contact with carbonates when exposed to accidental discharges of acidity and copper at high and low concentrations.

### Water Quality Scenario Testing Conditions

The means to evaluate the impacts of possible acid mine drainage on Williams Creek is to conduct a step-wise 'titration' of the creek water with an example waste stream. Since Williams Creek varies only slightly in major ion and acid/base chemistry an average water

quality composite was used for simulation of the natural in-stream conditions. For simulation of 'theoretical' waste streams 1.0M and 0.1M H<sub>2</sub>SO<sub>4</sub> acid solutions containing 0.3 mg/l Cu<sup>2+</sup> was added to the creek water at incremental volumes/flows of 10% of the stream volume/flow up to 200% of the creek flow. The equilibrium chemistry of the resultant mix of waters was calculated for each sequential addition to yield 'break through' points of acidity total and free copper concentrations. Solid phases of copper were allowed to precipitate when mineral saturation indices exceeded equilibrium. As discussed above, two sets of conditions were simulated against two types of titrants (discharges); 1.) Williams Creek water in contact with dolomitic calcites and 2.) Williams Creek water not in contact with dolomitic calcites.

The results for the breakthrough titration simulations/calculations are shown below in Figure 1. Note that regardless of the concentration of the acid component of the titrant, the results from the case where the creek water was assumed to be in contact with Ca/Mg carbonates were the same and are represented by a single output curve (solid black line). If carbonates are present in excess along drainage flow paths, acids added to the drainage system will be neutralized without depletion of available dissolved carbonates. Also under the scenario of carbonates present along the flow path, dissolved copper (added at the arbitrary concentration of 0.3 mg/l) is reduced by an order of magnitude through precipitation of copper carbonates (such as malachite). Further with added carbonates dissolved into solution through the reaction with added acids, the concentration of biologically deleterious free copper, [Cu<sup>2+</sup>], is greatly reduced through chelation and complexation with various soluble ligands.

Addition of titrants to Williams Creek in the case where the runoff does not contact Ca/Mg carbonates yields considerably different results. Additions of both dilute (0.1M) and concentrated (1.0M) acids depress pH to predictably variable levels through the course of standard additions. The dilute acid addition depresses the pH roughly linearly up to the maximum simulation of a 200% addition (2:1 titrant:creek water). However, the strong acid addition depresses the pH of the combined waters much more rapidly and hitting a theoretical curve break (where buffering capacity is fully depleted) around the 90% titrant addition point.

Dissolved copper behavior with acid additions in the absence of solid phase carbonates also behaves as expected. When copper is added as a titrant in a dilute acid solution where the concentration of dissolved carbonates are not immediately overwhelmed (up to ~25% titrant addition), the resultant concentrations of total dissolved and free Cu depend upon a combination of the concentration of total Cu added along with the availability of complexing agents and co-precipitates. A portion of soluble copper will tend to precipitate as a carbonate up until the point where soluble carbonates are depleted (titrant > 25%). After that point total dissolved and free Cu largely follow a dilution curve.

Total dissolved and free Cu in the mixed waters, added along with a strong acid solution, largely follow dilution curves. The saturation indices for common precipitates are immediately and consistently below zero due to the lack of co-precipitates in solution.

