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# MEMORANDUM

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| **TO:** | Kathy Arnold | **FROM:** | Mark A. Williamson, PhD |
| **ORGANIZATION:** | Rosemont Copper Company | **DATE:** | December 23, 2011 |
| **CC:** | File | **PROJECT:** | 1002.3 |
| **SUBJECT:** | Perspectives on Uncertainty in Water Quality Predictions | | |

## Purpose and Scope

The purpose of this document is to present an overview to Maest and Kuipers (2006; hereafter M-K (2006))[1] and that study's effort to assess the reliability of water quality predictions reported in environmental impacts statements (EIS) for hardrock mines in the United States. The intent of this document is not to provide a detailed critical review of M-K (2006), but instead to convey the

- general methods used,
- limitations of the assessment,
- major findings, and
- application to the proposed Rosemont project.

## M-K (2006) Overview

*Process for Identifying Inaccurate Predictions*

It is important to recognize that the assessment of water quality predictions made by M-K (2006) is potentially affected by three components: geochemical, hydrologic and engineering. One or all the components may be involved in any given site evaluated in M-K (2006). It is the quality of water observed on site that is the focus, not simply, as some have thought, the field sampling and laboratory testing of mine rock and tailings. The prediction of water quality in the receiving environment is the focus not, for example, the water quality estimated for a waste rock facility.

M-K (2006) have compiled data and information for 25 case studies, spanning years from 1979-2005, to assess, in as much detail as information would allow, a comparison of predicted site water quality with as-observed water quality later on. Many sites have multiple predictions, associated with multiple environmental evaluations. Not all predictions presented by M-K (2006) are associated with EISs. Some are simpler environmental assessments (EA) and similar evaluations. For the purposes of their study, M-K (2006) considered a site a predictive failure if any environmental assessment document produced a predicted water quality that did not match ultimate site water quality (irrespective of applicable water quality standards). They did not account for multiple predictions to truly assess how frequently predictions were off. They also considered a site a failure if a given chemical constituent was not identified precisely, regardless of whether or not all other constituents were accounted for. Overall, M-K (2006) cast a wide net for identifying their mode of prediction failures, with no consideration of the magnitude of an error, and the extent to which errors are reasonable and expected (as a fundamental element of the NEPA process). In other words, there is no discussion of the inherent error in all predictions and the extent to which their identified errors are within the reasonable limits of unavoidable error as compared to genuine catastrophic errors.

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[1] Maest, A. S. and J.R. Kuipers (2006) *Comparison of Predicted and Actual Water Quality at Hardrock Mines: The reliability of predictions in Environmental Impact Statements.* A report published by Earthworks, Washington, DC, 194 pp.

*Summary of Fault Modes*

In instances where water quality predictions were identified by M-K (2006) as inaccurate, an assessment was made of the influence of three potential failure modes:

- Geochemical;
- Hydrologic; and
- Engineering (mitigation).

That is to say, M-K (2006) tried to assess, given the available information, which of these influenced or was solely responsible for the diminished water quality on site, relative that which was predicted.

The geochemical fault mode considered the extent to which chemical constituents were potentially unidentified as a chemical constituent of concern (COC), or the predicted concentrations were inaccurate. This fault mode was influenced by several possible factors including

- lack of representative sampling;
- lack of appropriate testing; and
- inaccurate assumptions.

The hydrologic fault mode relates to missteps concerning the site water and water balance interpretations and predictions. Components of this failure mode included the rate and direction of groundwater flow, surface water flow, and water quantities within various mine elements (e.g. water level in conventional tailings impoundments). The hydrologic component is related to and overlaps engineered mitigation plans such as the performance of under drains.

In general, the engineering/mitigation failure mode included any and all mine planning features that were designed to collect impacted process water, or restrict its movement. These features include under drains, liners, pump-back systems, treatment ponds and processes, waste rock segregation and blending, etc.

As part of a summary of finding, M-K (2006) tabulated the number of instances in which one of the above failure modes contributed to or was responsible for their assigned prediction failure. The distribution of failure modes reported by M-K (2006) are reported in Table 1.

