Comments on Air Quality modelling sections of the KGHM Ajax Mining Inc. proposal for development of the Ajax mine.

I comment only on sections of ERM (2015) that lie within my area of expertise. These sections are principally 10.1 (*Air Quality*) and Appendix 10.1-A (*Air Quality Technical Data Report*) and appendices A to I of this appendix. I will refer to these documents generically as "t*he report*".

1) Response to advice in Steyn & Ainslie (2012):

In 2012 I was asked by concerned citizens of Kamloops to provide a set of questions that could be submitted to the to Environmental Assessment Process (EAP) engaged in considering the proposed development of the Ajax mine near the city of Kamloops. The purpose of the questions was to see that the EAP included a thorough assessment of concerns these citizens had about the possibility of degraded air quality in Kamloops resulting from atmospheric dispersion of atmospheric pollutants from the mine site. My questions are included in *the report*, where they are referred to as Steyn & Ainslie (2012). In general, *the report* acted on some of the advice we gave. However, in some critical parts, *the report* ignores advice we gave. These parts will be dealt with in my specific comments below.

2) General modelling approach:

Air pollution dispersion modelling performed in support of the proposal is done using models approved for regulatory modelling such as this in the Province of British Columbia. These models (CALMET and CALPUFF) exist in the regulatory (not research) realm, and are generally appropriate for the purposes in the present case. Because of the enormous complexity of atmospheric dispersion, the models are correspondingly complex, having a wide variety of settings, options and switches which must be specifically selected for particular applications. These settings, options and switches appear to have been appropriately selected in the present case. Once these settings have been decided upon, the far more complex task of deciding on the general modelling approach must be undertaken. Part of this task is deciding on the most appropriate input data to use for the model runs. These data include meteorological data covering many variables, and emissions data from the source in question, from existing sources, and from outside the modelling domain. I have considerable concern about some of the input data used to drive the models, and some of the more general modelling approaches taken.

2.1) Atmospheric Stability:

In simple terms, atmospheric stability is a property of the atmosphere which determines the extent of vertical mixing. If stability favours vertical mixing, pollutants are readily diluted. Conversely, if stability suppresses vertical mixing, pollutants remain concentrated. These latter conditions are known as temperature inversions. It is well known that the City of Kamloops experiences its worst (wintertime) air pollution episodes when atmospheric vertical mixing is limited by the existence of temperature inversions. This fact is repeatedly referred to in *the report.* (see for example Appendix 10.1-A page ii). In order to properly capture the strength (quantified by the vertical gradient of temperature in the lowest model layers, or the simpler surrogate Pasquill-Gifford stability classes) and frequency of occurrence of various levels of stability, CALPUFF must be supplied with data which reflect actual conditions. In conditions of complex terrain (such as Kamloops and its surroundings) atmospheric stability is spatially variable, and a single value for the entire modelling domain may not be appropriate. This is particularly true for locations (such as Kamloops) which lie in a topographic basin, where temperature inversions will be stronger and deeper than in surrounding highland areas. These characteristics add substantial difficulties to the present case, but cannot be avoided. They demand that particular care be taken in ensuring that stability is properly captured in model input data. As noted in *the report,* stability data are derived from output of MM5 model runs provided by BC MOE (appendix C-12), and augmented by upper air data from Kelowna Airport. I note this is what was recommended in Steyn & Ainslie (2012), but have concerns that the approach was not carried out with the care demanded by real technical difficulties.

Given the smoothing inherent in the MM5 model runs (because of the 12 km grid resolution), it is likely that extremely steep surface based (wintertime) temperature inversions are underrepresented in CALPUFF input data, and therefore that vertical mixing in these conditions is not suppressed strongly enough. Furthermore, *the report* employs Pasquill-Gifford classes determined “at the project site location” (Appendix C-16). In wintertime stable conditions, the atmosphere in the valley containing the City of Kamloops is likely to be more stable than at the upland project site. This will result in the model underestimating the severity of air pollution at the most polluted times.