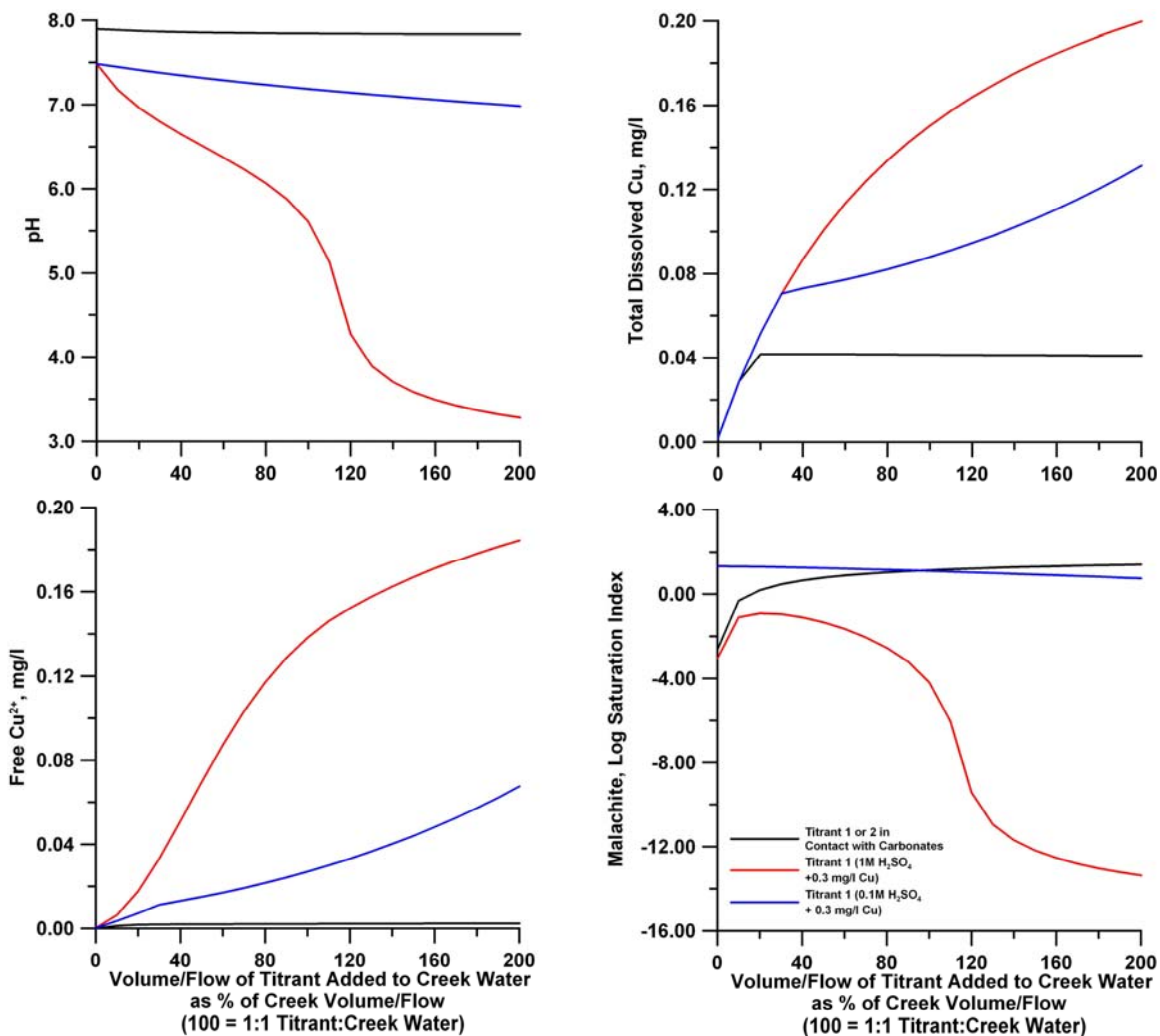


Figure 1 Williams Creek Titration Simulation Results

Relevancy to Neutralization Test Work on Process Solutions:

In June of 2006, Canadian Environmental and Metallurgical, Inc. (CEMI) conducted neutralization experiments on simulated waste streams for the operational mine site. CEMI sequentially added lime (CaCO<sub>3</sub>) to waste streams of pH 3.84 and 1.12 to achieve target pHs of 7.5, 8.5 and 9.5.

Several aspects of CEMI's experiments are relevant to the understanding of the response of Williams Creek to potential outflow from the proposed mining operation:

- 1.) A treatment pH of 7.5 was shown to be optimal from the standpoint of compliance with the resultant total concentration of copper in the treated solution. Simulated titrations of discharges of copper into natural conditions within Williams Creek indicated similar results with total copper concentrations remaining low due to the relatively well buffered stream water.

- 2.) The concentration of lime solutions necessary to neutralize the simulated effluent to optimal pHs in CEMI's experiments ranged from 10-13 g/l at 10% in static experiments. By comparison, the natural alkalinity of Williams Creek typically ranges from 0.1-0.2 g/l, within stream flow rates of 1-100 l/s. Under these conditions, ***Williams Creek has the natural capacity to dilute a treated waste stream to total copper concentrations well below acceptable limits and to also assimilate and neutralize small to medium releases of untreated or accidental discharges of acidified copper solutions.*** Taken in further context with the 2d modeling results, since it takes a minimum of ~12 hours for Williams Creek water to travel from the mine discharge site to the confluence with the Yukon River, there would be ample time for the in-situ neutralization and attenuation of treated and accidental waste streams.
- 3.) CEMI's results showed increasing total copper concentrations with increasing treated water pH. This is not entirely surprising since during a short (1 hour) reaction time, copper was likely held in solution through association (complexation) with soluble hydroxyl groups. While total soluble copper increased with treatment pH, the total concentration of the biologically significant free soluble copper would have plummeted. Further, given more reaction time and when in equilibration with atmospheric CO<sub>2</sub>, the total dissolved copper in the higher pH treatment solutions would likely precipitate as copper carbonates, reducing all forms of soluble copper. This is consistent with the simulations of the effects of total soluble copper additions into Williams Creek – total and free copper dropped quickly as natural carbonates and hydroxyls chelated and co-precipitated with available copper.