*Table 1. Summary of failure modes in M-K (2006) 25 case study sites.*

| FAILURE MODE | NUMBER OF MINES SHOWING FAILURE MODE | PERCENTAGE OF CASE STUDIES |
| --- | --- | --- |
| Hydrologic Characterization | 6 | 24% |
| Geochemical Characterization | 11 | 44% |
| Mitigation | 16 | 64% |

Remember that M-K (2006) does not necessarily specify only one failure mode, and instead records the number of times that any failure mode, in their view, contributed to erroneous prediction of future site water quality. Thus, the number of mines showing a failure mode is greater than the total number of case study mine sites (25). Note that it is the number of sites (case studies) showing a failure mode that is counted, not the total number of predictions. Many of the case study sites had multiple predictions and assessments, only a portion of which were erroneous. Thus, the summary figures in Table 1 are a bit misleading, as the percentage of actual predictions (as opposed to case study sites) is actually smaller. And there can be debate regarding the M-K (2006) report conclusion regarding many of the identified failure modes.

Although some may find it concerning that any erroneous predictions occur at all, it is best viewed as an expected result. In making predictions, there is inherent statistical uncertainty and never a

100% guarantee of accuracy. Consider weather reports and stock price projections in the financial sector. Projections may be literally incorrect, but functionally acceptable. A modeled daily high temperature for one week from today that is one degree too low is incorrect, but anyone will accept it as functionally accurate. The M-K (2006) report confirms that when making projections, some will be less accurate and indeed literally wrong. But some of these will be functionally correct and useful for best management practices. Thus the need for operational monitoring, contingency plans and appropriate bonds for suitable response.

The trouble is that natural, and many engineered, systems are open and therefore not everything can be known, particularly for future conditions. Thus, the need is created for models and predictions. The real value of M-K (2006) is how the study shows that characterization approaches have improved over time and where potential sources of serious concern may exist, guiding additional studies that in turn might affect management and bonding factors. When concerns are expressed that predictions (in M-K (2006)) under-predict water quality they do not recognize that it is unavoidably true that some predictions will be low, some will be high, and a few will be spot on.

Unfortunately, by my read of it, M-K (2006)'s representation of the percentages of failures does not fully account for all predictions at their case study locations and is a bit harsh in identifying some functionally correct predictions as errors. As discussed by Oreskes, et al. (1994)[2], "In practice, few (if any) models are entirely confirmed by observational data, and few are entirely refuted. Typically, some do agree with predictions and some do not. Confirmation is a matter of degree." It seems to me that M-K (2006) may have exploited this reality to cast a critical eye on water quality predictions at hardrock mine sites. Confirmation being a matter of degree, results can easily be skewed and the results of any such effort like M-K (2006) require context and perspective.

*Geochemical Fault Mode Analysis*

Given my chosen area of work and study, geochemistry, I took a closer look at the M-K (2006) assessment of occurrences of this failure mode. In addition to my own area of interest, it is also the fundamental starting point for identifying the need for mitigation and potential hydrologic concerns. Consideration of the identified geochemical failures serves to highlight the bias that may be introduced when not considering all predictions, in favor of lumping a site into a failure pool for only one erroneous prediction.

I reviewed the case study sites identified by M-K (2006) as showing a geochemical fault mode and, unlike M-K (2006), tried to consider all predictions. I also discounted any of their identified failures that could arguably be considered functionally correct, or those that are arguably simply not a geochemical fault mode. My purpose for this simple assessment is to add some perspective to the summary findings of M-K (2006) for geochemistry, presented in Table 1 above. A similar perspective may be appropriate for the hydrologic and engineering failure modes.

There are 11 case study sites identified by M-K (2006) as having a geochemical fault. For these 11 sites, by my count, there were actually at least 22 separate predictions/assessments made. Discounting supposed failures that are arguably functionally correct, or not really (in my opinion) a geochemical fault mode, I tally 6 truly erroneous predictions of the 22 assessments. This translates to 27% faulty predictions that can be solidly associated with geochemistry. Extending this, there are 6 truly erroneous geochemical assessments for the 36 possible (22 predictions for the 11 sites noted by M-K (2006) as geochemical failures plus the remaining 14 sites). This results in a 17% geochemical failure rate, compared to M-K (2006)'s 44% (Table 1). I suppose taken together, and allowing for some difference of opinion ("Confirmation is a matter of degree"[2]), these values may bound the range of erroneous prediction. Clearly, the predictions made are likely more successful that M-K (2006) would have the reader believe. This, of course, does in no way suggest that predictions cannot and do not under predict impacts some of the time. It is also worth noting that the bulk of the true failures that can be associated with geochemistry are on the order of 30 years in the past when the "science" of water

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[2] Oreskes, N., Shrader-Frechette, K. and Belitz, K. (1994) Verification, Validation, and Confirmation of Numerical Models in Earth Sciences. *Science* **263:** 641-646.

quality prediction of mines was in its infancy, lending another level of perspective not addressed by M-K (2006).