In *the report*, no attempt is made to confirm that atmospheric stability in the lowest model levels captures actual atmospheric stability anywhere in the modelling domain. This would be easily achieved using meteorological data from Kamloops airport as Pasquill-Gifford classes are estimated from routine meteorological data (daytime/nighttime cloud cover and wind speed). A simple extension of Table C-8 (Appendix C-17) showing predicted and actual Pasquill-Gifford classes for the years 2003-2005 would answer this question in a statistical way. A more careful (but still simple) analysis of stability classification during classes E and F would be needed to determine if stable condition frequency and strength are appropriately captured in CALPUFF input data.

These specific deficiencies are in direct contradiction of the claim that the model is operated in a conservative way. I note here that this deficiency is caused by authors of *the report* ignoring much of the advice that Steyn & Ainslie (2012) give regarding comparison of model input and output data with actual observations.

2.2) Modelled Wind Fields:

Pollutants emitted into the atmosphere are mixed (and diluted) by turbulence, and carried downwind (advected) by mean wind patterns. Wind fields are spatial patterns of wind that do the advection, and hence determine where pollutants travel. If this is to be properly modelled, the model must be provided with wind fields that match those that actually occurred. The wind fields in *the report* were appropriately determined by a combination of MM5 modelled winds at coarse spatial resolution and CALMET-produced fine resolution wind fields. This is appropriate, and is as suggested by Steyn & Ainslie (2012). However, Steyn & Ainslie (2012) suggest that “it must be demonstrated that the atmospheric modeling exhibits a fair amount of skill reproducing the hourly observed meteorological conditions”. This step is notably absent in *the report*. Steyn & Ainslie (2012) acknowledge that full model evaluation (the process whereby model output is compared with observations) would be difficult because of a paucity of observations. There are however, available observations which could form the basis of a very revealing model evaluation.

Appendix C-12 &13 presents a largely inadequate attempt to justify the veracity of meteorological data input to CALPUFF. It is simply not enough to refer to model evaluations performed by another consultant (referred to as JWA, 2009). That report is not readily available, and in any case there is no indication that the wind fields generated in that report were comparable to wind fields used as model input in *the report*. All that can be said is that the same model was used over a similar modelling domain. To be relevant to questions addressed in *the report*, a model evaluation must not only evaluate the general performance of the model, but must also evaluate the ability of the model (and its input data) to capture phenomena of particular importance. In the case of the proposed Ajax mine, these include (but are not limited to) light wind conditions in the presence of temperature inversions that are responsible for limited pollutant dilution in the Kamloops valley, high wind conditions at the proposed mine site that will be responsible for elevated levels of particulate matter suspension from the various tailings sites and meteorological conditions that result in wind trajectories that will carry pollutants from the mine site towards the city of Kamloops.

The CALMET modelled wind roses presented in Appendix 10.1-A, Figure 4.3-2 show dramatically how strongly variable wind speed and direction are across the modelling domain. While wind roses are indeed a convenient way of showing the frequency of occurrence of wind speed and direction, the graphical device is of very limited utility as a model evaluation tool on its own. At the very least, similar wind roses must be shown for observations over the same period. Clearly this could be done at a number of locations to reflect spatial variability of the wind field. I suggest that this should be done at the Kamloops airport for 2003-2005. I also suggest that this should be done at at least one additional measurement site in an upland part of the model domain. I note that a CALMET modelled wind rose has been presented for the “Ajax Met” station. This station has been operational for just over a year, and would be a good location for evaluation of modelled wind fields. I note that Steyn & Ainslie (2012) emphasized the need for data from a site such as this, though they suggest Sugarloaf Hill or Coal Hill as appropriate locations.

I must also note that merely having similar wind roses confirms that model and observations are in agreement only in a statistical sense. Evaluation of model wind speed and direction against observations during a range of air pollution conditions is necessary to confirm that the model fields are adequate to characterize air pollution conditions in the modelling domain. This is done using any of a number of model evaluation statistics, all of which are relatively simple computational tasks that can easily be done for at least the Kamloops Airport site. I note here the difficulty of this step in that CALMET uses both modelled and observed data to generate wind fields. This is referred to in Steyn & Ainslie (2012).

