TECHNICAL MEMORANDUM

To: Lindsay Dehart
Yukon Government

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From: David Flather
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Project #: 487-1

Subject: Carmacks Copper Project: Technical Review of Acid Heap Leach Detoxification Program

Western Silver Corporation is planning to develop the Carmacks Copper Project which will recover copper as cathode, using an acid heap leach and SX/EW process. Closure considerations for this project revolve around expected water chemistry emanating from the spent leached ore. To address these issues, Western Silver Corporation commissioned rinsing and detoxification studies on representative ore material and developed a Conceptual Closure and Reclamation Plan as part of their application for a Quartz Mining License for the Carmacks Copper Project.

The Yukon Government commissioned Lorax Environmental Services Ltd. to perform a technical review of the proposed heap detoxification process and relevant closure strategies. The following technical memorandum has been prepared following the review of information prepared by Western Silver Corporation and its consultants. Specifically, the following documents have been reviewed:

- Project Description and Environmental Assessment Report for the Carmacks Copper Project (2005);
- Conceptual Closure and Reclamation Report (Appendix F);
- Beattie Consulting Ltd. (2001) Report on Leaching and Decommissioning of Samples from Carmacks Oxide Copper Project (Appendix E);
- Detoxification and Rinsing Testwork Report (Alexco Resources Ltd. 2006);
- Clearwater Consultants Ltd. memorandum CCL-CC6 and CCL-CC7 (2006)

Overview and Summary

Prior to a detailed discussion of the key aspects of the technical review, provided below is a summary of the most salient review comments with respect to the proposed Carmacks Copper acid heap leach detoxification program:

- Laboratory column rinse testing is an acceptable and widely practiced approach to evaluating closure strategies for heap leach operations.

- The methods employed in neutralization and rinse column testing for the Carmacks Copper Project are acceptable and fully documented in the proposal.

- There appears to be a lack of integration of the laboratory rinse data with the proposed closure plan for the heap leach and important aspects of the conceptual plan (*e.g*. rinse times; water treatment method) are not supported by the data. Most notably, the most recent column rinse testwork (Alexco 2006) did not produce acceptable draindown chemistry until solution:ore ratios of 3.0 had been achieved. When these rinse volumes are scaled to the proposed actual heap tonnages, the volumes are equivalent to rinsing with approximately 40 million m^3 of water. If rinsing can only be employed during the six-month ice-free period, this translates to a rinse-time (to achieve water chemistry observed in the column testing) of over 17 years (see Table 1).

- The proposed plan is stop rinsing/neutralization after three years. Considering that the heap leach pad at closure will contain 13.3 M tonnes of spent leached ore, a rinsing rate of 540 m^3/h and a rinse time of three years, the proposed plan is equivalent to a total rinse solution:ore ratio of 1.07. Based on the most recent column detoxification testwork for a similar solution:ore ratio, the drainage chemistry from the heap leach pile would be expected to contain very elevated concentrations of copper, molybdenum and selenium (see Table 1).

- With respect to the above, the proposal needs to state if neutralization and rinsing will occur year-round or only during the ice-free periods as this could affect the amount of rinsing that occurs and the resultant drainage chemistry at the cessation of rinsing/neutralization.

- Water chemistry from the column neutralization and rinse testing indicates that elevated levels of selenium (Se) could be expected at Carmacks, particularly in the early phases of rinsing, which often poses treatment difficulties.

- The proposal would benefit from bench-scale water treatment testing of actual column rinse draindown waters, which currently represent the best estimate of future rinsate quality. The data could then be used to better demonstrate the efficacy of the proposed water treatment scheme to treat rinse solutions that are not economical for copper recovery. The presence of Se in heap leach neutralized rinsate was not known and therefore not considered in the 2005 Project Description and Environmental Assessment report. Experience at other mines indicates that the proposed water treatment scheme of lime neutralization is not generally successful at reducing Se concentrations, particularly from oxidized solutions where Se exists as the less particle reactive selenate ion.

