Role of Professional Judgement and Scaling in Interpretation of Water Quality Model Results

Paul Beddoes[1], Michael Herrell[2], Jerry Vandenberg[3]

[1]Golder Associates Ltd., Burnaby, BC, V5C 6C6, Canada, paul_beddoes@golder.com
[2]Golder Associates Ltd., Burnaby, BC, V5C 6C6, Canada, mherrell@golder.com
[3] Golder Associates Ltd., Kelowna, BC, V1Y 5V5, Canada, jvandenberg@golder.com

Abstract Water quality models are routinely used to identify issues of concern, develop monitoring programs, and establish mitigation strategies for mining projects. Model results are a function of several inputs which introduce uncertainty. Mass loading rates determined from laboratory tests are common inputs to water quality models. These rates require scaling from laboratory conditions to estimate ambient rates. Scaling factors introduce additional uncertainty in results and professional judgement is required in interpretation of those results. This paper presents common water quality modeling challenges associated with laboratory loading rates and scaling factors. Methods for addressing unrealistic model results and the use of professional judgement are discussed.

Keywords water quality modeling, mine water quality, best practices, scaling factors

Introduction

Water quality models are routinely used to identify key issues of concern, develop monitoring programs, and establish mitigation strategies for proposed mining projects. Results of these models are used to provide estimates of expected drainage qualities from proposed mine facilities such as waste rock piles and tailings storage facilities throughout the mine life and into closure. These estimates are based, in part, on geochemical input data from laboratory testing of mine waste material.

Mass loading rates (mass of solute released per unit mass material per unit time) obtained from humidity cell tests (HCTs) are commonly used to represent the solute mass released into water from expected mine materials (*e.g.* tailings, waste rock). Since loading rates under laboratory conditions may not be representative of ambient site conditions, results from these tests generally require some type of scaling factor when used as inputs to environmental models.

Differences between laboratory and ambient site conditions can be addressed through the use of scaling factors (Kempton 2012) that account for the following characteristics: grain size of test material (SF_{size}), channelization/water contact ($SF_{contact}$), temperature (SF_{temp}), oxygen concentration (SF_{O2}), and moisture content (SF_{moist}). Kempton (2012) presented the following equation for calculating field loading rates (R_{field}), which is equal to laboratory loading rates (R_{lab}) multiplied by appropriate scaling factors:

$$R_{field} = R_{lab} \times SF_{size} \times SF_{contact} \times SF_{temp} \times SF_{O_2} \times SF_{moist} \qquad (1)$$

Application of scaling factors can involve the use of any combination of these factors, and each factor can reduce the field loading rate by orders of magnitude. Therefore, developing a reasonable scaling approach is essential to predicting realistic water qualities. Site-specific information (*e.g.* temperature, precipitation) must be used to inform the approach; however, ultimately this selection of scaling factors will be based, in part, on professional judgement.

The development of realistic scaling approaches can be iterative; factors may have to be added, eliminated, or modified to achieve reasonable model results. Modeling in general should also be iterative and input assumptions (*e.g.* scaling approach)should be modified to more closely represent ambient conditions as additional site data and monitoring information become available. However, water quality modeling is often based on limited information for projects that are still in planning as well as design stages.

While validation of model inputs is always preferable, it is often not possible for proposed projects. In the absence of site-specific water quality monitoring data, the reasonableness of model results can be assessed by comparing model results to expected water quality ranges provided in the literature (*e.g.* Plumlee *et al.* 1999) as well as to observed water qualities at analogous mine sites. Sensitivity analyses and multiple model scenarios can also be used to evaluate the validity of a water quality model. Multiple model scenarios can be run to evaluate water quality under a range of plausible climatic conditions, mine plan changes, or changes to other site variables. Predicted water qualities should be within, or similar to, the expected range for the deposit type for all modeled scenarios, unless site specific conditions dictate otherwise.

This paper examines the differences in water quality model results using combinations of scaling factors introduced above. A case study of a hypothetical copper mine in Arctic Canada is used to evaluate how selection of the scaling approach can affect model results.

Methods

A mass-balance water quality model was developed using the GoldSim™ Contaminant Transport Module (GoldSim 2010) for a hypothetical project at a copper porphyry deposit in Arctic Canada. This model is described in greater detail in Herrell (2012). The model was designed to predict water quality in a collection pond downstream of a Tailings Storage Facility (TSF). The collection pond receives runoff from the TSF tailings beach area.