**Application to Rosemont**

The findings of the M-K (2006) assessment apply to all hardrock mines, including Rosemont. Although the literal findings of M-K (2006) can be argued, their report very effectively serves to identify areas where predictions of water quality deserve scrutiny. I have, to the best of my current understanding, summarized the aspects of the Rosemont project where the findings of M-K (2006) most solidly apply.

*Hydrologic Fault Modes*

Hydrologic modeling plays a role in water quality predictions in a couple of important ways. One aspect is, clearly, related to site characterization. For example, suitable characterization of the hydrologic properties of materials to constrain their ability to conduct water. M-K (2006) provide an example where no groundwater impacts were anticipated owing to a "tight" formation underlying mine rock that would function as a barrier. Otherwise, model calculations are the fundamental area of concern, for surface water, groundwater and water balance and management within the site boundaries. There are several areas of the proposed Rosemont project that seem to be consistent with potential faults identified by M-K (2006). These areas include:

- Groundwater modeling of inflows to the pit on cessation of dewatering. There is a variation of groundwater quality in the vicinity of the pit and the rate at which each type will contribute is not well established. The pit lake water quality calculations used an average groundwater quality as, at the time, no further resolution was possible. The net effect may be, as an estimate, a change in the rate of buildup of chemical constituents in the lake. The final, steady state, condition will not be exactly as modeled (few things are precisely the same as modeled), but I would expect them to be consistent with modeling, and therefore functionally correct.
- Draindown of the heap leach facility. Presumably the design of the constructed pond to collect and treat draindown is consistent with hydrologic modeling of the draindown. To the extent that draindown rates are, for example, higher than modeled there is a potential failure. This is related to mitigation matters, discussed below.
- Potential discharge from waste rock facilities. Modeling is used to estimate the potential rate of flow of flow through the waste rock facility. Does it also account for surface runoff quantities and what the fate of that flow might be? I am not familiar with any engineering design to collate and surface runoff, which is related to mitigation below.

*Engineering (Mitigation)*

This area of fault mode for prediction should be considered for any instance in which engineering plans are developed to address water quality. Potential application at Rosemont, that I am aware of, include:

- Performance of the biological treatment basin. Were the treatment basin to either leak, or fail to treat anticipated water quality to the desired concentrations, it could translate to a negative impact on water quality. Also, should draindown flow (see above) exceed design capacity, unanticipated discharge would result.
- Waste rock management plan that incorporates blending of any encountered PAG with limestone as well as insuring that PAG is not placed on the surface of waste rock facilities. Robust, on-going operational rock characterization will be required.
- Any instance where engineering (mitigation) efforts are part of the operational plan.

*Geochemistry*

Instances of genuine erroneous geochemical prediction, as discussed by M-K (2006) are most often related to

- an essentially non-existent characterization program,
- lack of representativeness,
- lack of long-term testing (HCT, or columns),
- incorrect assumptions made in relating background weathering with weathering in engineered facilities, or
- simple state of infancy of hardrock mine characterization practices.

Potential fault modes attributable to geochemistry failures at Rosemont could be associated with the lack of representative sampling throughout the volume of the proposed pit. Most sampling to date has been in the core of the deposit and only approach the ultimate pit surface near the bottom. At positions within the projected pit volume distal to the core, sampling has been limited. This is not a new topic of discussion and has been brought up during the EIS process, but I am stating here for completeness. It is correct that the mine rock that has been testing is below ore grade and, therefore, waste. But a three dimensional sampling throughout the volume to be excavated is empirically beneficial.

The pit lake calculations could also be negatively affected by the mineralogy of the ultimate pit surface. Although pit planning models provide anticipated outcrop areas for various types of mine rock, they cannot be 100% certain. Nor can they account for mineralogical variation within any mapped unit, as mineralogical information pertinent to environmental impacts are not currently robust. The calculations for the pit lake included a range of input concentrations to provide some sensitivity assessment, which indicates that due to infrequent rain, rinsing of pit walls and associated chemical loading is a relatively small feature at Rosemont. I would anticipate the result of this uncertainty to translate to a change in the timing of concentration change in the pit lake, and probably not a substantial deviation from long-term conditions.

A companion report (Maest and Kuipers, 2005; M-K, 2005)[3] identifies what are generally regarded as appropriate tests and their use. This document also discusses representative sampling presented above. Many of the geochemical failures identified in M-K (2006) correspond to lack of application of methods in past times that are currently recognized today and outlined by M-K (2005). Rosemont has incorporated the appropriate tests for characterizing mine rock and thus avoids a principal basis for most failures identified in M-K (2006).