- The long-term closure scenario currently relies on metal removal following carbon addition, initially to heap recirculation waters during rinsing and possibly directly into the passive infiltration field. The geochemical processes invoked to control metal concentrations subsequent to these carbon additions are inconsistently described. In some descriptions of the Conceptual Closure and Reclamation Plan, metals are stated to be "stabilized" in the heap (pg. 3-7, 3-11), where as in others it is stated that carbon addition is not intended to "actually immobilize metals in the heap" but rather to provide a means of precipitating metals in soil horizons (pg. 3-8). It is not clear from the descriptions if, in fact, the intended metal removal mechanism is via the fostering of reducing conditions to precipitate metals as insoluble metal sulphides (either in the heap itself or the infiltration gallery) or adsorption of metals onto soil surfaces in the infiltration gallery.

- The baseline water quality data for the receiving environment (*i.e*. Williams Creek) is limited and suffers from historically high detection limits for key environmental parameters. As such, the actual assimilative capacity of Williams Creek at the proposed compliance point (W10) is poorly constrained. Additional data, employing more appropriate detection limits, should be collected during the expected discharge window (*i.e*., May to October). These data have the potential to demonstrate that the assimilative capacity of Williams Creek is quite high and that the potential for environmental impacts are low.

- The proposal should develop site-specific discharge limits for discharge water for closure considering the closure water balance and expected water treatment performance. To state that discharge will meet MMER may not always be consistent with the other objective of meeting CCME criteria at the compliance point. This is particularly true for Cu during the early phases of rinsing when discharge treatment volumes are expected to be greatest. Moreover, MMER does not have limits for the full suite of parameters that are typically considered important in current environmental evaluations.

Detailed aspects of the above findings and review are provided in the sections below.

Integration of Laboratory Detoxification and Rinsing Testwork with Proposed Closure Plan

Rinse Time and Expected Chemistry

The results from the laboratory column detoxification and rinsing testwork completed to date (Beattie 2001 and Alexco 2006) do not appear to have been directly used in the development of the conceptual heap closure plan for the Carmacks Copper facility. The testwork completed by Beattie (2001) was somewhat inconclusive and complete rinsing and neutralization was not accomplished in the 1996 testwork (Western Silver Corp.;

Appendix F pg 3-2). Based on these results, further column rinse-detoxification-neutralization work was commissioned in 2004 and 2005 to evaluate the recommendations from Beattie (2001) that more fresh water rinsing be completed up front to remove a larger inventory of sulphate prior to the addition of base (Alexco 2006).

Test results from the Alexco work indicated an optimum rinsing strategy that employed an initial fresh water rinse followed by pH adjustment through pulse addition of 5% solution of sodium carbonate; continued rinsing then occurred using fresh water pulses. The primary conclusions of this testwork based on the results from Column 9, which received the preferred rinsing program, are stated as follows:

- Acceptable copper and pH standards were met within reasonable timelines of 200 column days;
- Continued rinsing with fresh water following neutralization with sodium carbonate was successful in reducing copper concentrations to below MMER discharge standards (*i.e*. 0.3 mg/L); and
- The testwork has demonstrated that it is technically feasible to rinse the free acidity and reduce metals to acceptable standards (Alexco 2006; pg 29).

Based on Column 9 results and the fact that 200 column days were required to produce acceptable pH and copper values, Alexco scaled-up the program to the full heap size and suggested that full rinsing could be achieved following approximately 1,600 days (4.4 years) of rinsing. Key assumptions in the calculation were:

1. A fresh water addition rate of 400 m^3/h (note this is lower than the Clearwater Consultants Ltd. water balance assumptions of rinsing at 540 m^3/h; CCL-CC7 2006);
2. Surface area under rinse of 40,000 m^2, average ore height of 26.4 m and total surface area of heap of 315,000 m^2;
3. 200 days to rinse 40,000 m^2 and therefore a total rinse time of ~1,600 days for the entire 31.5 ha heap ((315,000 m^2/40,000 m^2)*200 days)

There is a flaw in the scale-up approach provided by Alexco, specifically in the assumption that 200 days of column rinsing of 40 kg of material can be directly applied to the rinsing of 1.68 Mtonnes of heap ore (40,000 m^2 * 26.4 m * 1.6 t/m^3). Indeed, time is not the relevant parameter, but rather the quantity of rinse water used relative to ore in order to achieve the desired drainage chemistry. The latter is typically calculated in rinse testing as a *solution:ore ratio,* which is simply calculated as the volume of rinse water passed through the column per tonne of ore.