#### Conclusions:

MINTEQ simulations reported in Section II indicate that excess copper added to Williams Creek without additional acids would likely be scoured from solution through the rapid formation and precipitation of copper carbonates. The titration simulations reported above expands this range of understanding to include the possible co-introduction of dilute and strong acids along with copper into the creek in the presence and absence of solid phase carbonates. Considering the bulk simulation chemistry alone, the following points may be made:

- Williams Creek is relatively and consistently well buffered and will likely be able to absorb moderate additions/discharges of copper in non-acidic or weakly acidic solutions without reaching biological impact limits, and
- If the buffering capacity of Williams Creek is controlled through contact of surface waters with solid phases of Ca/Mg carbonates, Williams Creek would be able to assimilate larger additions/discharges of copper, even when introduced within stronger acid solutions.

Considering the bulk chemistry in light of the previously reported QUAL hydrologic and transport simulations, the following points may also be made:

- Mitigation of excess soluble copper discharged into Williams Creek would likely occur through mineral precipitation. Since the creek is shallow and the time of travel from the projected discharge point to the confluence of the Yukon River is relatively

slow (0.5-1 day) copper solids would likely be deposited in the creek sediment as amorphous carbonates,

- Copper carbonates, or other co-precipitates accumulated within the creek sediments would remain immobile under current creek chemistry, but may re-enter the system in a soluble form if in-stream alkalinity is depressed through subsequent acid additions.

## **II. Williams Creek Hydrologic Simulation and Chemical Condition Assessment**

### Objectives:

- Select, construct and execute an appropriate model for simulation of the hydrology and base water quality of Williams Creek before and during simulated conditions of a copper mine operation.
- Execute the hydrologic models under a range of conditions resulting from the likely climatic conditions at the site on a monthly basis and in conjunction with the projected mine operations.
- Assess the probable fate and distribution of chemical constituents added to the stream through routine and aberrant mining operations through extreme variance of the base hydrologic model and integration with a chemical speciation program.

### Model Selection and Methods:

QUAL2K was selected as the base hydrologic model for simulation of Williams Creek. QUAL2K (or Q2K) is a river and stream water quality model that is intended to represent a modernized version of the QUAL2E (or Q2E) model (Brown and Barnwell 1987). Q2K is similar to Q2E in the following respects:

- One dimensional. The channel is well-mixed vertically and laterally.
- Steady state hydraulics. Non-uniform, steady flow is simulated.
- Diurnal heat budget. The heat budget and temperature are simulated as a function of meteorology on a diurnal time scale.
- Diurnal water-quality kinetics. All water quality variables are simulated on a diurnal time scale.
- Heat and mass inputs. Point and non-point loads and abstractions are simulated.

The QUAL2K framework also includes the following key elements:

- Software Environment and Interface. Q2K is implemented within the Microsoft Windows environment. It is programmed in the Windows macro language: Visual Basic for Applications (VBA). Excel is used as the graphical user interface.
- Model segmentation. Q2K uses unequally-spaced reaches. In addition, multiple loadings and abstractions can be input to any reach.

- Carbonaceous BOD speciation. Q2K uses two forms of carbonaceous BOD to represent organic carbon. These forms are a slowly oxidizing form (slow CBOD) and a rapidly oxidizing form (fast CBOD). In addition, non-living particulate organic matter (detritus) is simulated. This detrital material is composed of particulate carbon, nitrogen and phosphorus in a fixed stoichiometry.
- Anoxia. Q2K accommodates anoxia by reducing oxidation reactions to zero at low oxygen levels. In addition, denitrification is modeled as a first-order reaction that becomes pronounced at low oxygen concentrations.
- Sediment-water interactions. Sediment-water fluxes of dissolved oxygen and nutrients are simulated internally rather than being prescribed. That is, oxygen (SOD) and nutrient fluxes are simulated as a function of settling particulate organic matter, reactions within the sediments, and the concentrations of soluble forms in the overlying waters.
- Bottom algae. The model explicitly simulates attached bottom algae.
- Light extinction. Light extinction is calculated as a function of algae, detritus and inorganic solids.
- pH. Both alkalinity and total inorganic carbon are simulated. The river's pH is then simulated based on these two quantities.
- Pathogens. A generic pathogen is simulated. Pathogen removal is determined as a function of temperature, light, and settling.