The lack of even rudimentary evaluation of modelled CALMET wind fields introduces considerable uncertainty into the veracity of modelled pollutant distributions (and to a lesser extent, concentrations) in the modelling domain.

2.3) Modelled Pollutant Concentration Evaluation:

Air pollution model evaluation is a field of work rich in publication and with a long history. In a very general way, the work of Dennis et al. (2010) summarizes recent approaches. Steyn et al. (2013) demonstrate the application of one of the leading frameworks for air pollution model evaluation. It is therefore surprising that *the report* pays scant attention to evaluation of the extent to which modelled pollution concentrations match those measured, in spite of recommendations by Steyn & Ainslie (2012) that this be done for a known pollutant (such as SO_2). The practise of model evaluation in environmental assessments of industrial expansion in British Columbia is well established. Excellent recent examples are to be found in the two reports considering air pollution consequences of industrial expansion in Kitimat (ESSA 2013 and 2014).

Appendix D 36-44 provides pollutant specific analyses at Kamloops Federal Building and Kamloops Fire Station #2. These analyses are rudimentary at best, using a heavily averaged statistic (predicted/measured) over three years (2003-2005) for 24 hour - and annual average concentrations. These analyses are based on model output and measurements that could easily have been used to provide a much more revealing assessment of model ability with very little extra effort. Most important, simple scatter plots of measured against modelled pollutant concentration (24 hour averages) with accompanying statistics (Root Mean Square error and Mean Bias Error as a minimum) for the Base Case (*the report* defines this set of model runs using only emissions from existing sources in the model domain - excluding emissions from the proposed Ajax mine) would reveal important features of model veracity, and would greatly increase confidence in modelled pollution as a best estimate of conditions that would occur in project cases.

Base Case model evaluation as described above at as many points as possible without addition of a background concentration would be extremely important as this would give crucial guidance on the need for and possible magnitude of an appropriate background concentration. I deal with this matter further in section 2.5.

Without an appropriate evaluation of base case modelled pollutant concentration, it is very difficult to assess the reliability of project case modelling results. The additional effort is very small, and the returns large. This step is considered an essential part of any regulatory model application, was recommended by Steyn & Ainslie (2012), and should have been included in *the report*.

2.4) Background Pollutant Concentration Values:

In almost all regulatory modelling exercises, it is necessary to add a background concentration to account for pollution brought into the modelling domain from regions outside the domain. In the case of primary pollutants (all substances considered in *the report* are treated as primary pollutants), it is appropriate to simply add the background concentration at every modelled point (receptor). A vital question is, of course, the exact value chosen for the background concentration. Data for determining global background pollutant concentrations are available from the internationally supported Global Atmosphere Watch (GAW) program of the World Meteorological Organization http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html.

While *the report* refers to “Global/Regional background ambient air quality” (Appendix 10.1-A iii and following), in reality it is a Regional Background concentration that is needed since a global background is considered to be the background concentration of pollutants away from the influence of individual sources, and the study area is strongly influenced by terrestrial pollutant emissions from upwind surfaces on the scale of a few hundred kilometres. The regional background is influenced in only the smallest of ways by the upwind (Pacific Ocean) global background pollution because of regional (BC) sources. It is however entirely wrong (as has been done in *the report*) to estimate the regional background concentration of any pollutant by examining averaging pollutant concentrations measured inside the study domain, and particularly concentrations at monitoring locations surrounded by significant sources from many source sectors.

In the present case, *the report* refers to the use of “low percentile of continuously monitored gases”, and goes on to define “low” as " The 1 hour values are 50th percentile measured, the 24-hour values are the 25th percentile measured, and the annual values are the 10th percentile measured 24-hour concentrations.” (Appendix 10.1-A page 15). These particular percentiles are arbitrary, or at least unjustified. Such arbitrariness can be used to achieve almost any desired outcome.