In the Alexco testwork, a solution:ore ratio of 3.0 was necessary to achieve acceptable drainage chemistry described in the report conclusions (Table 1). Assuming a total ore tonnage at closure of 13.3 Mtonnes, the scaled-up rinse volume can be estimated (13.3 Mtonnes * 3.0 m^3/tonne) and suggests that upwards of 40 million m^3 of rinse water would be necessary to produce drainage chemistry observed in the columns. Assuming that rinsing can be accomplished year-round, rinsing to these concentrations would be on the order of 9 years. These calculated rinse times are significantly higher than the 4.4 years proposed in Alexco (2006; pg 30). Table 1 provides a summary of these calculations in relation to the data supplied by Alexco. In addition, the proponent needs to substantiate the assumption that rinsing with fresh water can occur during the winter months without substantial freezing. Recall that the very concentrated solute concentrations in the raffinate, along with the provision for heating of the leaching solution, allow leaching during winter during operations; these conditions do not apply to rinsing.

In the Conceptual Closure and Reclamation Plan (Appendix F of Project Description and Environmental Assessment Report) a rinse and neutralization period of three (3) years is proposed. Again, considering that the heap leach pad at closure will contain 13.3 M tonnes of spent leached ore and assuming a rinsing rate of 540 m^3/h the proposed 3-year rinse phase would achieve a solution:ore ratio of 1.07 (if rinsing occurred 365 days/annum). Based on the most recent column detoxification testwork for a similar solution:ore ratio, the drainage chemistry from the heap leach pile would be expected to contain very elevated concentrations of copper, molybdenum and selenium, although direct measurements were not available (see Table 1).

While it is understood that the 2006 detoxification data were not available during the development of the Conceptual Closure and Reclamation Plan (Western Silver Corp. 2005), the plan does not provide the basis or rationale for selecting the three-year rinse cycle nor does it describe the overall objective of the rinsing with respect to heap drainage chemistry. In the work completed by Alexco (2006), it appears that one objective of the rinsing was to demonstrate that pH and copper levels could be reduced (through rinsing and neutralization) to acceptable discharge levels. This was largely demonstrated but would appear to require significant rinse volumes that may not be practical.

Table 1:
Summary of Most Recent Detoxification and Rinse Test Results for Preferred Rinsing Program (Column 9)

Column 9

Weight of Material in Test Column tonnes		**Expected Closure rinse rate (m^3/day)**	
tonnes	0.04		12960

Rinse Volume *m^3*	Cumulative *m^3*	Cummulative S:O *m^3/t*	Time to Rinse 13.3 Mt Heap (days)	Years to Rinse 13.3 Mt Heap (365 days Operation)	Years to Rinse 13.3 Mt Heap (6 months/yr Operation)	pH	Ag *mg/L*	Al *mg/L*	As *mg/L*	Cd *mg/L*	Cu *mg/L*	Mo *mg/L*	Pb *mg/L*	Se *mg/L*
0.0137	0.0137	0.34	351	0.96	1.9						930			
0.0137	0.0274	0.69	703	1.93	3.8									
0.0137	0.0411	1.03	1054	2.89	5.8									
0.0137	0.0548	1.37	1406	3.85	7.7	9.87					1.85	27.6	<10	0.574
0.0137	0.0685	1.71	1757	4.81	9.6	9.65	0.061	1.5	0.07	0.005	0.846	15.28	<10	0.112
0.0137	0.0822	2.06	2109	5.78	11.5	9.72	0.023	0.59	0.049	0.00116	0.4276	7.39	1.8	0.0758
0.0137	0.0959	2.40	2460	6.74	13.4	9.36	0.07	0.6	0.03		0.376	4.115	<10	0.037
0.0137	0.1096	2.74	2812	7.70	15.4	8.73	0.033	0.4	0.03		0.261	3.52	<10	
0.0137	0.1233	3.08	3163	8.67	17.3	8.5			0.03		0.241	1.74	<100	