It is important to note that most of the advanced water quality functions of QUAL2K were not used in this exercise as they represent simulations beyond the immediate scope of this project. The functions in Q2K are used in this instance to verify pH, alkalinity and conductivity, the poisoning parameters that control soluble metals concentrations. All Q2K base simulation files were included on the accompanying disk in the instance that the client wishes to employ the advanced features for other future uses.

It is also very important to note that Q2K does not directly simulate equilibrium chemistry for soluble and solid phase metals, including copper. To assess the response of the stream relative to the possible discharges from the mine site, a separate chemical equilibrium program, Visual MINTEQ, was used to establish the likely equilibrium status of the aqueous system. MINTEQ solves for aqueous chemistry conditions by minimizing the Gibbs Free energy of constituents within solution subject to mass balance constraints. In plain terms, MINTEQ determines whether or not copper released into Williams Creek from a mining operation would tend to stay in solution or precipitate out as a solid. In the case of the former, MINTEQ also provides the likely species of copper in solution, providing the opportunity to assess the likely toxicity of residual concentrations.

The use of surrogate 'tracers' in Q2K enable the examination of the fate of soluble and particulate material introduced into the creek. The two models together then provide the ability to assess the fate and transport of metals fluxed into the system.

Other models exist that combine the fate and transport of metals within aqueous systems in one approach (such as PHREEQC, etc...), but the combination of Q2K and MINTEQ addresses the case of Williams Creek in the best and most flexible manner.



Assumptions, Conditions and Run Descriptions:

### **Q2K:**

The computer code used to implement the calculations for QUAL2K is written in Visual Basic for Applications (VBA). Excel serves as the user interface.

Color is used to signify whether information is to be input by the user or output by the program:

**Pale Blue** designates variable and parameter values that are to be entered by the user.

**Pale Yellow** designates data that the user enters. This data are then displayed on graphs generated by Q2K.

**Pale Green** designates output values generated by Q2K.

**Dark solid colors** are used for labels and should not be changed.

- Physical Description
  - A model Williams Creek was devised on the basis of the working site hydrologic diagrams and sampling sites previously established by Access Consulting. The model sequential and reach-based, starting with Williams Creek W9 and ending in the Yukon River at Y2.
  - Reach node coordinates positions and elevations were determined through geo-spatial analysis; channel slopes were derived from the spatial analyses. Channel characteristics (width and type), were extracted from existing site data. Channel roughness (Mannings 'N') was estimated for each reach using accepted ranges for similar systems.
  - Base monthly flows for Williams Creek were derived from data provided and are listed in the accompanying file 'Williams Creek Q2K Model Input Files.' Yukon River base flows (relevant for sites Y1 and Y2) were extracted from supplemental data (USGS Yukon Report). Expected settling pond(s) outfall and make-up water requirements were derived from data provided and also reported in 'Williams Creek Q2K Model Input Files.'
  
- Water Quality Parameters
  - Temperature, Conductivity, DO, Alkalinity, and pH were entered into the model initial conditions as averages derived from the water quality information provided from the site.
  - BOD, Nutrient, Plankton and Pathogen inputs were set as null and ignored through the course of this exercise.
    - Primary productivity, nutrient cycling, etc... may affect the pH/pE of the system and hence the conditions by which metals may react. However, Williams Creek is naturally well buffered (Alk ~ 150mg/l; pH ~7.8) and likely low in relative productivity. It is assumed that variations in these constituents would not impact the overall redox condition in an appreciable manner. The client may examine this

assumption through more extensive model sensitivity analysis using additional field or regional data.

- Solar, air temperature, cloud cover, shade, wind and other meteorological factors are held constant at logical levels.
- ***Inorganic Solids (ISS), are use within the model as a conservative tracer for materials introduced into the creek. The fate of ISS is controlled by settling velocities which for normal inorganic materials is about 1.0m/day. Settling velocities of 0.1m/day and 0.001m/day were used to simulate the behavior of newly precipitated amorphous metals and near soluble materials respectfully. Under base simulation conditions, ISS are introduced at the headwaters (W9) at an arbitrary value of 1.0 mg/l so that the natural in-stream behavior may be expressed as a proportion of 1. Under simulated mine operation conditions, ISS were introduced with waste discharges at an arbitrary value of 100 mg/l so that the behavior of any introduced materials may be easily expressed as a percentage.***
- Diel variations are negated.
- Rate functions and stoichiometries are held constant at logical levels.