Sampling aside, a point of discussion with respect to testing for the Rosemont project will concern the length of long-term tests. In general, and as discussed in M-K (2005), short-term tests are generally inappropriate for long-term predictions. For Rosemont, both short-term and longer-term humidity cell tests (HCT) have been conducted. Although HCT is conducted foremost and fundamentally to assess the potential for formation of acid rock drainage (ARD) from materials classified as uncertain in static tests, HCT is more and more commonly used to assess potential future water quality. Most Rosemont mine rock is not uncertain with respect to ARD, it is clearly alkaline. Some units (andesite and quartzite) have a portion of their total mass that is potentially acid generating. The duration of HCT work, as pointed out by M-K (2005), should be sufficient to reach steady state chemical quality. Rosemont HCT were run to steady state and the mass of water passing through the test columns corresponds to a significant amount of time in the field (given the very low site rainfall).

Rosemont has tested clearly alkaline rock (some limestone) as well as PAG samples of andesite and arkose with HCT to steady state. These samples represent a small portion of total mine rock. Thus, Rosemont has done a bit more than would normally be done to examine alkaline rock leaching characteristics. PAG material was also tested to stead-state, and only the quartzite produced a

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[3] Maest, A. S. and J.R. Kuipers (2005) *Predicting Water Quality at Hardrock Mines. Methods and Models, Uncertainties, and State-of-the-Art.* A report published by Earthworks, Washington, DC, 77 pp.

depressed pH, although a generally low total chemical load. Unusually, short-term leaching tests (SPLP) for Rosemont materials produced chemical results that were comparable, or had higher concentrations than the long-term HCT. Thus, SPLP results were used for most Rosemont calculations as they provided a bit of a bias toward a worst case scenario. The results from these tests will present some concern as they are essentially fresh core, but that is the material that Rosemont has to work with.

## Conclusions

The M-K (2006) study successfully points out that ultimate site water quality at hard rock mines is a combination of contributions from geochemical, hydrological and mitigation factors. For geochemical failure modes at a given site, their assessment somewhat inaccurately biases that rate of failure high, as they do not evaluate success based on total number of predictions, but instead consider a site a failure if only one inaccuracy is identified. This same level of exaggeration may extend to hydrologic and mitigation issues as well. Moreover, the basis for identifying an inaccuracy is unduly harsh for the scale of the systems (mines) under study and the impossibility of knowing everything about that system. If we could know all these things, models would not be required.

Generally speaking, older projections are less reliable than more recent. This would be the expectation, as technologies have been researched, developed and improved with time, as is the nature of science and engineering. This trend is somewhat overprinted by multiple predictions at a given site over time. Predictions do improve with time, but some of this is due to technology advances and part is having the opportunity to learn more about the given site. Both are expected.

Most notable potential failures associated with the Rosemont project include the following.

- The treatment pond for the heap leach drain down and its ability to handle expected flows (which provide some uncertainty themselves), maintain liner integrity, and treat water to the target concentrations.

- Water quality in the pit lake may be more strongly influenced by inflow from discreet water-bearing zones that have lower water quality than the average used in model calculations. It is not certain, however, that those lower water quality zones will exist following dewatering.

- At Rosemont, as well as at other mining sites, chemical water quality predicted from laboratory tests is subject to grain size differences between field and lab materials as well as rate of exposure to water (the water to rock ratio). The result is that actual water quality is literally always different than predicted, with the general expectation that it is generally consistent. That is, not catastrophically different, which is what I believe is the basic goal.

- Water quality in the pit may be negatively influences by rock/mineral outcrop characteristics that were not sampled during initial characterization. The combination of this, and the two items immediately above are unlikely to radically change ultimate pit lake water quality, but could result in shortening the time it takes to get to that condition.

- Uncertainties in pit lake water quality are tempered somewhat owing to its being an anticipated hydrologic sink. If the pit were to in fact have a flow through character, it is possible that negative impacts to the down gradient groundwater could result.

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# Memorandum

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| **To:** | Bev Everson |
| **Cc:** | Chris Garrett |
| **From:** | Kathy Arnold |
| **Doc #:** | 014/12 – 15.3.2 |
| **Subject:** | **Response Information for Questions by Public** |
| **Date:** | February 13, 2012 |

Rosemont is providing this information in response to several questions raised by the public during the public comment period. These questions appeared to be more policy and/or analytical and outside of the main project discussions but could be confusing if not fully addressed.

Please let me know if there are other issues that our people can assist clarifying.