Solution:ore ratios calculated from the data provided and not included in Alexco (2006) tables
Summarized from Table 6 of Alexco Report

The most recent column rinse testwork also indicated that selenium levels could be expected to be elevated in heap drainage waters, particularly under early rinsing conditions when solution:ore ratios are less than 2.0 (Table 1). Selenium is a group VIa element sharing many similarities with sulphur. Not only do both elements share oxidation states (-2, 0, +4 and +6), but their speciation in each oxidation state is similar. In general, selenate (Se^{6+}: the most oxidized species, and the species most likely to be present in oxic heap drainage waters) exists primarily as a dissolved oxyanion having a weak affinity for solid surfaces.

The major concern related to selenium is its accumulation in the organic form in aquatic invertebrates, amphibians, fish, and water birds such that elevated organo-selenium concentrations are passed to the eggs of fish or water birds, which can result in juvenile abnormalities and/or embryo death. Under certain environmental conditions, selenium is capable of making a transformation from the inorganic oxyanion (the predominant species in oxygenated surface waters) to organo-selenides within the proteinaceous material of the food chain. Elemental selenium (Se^0) and selenate (Se^{6+}) are the least bioavailable and least toxic forms, followed by selenite (5 to 10 times more toxic than selenate) and organic selenides (Se^{2-}) being the most toxic (1000 times more toxic than selenate). Thus, any environment that favors the formation of the more reduced species of selenium such as selenite or selenide (*i.e.* wetlands, organic-rich sediments, reducing groundwater) will tend to represent greater environmental liabilities than those that favor the stability of selenate. Therefore, the proposed carbon addition to the heap or infiltration gallery, which is designed to induce reducing conditions (see discussion below), needs to consider the presence of Se in heap drainage waters.

Selenium is comparatively difficult to treat to low levels. As discussed, it exists as an oxyanion and does not precipitate out of solution as a hydroxide following pH adjustment (either through lime or caustic soda addition). As such, the proposed water treatment plant and process would have little effect on reducing Se concentrations in heap drainages. Alternatively, ferrihydrite precipitation is the USEPA's best demonstrated available technology for reducing Se concentrations in waste waters. The process adds ferric chloride to produce ferric hydroxide floccs, which adsorb Se and precipitate it out of solution. The current water treatment plant will likely require modification in order to address all the treatment requirements for the heap rinse solutions.

The proposal indicates that additional larger-scale column testwork is planned. During this phase of testing it is suggested that column rinse waters also be utilized for bench-scale water treatment testing. The data could then be used to better demonstrate the efficacy of the proposed water treatment scheme to treat rinse solutions that are not economical for copper recovery. Water treatment plant effluent quality could similarly be used, in conjunction with the updated Williams Creek hydrology data, to provide estimates of water chemistry at the compliance point in Williams Creek (W10) and to verify that CCME or other similar site-specific water quality objectives can be achieved (see section below).

Carbon Additions to Heap/Infiltration Gallery and Passive Long-term Treatment

There is an apparent reliance in the proposal on the eventual success of carbon addition to the heap rinse waters to "stabilize" metals in the pile. Reference is also made to potential addition of carbon to the infiltration gallery to "biologically reduce any remaining contaminants in the anaerobic zone prior to entering the deeper groundwater system" (Appendix F; pg. 3-17).