All Q2K values are easily inspected and modified within an Excel framework.

92 sets of model runs are provided, simulating 3 basic scenarios under high and low flow conditions in Williams Creek (note YEAR2 runs for month 12 do not exist since mining ops do not affect the system in December). The models are designated:

RUN WC Base xx hf:	Williams Creek high flow base conditions, month xx, 1.0 ISS at W9 @ 1.0m/d $V_s$ for tracing purposes
RUN WC Base xx lf:	Williams Creek low flow base conditions, month xx, 1.0 ISS at W9 @ 1.0m/d $V_s$ for tracing purposes
RUN WC Floc xx hf:	Williams Creek high flow base conditions, month xx, 1.0 ISS at W9 @ 0.1m/d $V_s$ for tracing purposes
RUN WC Floc xx lf:	Williams Creek low flow base conditions, month xx, 1.0 ISS at W9 @ 0.1m/d $V_s$ for tracing purposes
RUN WC Base xx hf YEAR2:	Williams Creek high flow YEAR 2 mine operation conditions, month xx, make-up water diffuse extraction near W9, 1.0 ISS at W9, 100 ISS at entry points E, H, and J @ 1.0m/d $V_s$ for tracing purposes.
RUN WC Base xx lf YEAR2:	Williams Creek low flow YEAR 2 mine operation conditions, month xx, make-up water diffuse extraction near W9, 1.0 ISS at W9, 100 ISS at entry points E, H, and J @ 1.0m/d $V_s$ for tracing purposes.
RUN WC Soluble xx hf YEAR2:	Williams Creek high flow YEAR 2 mine operation conditions, month xx, make-up water diffuse extraction near W9, 1.0 ISS at W9, 100 ISS at entry points E, H, and J @ 0.001m/d $V_s$ for tracing purposes.
RUN WC Soluble xx lf YEAR2:	Williams Creek low flow YEAR 2 mine operation conditions, month xx, make-up water diffuse extraction near W9, 1.0 ISS at W9, 100 ISS at entry

points E, H, and J @ 0.001m/d  $V_s$  for tracing purposes.

### Visual MINTEQ:

Visual MINTEQ is a Windows version of MINTEQA2 ver 4.0, which was released by the USEPA in 1999. MINTEQA2 is a chemical equilibrium model for the calculation of metal speciation, solubility equilibria etc. for natural waters. It is probably the most widespread model for these purposes today, and it is renowned for its stability. The development of the Windows version of MINTEQA2 is supported by two Swedish research councils [VR](#) and [MISTRA](#).

The MINTEQ model is included with the results for client inspection and future use.

MINTEQ is a relevant model for Williams Creek as it determines:

- the probably speciation of metals naturally found in the Creek
- the likelihood of the removal of metals through sorption and/or precipitation
- the likely impact of metals added to systems from activities such as mining, and
- possible mitigation/remediation strategies for reducing metals and metal toxicity in natural systems.

MINTEQ and all chemical equilibrium programs that attempt to predict the compositions of metals in natural systems have two major dependencies:

- 1.) Equilibrium reactions are predictions of an end state. The rate by which reactions approach equilibrium may be known in well constrained conditions, but vary widely in natural systems. In some instances, equilibrium may not be reached without the action of appropriate catalysts. Therefore, MINTEQ results must be considered as likely end members rather than as definite and immediate products, and
- 2.) Naturally occurring dissolved organic substances such as humic and fulvic acids provide strong sorptive surfaces that may bind to metals in solution and remove them from reaction with other substances. While there is capacity within MINTEQ and other programs to model this behaviour, accurate field measurements of the sorption capacities of naturally occurring organics has never been achieved. It is therefore difficult to determine how much of a given metal will be available for reaction with other constituents. However, with a reasonable understanding of a system, intelligent assumptions may yield the most likely and verifiable results.

Regardless of these dependencies, chemical equilibrium modelling is a useful exercise as it 'brackets' the likely outcome for a given system. And in the case of Williams Creek (well buffered, medium conductivity, low organics), MINTEQ results are very useful for understanding system behaviour.