Background $PM_{2.5}$ concentrations in British Columbia have, in fact, been well investigated. McKendry (2006) concludes that the mean background $PM_{2.5}$ in B.C. is 2 µg m^{-3} with a seasonal variation between 1-4 µg m^{-3} with values closer to 4 µg m^{-3} in summer due to forest fires, and slightly higher values in drier areas. Cheng et al. (2000) studied six remote rural locations in Alberta (where prairie soils contribute substantial sources of PM), finding an average $PM_{2.5}$ concentration of 3.2 µg m^{-3} with a range of 1.7 to 3.8 µg m^{-3}. Suzuki and Taylor (2003) concluded that natural sources of PM in non urbanized regions in B.C contribute 25% of the ambient $PM_{2.5}$ concentration. It is disappointing (at least) that authors of *the report* appear to have ignored this research.

In *the report*, the "global/regional" background $PM_{2.5}$ is estimated at 3.8 µg m^{-3} which is then added to the base case. It is likely that this value is an overestimate by at least 0.8 µg m^{-3} with some margin of error. This bias casts doubt on the overall conclusions about $PM_{2.5}$ concentrations attributable to the project, relative to those from existing sources. However, the inappropriate way in which "global/regional background" is used in the modelling is a cause for even greater concern.

2.5) Adding Background Pollutant Concentration Values to modelled values:

As explained in section 2.4, It is entirely logical to add an appropriately determined background (global or regional) primary pollutant concentration to pollutant concentrations modelled inside a study domain. However, if the background concentration is computed from data measured in the core of an urban area, it cannot be considered a background concentration. This is true even if the "background" concentration calculated this way is incidentally equal to the true background calculated from (regional) background measurements not influenced by sources in the study domain. To make this clear, consider the two quantities that are added in *the report:*

i) *The so-called background*: This is a value based on pollution measurements at locations in the suburban parts of Kamloops (details of the statistical manipulation used to find the exact value, and which station is used are not important). What matters is that pollution sources contributing to the measured pollutant value are all within the study domain, and notably, in the City of Kamloops. They are sources from all sectors; residential, road, rail, area and industry, and emissions from these sources are mixed by atmospheric turbulence and contribute to the measured ambient concentration.

ii) *Base case modelled pollution concentrations*: These are estimated by the CALMET/CALPUFF model, using sources from all sectors in the modelling domain residential, road, rail, area and industry (but of course excepting Ajax Mine project sources).

In a very real sense then, at least part of what has been called "background" is also captured by the model. To add modelled Base Case and "background" calculated from inside the model domain is effectively double counting of pollution emitted by the same sources. This inflates values in Kamloops proper, and strengthens the overall argument that the proposed Ajax mine development has negligible effect in the city

A proper estimate of regional background pollutant concentrations is needed. A strong indication of the value to be used can be derived from a proper evaluation of the Base Case model runs (as described in section 2.3). A statistically determined low model bias in the base case runs (without adding a background) will be an indication of the need for, and magnitude of the regional background to be used. This value should ultimately be determined by measurements made well away from the influence of emissions inside the study domain

2.6) Years Modelled:

In regulatory studies such as this, modelling is usually conducted over a full year, or multiple full years. If only one year is chosen for modelling, it must be shown that the chosen year is not climatologically anomalous in ways that would bias results. In *the report,* meteorological modelling was conducted for three years: 2003, 2004 and 2005, but only 2003 was chosen for further analysis because the modelling results show it "produced the highest results on the plant boundary" (Appendix D 37-44). This is a most unusual justification for choosing a single year. Given the topographic and meso-meteorological differences between plant boundary and central Kamloops, there is no reason to believe that this year will also give the highest pollution concentrations in the most populated parts of Kamloops. While it is clear that the chosen strategy was intended to result in a conservative modelling approach, the topographic and meteorological complexity of the study region does not guarantee that this would be the case. Furthermore, the decision depends on the strength of modelling results, which have not been fully established (see my comments 2.1, 2.2 and 2.3).