The geochemical processes that are expected to control metal concentrations subsequent to these carbon additions are inconsistently described. Specifically, in section 3.3.1 of Appendix F the addition of carbon to heap pore waters is:

> *"…not to actually immobilize the metals in the heap (as is the case in a cyanidation heap breaking down cyanide complexes), rather it is to amend pore waters so that they will cause the mineralization of the contaminants within (the heap) pore waters onto the solids which they pass."* (Appendix F; pg 3-8)

The reviewer is not aware of carbon addition resulting in "mineralization" of contaminants. In fact, mineralization processes tend to release compounds or metals that are bound to organics or solid-phase surfaces. Generally, the addition of a carbon source to mine waste or waste solutions is intended to biologically consume oxygen and generate sufficiently reducing conditions that sulphate reduction to sulphide occurs with concomitant sulphide precipitation of metals.

Elsewhere in the proposal, the latter mechanism is suggested by stating that the addition of carbon will "stabilize" metals in the heap (Appendix F; pg 3-11). The basis for the carbon-nutrient addition approach is the reference to this strategy working at the Brewery Creek project. The proposal would benefit from a discussion of how the Brewery Creek ore deposit and leaching conditions are similar to those proposed at Carmacks. At a first glance, a high pH cyanide, gold heap leach operation does not appear to share many commonalities with an acidic oxide copper leach, such that the reasons for success at Brewery Creek may or may not be directly transferable to Carmacks. At a minimum, a discussion of the Brewery Creek scenario and why it is relevant to Carmacks, other than climatic conditions, needs to be included in order to provide some confidence that the approach would be similarly successful.

Further, and with respect to the above, some areas of concern that need to be addressed by the carbon-nutrient addition approach is the potential for increased solubility of certain parameters, most notably arsenic, following creation of more reducing conditions in the pile. Elevated As concentrations (~4.0 mg/L) are observed in leach solutions (Beattie, 2001) as well as in column rinse solutions during the early phases of rinsing (Table 1). Controls on As concentrations in solution are largely dictated by the strong affinity of As for Fe and Mn oxide surfaces, which would be prevalent in a neutralized heap leach pile. While arsenic is known to adsorb strongly to oxyhydroxides of iron and manganese in oxic environments, under suboxic conditions iron and manganese dissolve and release the associated arsenic to solution. Arsenic has been shown to associate with both iron and manganese oxide minerals in sediments and soils.

In summary, the creation of reducing conditions in the heap pile could result in the remobilization of As via the reductive dissolution of Fe and Mn oxyhydroxides within the heap. The proposal should address how this undesired effect would be dealt with in the passive treatment infiltration gallery.

It is recognized that the closure plan, and specifically the infiltration gallery, are conceptual at this stage. However, because most of the environmental performance of the system relies on the success of the infiltration gallery, the proposal should have more information as to how the infiltration gallery will actually work. In the absence of this information, it would be prudent to assume a longer period of active treatment to ensure environmental compliance.

Water Quality Predictions and Development of Site Specific Discharge Criteria

The proposal would benefit from the inclusion of water quality predictions at the compliance point (W10) in Williams Creek for the following scenarios:

- Rinsing phase when the potential for significant quantities of treated water need to be discharged; and
- Closure phase when comparatively lower volumes of heap seepage water will need to be discharged.

The updated hydrology of Williams Creek (CCL-CC6) provides the basis for a relatively simple yet useful assimilative capacity evaluation. A water balance update for the rinsing phase has been provided (CCL-CC7) and indicates the monthly distribution of excess water discharge requirements in relation to monthly flows in Williams Creek at the compliance point. The only limitation in the assimilative capacity approach is that the baseline water quality data for the receiving environment (*i.e*. Williams Creek) is limited and suffers from historically high detection limits for key environmental parameters. As such, the actual assimilative capacity of Williams Creek at the proposed compliance point (W10) is poorly constrained. Additional data, employing more appropriate detection limits, should be collected during the expected discharge window (*i.e*., May to October). These data have the potential to demonstrate that the assimilative capacity of Williams Creek is quite high and that the potential for environmental impacts are low.