- Input

- Chemical conditions for Williams Creek do not vary significantly throughout the year and input into MINTEQ was averaged across relevant time periods. The input file (Mean Average Input .VDA) lists all components used in the base simulation and all solid phases considered for reactions (N.B. the user may inspect and edit the full geochemical data base that is provided within MINTEQ – the database incorporates the latest referenced set of all parameters associated with aqueous chemistry)
  - The system was simulated as open-atmosphere with CO<sub>2</sub> at 350ppm, initial pH = 7.8, T=3°C and alkalinity expressed as CaCO<sub>3</sub> at 150 mg/l. Units were selected comparable to the input data provided.
- Model Runs and Output
    - As is common with chemical equilibrium models, numerous simulations were executed in order to determine the response levels for the system. From the results of these simulations, 3 representative MINTEQ simulations are reported. The titles are self explanatory and are listed as follows with accompanying output file (.OUT). Output results are also listed conveniently in Excel files named similarly.
      - 1.) Mean Average Input
      - 2.) Mean Average Input + 0.1 mg/l Cu
      - 3.) Mean Average Input + 10.0 mg/CU

### Results and Discussion:

#### Q2K:

A comprehensive listing of all model outputs is found in the individual output files. The following is a brief summary of major finding describing Williams Creek.

Under pre-mining conditions (current), Williams Creek hydrology is typical of small mountain systems. Water moves down from W9 at an average velocity of 5-20 cm/sec under low flow conditions and 10-40 cm/sec under higher flows (Fig 1.). It then may take a parcel of water anywhere between ½ and 4 days travel the course of the ~8.5km Creek into the Yukon River (Fig 2.). Under these flow conditions, particulate matter of normal density will likely settle out of solution within 2-4 km of creek travel distance, whereas more flocculent material may require 4+ km for partial removal (Fig 3.).