A far safer approach would have been to model three years, characterized by: low pollution, typical pollution and high pollution as measured, not modelled. This or a similar approach would add substantial confidence in overall conclusions.

2.7) Emissions Scenarios:

My section 2.6 explains why confidence in the conclusions of studies such as those documented in *the report* will be increased by the investigation of multiple, strategically chosen model years. In a similar way, results would be enhanced by utilizing a wider set of emissions scenarios. In its present form, *the report* employs only a single emissions scenario, and that is the most optimistic one, which assumes full intentional and natural mitigation of emissions from all sources within the proposed development (Appendix 10.1-A page 52, and Appendix E). Aspects of this mitigation are extremely ambitious. For example "a minimum of 90% dust suppression" and "a minimum of 45% natural dust suppression" (Appendix 10.1-A page 53).

It is generally true that even the most meticulously operated and managed industrial installations experience upset conditions. Such upset conditions could be expected to include staff absence, strike action, equipment failure, years of restricted water supply, and a myriad of other causes. It would therefore appear prudent to conduct the modelling with at least three emissions scenarios. Full mitigation; reasonable partial mitigation due to commonly occurring upset conditions; and "failed" mitigation due to unlikely but possible multiple upset conditions occurring simultaneously. This modelling strategy would help give confidence that the overall conclusions are correct, and give some indication of worst possible (but extremely unlikely) conditions.

I note that "The modelling considers both the Construction and Operations **worst-case emissions …** " (Appendix 10.1-A page 4, my emphasis). I see no indication that emissions considered are anything but the most optimistic best-case.

3**) Conclusions:**

My review of *the report* has revealed a number of instances of what I consider to be technical and study design weaknesses. These weaknesses are in the context of a regulatory study, rather than a study in the research realm. Their resultant effect is to undermine the robustness of the overall conclusions. I consider the most important of these to be:

3.1) Model Conservatism: While *the report* purports to perform the modelling in a conservative way (see Appendix 10.1-A pages i, iii, v, 15, 17, 94, 121, 125; Appendix B page 3.8; Appendix D page D-46; Appendix E pages E-9, E-29), the claim is undermined by some of the weaknesses. Specifically, sections 2.1, 2.5, 2.6 and 2.7 explain weaknesses that undermine the claim to conservative modelling. This is critical to the strength of the overall logic of the report.

3.2) Model Evaluation: I have been very critical of the almost complete lack of model evaluation. Data and model output exist which would easily allow the performance of model evaluation of the base case for both modelled meteorology, and ultimately modelled pollution. This is a severe weakness that undermines the confidence one can have in overall conclusions.

3.3) Emissions Source Strength: A crucial unknown in modelling such as that done in *the report*, is the emissions strength. As the Ajax mine is still in the proposal stage, the emissions figures can only be estimates based on design of the mine facilities, and intended mitigation practises. In order to account for the uncertainty in such estimates, best modelling practise demands that a range of emissions strengths be employed to give an indication of the likely environmental impact of the proposed development. This has not been done.

3.4) Proposed Ajax mine and Kamloops Air Quality:

The overall logic underlying the conclusion of *the report* is that the Ajax Mine project will add very little to an already polluted city. Appendix 10.1-A, Figure 5.1-2 illustrates this well. The (modelled) 8 $\mu g\ m^{-3}$ $PM_{2.5}$ isopleth effectively defines North Kamloops, and is of course the BC AAQO. If this is generally true, the City of Kamloops has no choice but to pursue an aggressive program of emissions reduction to improve AQ for its citizens in North Kamloops. This means reducing emissions from all sectors - domestic heating, road dust, diesel emissions, and of course all industrial emissions. In such a situation it makes no sense at all to allow a new industrial source of the pollutant in question ($PM_{2.5}$) no matter how small its incremental effect. This recommendation is in accordance with the work of Tsigaris and Schemenauer (2016) who have found that the long-term (1998-2015) Kamloops $PM_{2.5}$ annual average has been above the B.C. Guidelines of 8 $\mu g\ m^{-3}$.

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