These considerations notwithstanding, the basis for developing site-specific discharge limits for discharge water for Carmacks is available and establishment of such limits is typically included in applications and most likely would be necessary as part of the A License submission. To simply state that discharge will meet MMER may not always be consistent with the other objective of meeting CCME criteria at the compliance point. This is particularly true for As, Cu and Pb during the early phases of rinsing when discharge treatment volumes are expected to be greatest (Table 2). While it is recognized that water treatment should produce water quality better than MMER, the site-specific discharge limits should supplant MMER when MMER is insufficient to achieve the objective of meeting CCME at the compliance point. Moreover, MMER does not have limits for the full suite of parameters that are typically considered important in current environmental evaluations.

Table 2:
Summary of Predicted Concentrations at W10 During Heap Rinsing and Detoxification Stage Assuming Discharge at MMER Limits

Parameter	Assumed Baseline	$Q_{(W10)}$	$Q_{(treatment)}$	Discharge Concentration at MMER Limit	Predicted Concentration at W10	*CCME Water Quality Objective*
As	0.0005	0.874	0.022	0.5	0.013	***0.005***
Cu	0.001	0.874	0.022	0.3	0.0083	***0.002 - 0.003***
Pb	0.0005	0.874	0.022	0.2	0.005	***0.002***
Ni	0.001	0.874	0.022	0.5	0.013	***0.065***
Zn	0.005	0.874	0.022	0.5	0.017	***0.03***

Limiting Infiltration into the Heap Pile at Closure

The reviewer concurs that an important strategy for closure is to limit infiltration into the heap pile through the use of a cover system. The proponent needs to be cautious of ascribing too much benefit from a "store and release" cover system, particularly in northern climates when infiltration is greatest during periods when little to no evapotranspiration occurs (e.g. freshet). A cover system in this climate should be able to limit annual infiltration to values between 20 to 25% of total precipitation. For Carmacks, which is expected to receive on average roughly 350 mm of total precipitation, this corresponds to an annual seepage rate of approximately 30,000 m^3 which would occur during a six month window. This corresponds to annual average seepage rates on the order of 2 L/s with upwards of 3 to 4 L/s to be expected during peak snowmelt periods and much lower values <1 L/s during drier summer months. These values could then be used to develop site specific discharge limits for a suite of parameters. It is acknowledged that in all likelihood, MMER limits would suffice for the parameters regulated under this policy; however a table with the calculations and predictions at W10 for the key parameters would strengthen the proposal.

Recommendations

Based on the technical review of the Carmacks Copper Project proposed heap detoxification process and relevant closure strategies, the following recommendations for strengthening the Western Silver Corporation's proposal are advanced:

1. The proponent needs to re-evaluate the proposed rinsing-neutralization volumes and attendant rinse time required to achieve the objectives set forth in the proposal. Current estimates would appear to underestimate the volume and time required for detoxification of the heap. The more recent data prepared by Alexco (2006) needs to be considered in this assessment both from a rinsing and chemical perspective.

2. In light of the above, the proponent needs to further consider the issue of rinse pulsing (e.g. flushing followed by a period of “rest” followed by additional flushing) and how this strategy will impact expected rinse times.

3. The program at Brewery Creek is referenced in the proposal and presented as a case-study of a successful remediation approach for limiting metal release from a spent heap pile. The proposal needs to include a discussion of the approach and methods used at Brewery Creek; objectives; successes and failures; and how the Brewery Creek example is relevant to that proposed at Carmacks.

4. Because most of the environmental performance of the proposed heap closure strategy relies on the success of the infiltration gallery, the proposal should have more conceptual design information as to how the infiltration gallery will actually work. In particular, site-specific information on the hydrogeological conditions around Williams Creek where the proposed infiltration gallery is to be established needs to be included.

5. The proponent needs to update and improve the water quality database for surface water and groundwater, with improved analytical detection limits. Parameters of focus should be Se (detection limit of 0.5 to1.0 μg/L) and Cd (detection limit of 0.015 to 0.02 μg/L).