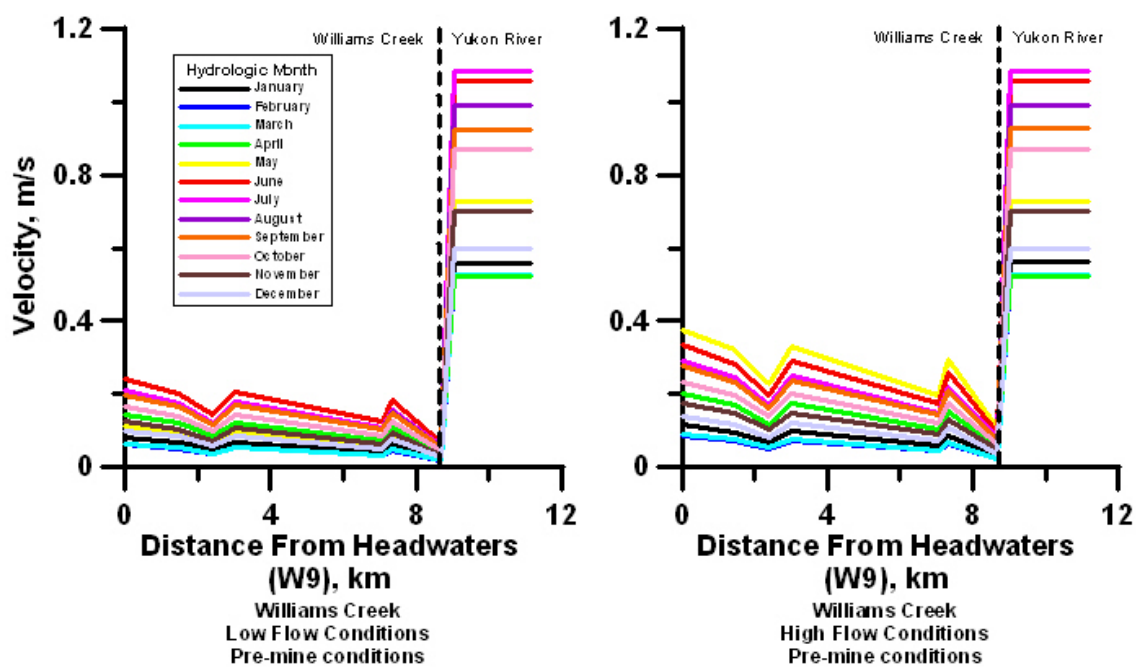


Figure 2

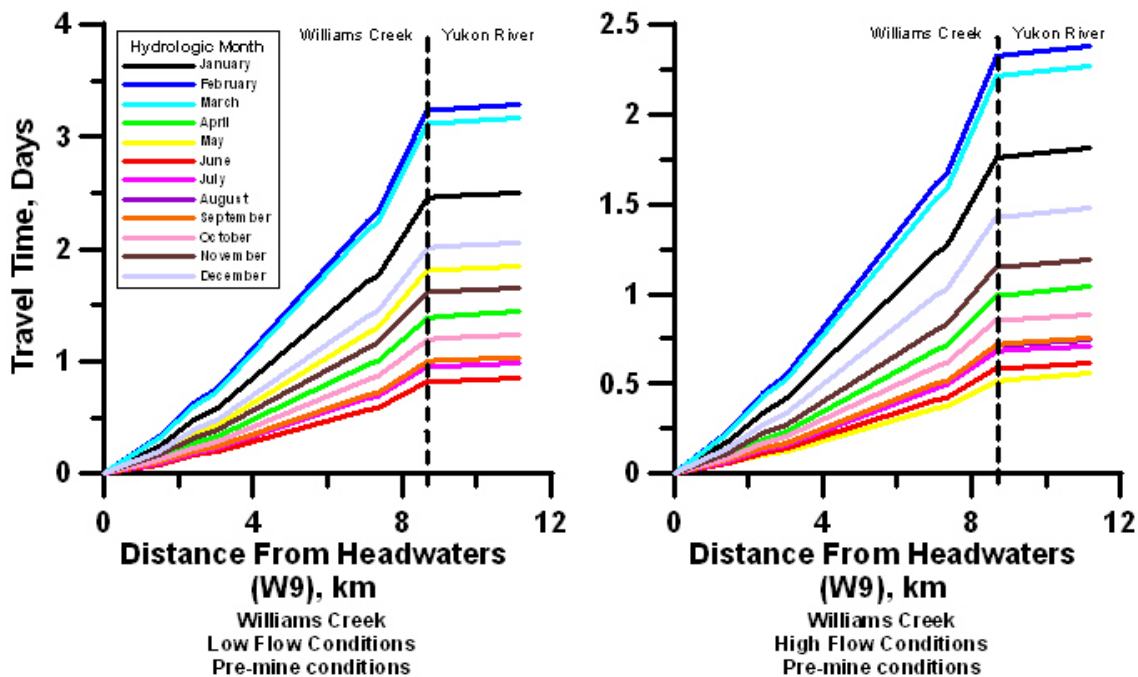


Figure 3

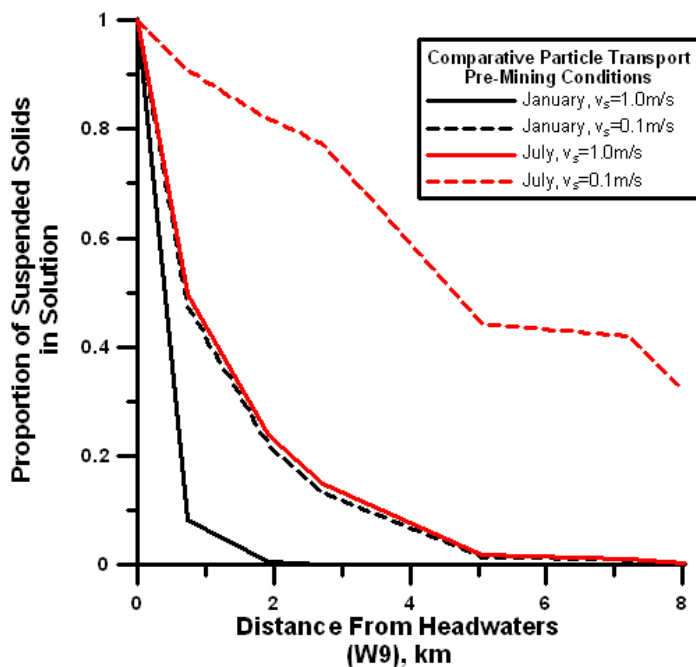


Figure 4

Water quality conditions during base simulations were rather invariant since the Creek is well buffered and no biochemical reactions were allowed to occur during the simulation. Full results of the chemical simulations may be reviewed and re-simulated in the appropriate accompanying models.

The hydrologic effects of the projected mining operations on Williams Creek are most pronounced in January when water discharges are greatest relative to typical stream flows (Fig 4.).

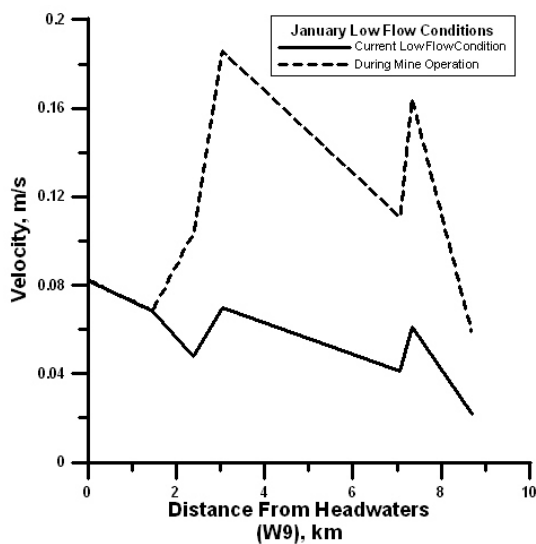


Figure 5

Analysis of conservative tracers hypothetically fluxed into the creek from mining pond(s) discharging in January indicate that 20% of the original concentration of particulate matter would immediately affect the system and then be removed by settling before entering the Yukon River. If material is entered into the system as a soluble substance, over 80% of that material would remain in solution at the point of confluence with the Yukon River.

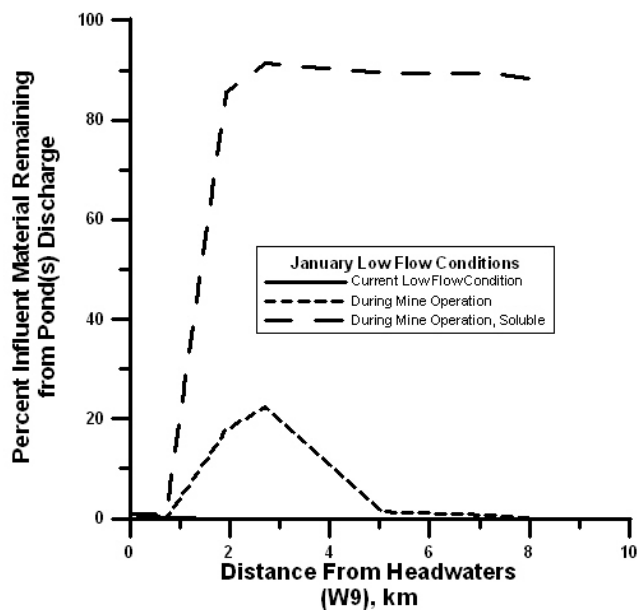


Figure 6

Low flow during the month of January represents an extreme condition for potential effects from mining operations with all other times and conditions showing much less potential impact. Also, note well that any soluble metals entering Williams Creek would likely form particulate material very quickly and be removed from the system with the length of the creeks run (see MINTEQ results).

### Visual MINTEQ:

Given the well buffered, well oxidized nature of Williams Creek, MINTEQ modeling indicates that under current conditions, there is the propensity for trace metals in solution and Cu in particular to form amorphous co-precipitates with ferric iron. For Cu, the likely solid phase is cupric ferrite with nearly all of the already low levels of Cu in ambient solution tending to be form this solid.

In examination of more extreme discharge conditions, adding equal amounts of discharge waters with a concentration of Cu at 0.1 mg/l to Williams Creek would likely still result in the removal of nearly all of the soluble copper as an amorphous hydroxide co-precipitate. Only at extreme conditions of Cu concentrations ranging upwards of 10 mg/l would the system be unable to precipitate all of the metal due to the limitation of a co-precipitate precursor, iron. N.B. that in order to reach this concentration in Williams Creek, discharge from the site would have to be equal in volume to stream flow and double (20 mg/l) in concentration – a very unlikely scenario.

Finally, any soluble Cu in solution within the well-buffered Williams Creek would likely exist either as a complex with soluble carbonates or in chelation with dissolved organic matter, of which both forms are very low in aquatic toxicity.



**Conclusion:**

Williams Creek behaves hydrologically as a typical small mountain stream system with a wide range of response between months and between high and low precipitation years. However, under most flow regimes suspended solids introduced into the creek near the headwaters are likely to fall out of solution by the time the creek enters the Yukon River. Since it is a well buffered system, soluble reactive substances, such as aqueous copper, would likely form precipitates quickly, provided that the system remains high in alkalinity and pH.

Due to its small and robust characteristics, Williams Creek lends itself well to regulatory compliance monitoring