Average winter temperatures at site were assumed to be approximately -10 °C (October to April), and approximately 10 °C in the summer (May to September). Rainfall was assumed to be distributed from May to September. Precipitation was assumed to be pure water containing no metals. Loadings of metals from the TSF were assumed to be stored over winter and released during freshet each May. Water in the TSF collection pond was assumed to be circum-neutral. Sulphide-sulphur concentrations in the tailings were assumed to be as high as 5 %. Two precipitation scenarios were used to evaluate model sensitivity to climate (Table 1).

Hypothetical HCT results representative of tailings material from a porphyry deposit were used to develop mass loading rate inputs to the model. For the purposes of this paper, model inputs and results are limited to three parameters: copper, iron, and zinc. Inputs are presented in Table 2.

The synthetic loadings rates are used to determine field loading rates for input to the water quality model using Equation 1. The laboratory loading rate was calculated as the average measured loading rate over the 56th to 60th week. The scaling factors used to calculate the field loading rates are presented in Table 3.

Model Scenario		Precipitation (mm/a)	Evaporation (mm/a)	TSF Footprint (km^2)	TSF Collection Pond Area (km^2)	Pond Capacity (m^3)
A	Net Surplus	840	550	1.0	0.1	115,000
B	Net Evaporative	400	550	1.0	0.1	115,000

Table 1 *Model Sensitivity Analysis Details.*

Grain size (SF_{size}) and moisture content (SF_{moist}) factors were not included in the water quality model. The tailings grain size in the HCT is expected to be similar to tailings deposited in the TSF at site and the moisture content of the tailings is not expected to be low enough to warrant scaling based on moisture content.

To evaluate model output sensitivity to application of these scaling factors, several model simulations were performed using different combinations of the scaling factors presented in Table 4. There is a range of reasonable SF_{O2} values in rock with a sulphide-sulphur concentration of ≈ 1 – 5 % (Kempton 2012). Two simulations were performed to evaluate model sensitivity using SF_{O2} values of 0.2 (SF_{O2-A}) and 0.5 (SF_{O2-B}).

Results

Monthly maximum predicted metal concentrations in the TSF collection pond water for two climate scenarios (Table 1) and four scaling factor simulations (Table 4) are illustrated in Fig. 1. Results are compared to expected concentrations in circum-neutral drainage from copper porphyry deposits presented in Plumlee *et al.* (1999).

The following observations can be made based on the water quality model results:

- Iron concentrations were within the expected range for copper porphyry deposits for both climate scenarios and all model simulations.
- When only a channelization factor ($SF_{contact}$) is applied, the maximum predicted concentration of copper is above the expected range for copper porphyry deposits for both climate secnarios, while the maximum predicted concentration of zinc is above the expected range for copper porphyry deposits in the net evaporative climate scenario (Scenario B).

Parameter	Units	Week 56	Week 57	Week 58	Week 59	Week 60	Model Source Term (R_{lab})
Copper (Cu)	mg/kg/week	0.0018	0.0023	0.0029	0.0026	0.0028	0.0025
Iron (Fe)	mg/kg/week	0.017	0.022	0.023	0.019	0.025	0.021
Zinc (Zn)	mg/kg/week	0.00012	0.00011	0.00012	0.00011	0.00012	0.0012

Results are hypothetical based on a one kilogram charge sample and one litre of water flushed per week.
Model source term is based on the average of the last five weeks of testing.

***Table 2** Hypothetical Geochemical Source Terms.*

Scaling Factor		Value	Description/Rationale
Channelization/ Water Contact	$SF_{contact}$	0.1	Reflects the difference in flow pathways under laboratory relative to ambient conditions. Synthetic loading rates reduced by a factor of 10 to account for preferential flow paths.
Temperature	SF_{temp}	0.37 (Summer) 0.04 (Winter)	Calculated using the Arrhenius equation* to account for differences in reaction rates between laboratory (20 °C) and ambient temperatures (MEND 2006).
Oxygen Content	SF_{O2}	0.2, 0.5	Reflects differences in oxidation rate due to oxygen content in test conditions relative to ambient; factors between 0.2 and 0.5 are reasonable in high sulphide conditions (Kempton 2012).

*An activation energy of 69 kJ/mol was used

***Table 3** Scaling Factors Used in Water Quality Modeling of a Hypothetical Copper Mine in Arctic Canada.*

Simulation	Scaling Factors Applied
1	$SF_{contact}$
2	$SF_{contact}$,SF_{temp}
3	$SF_{contact}$,SF_{temp}, $SF_{O2\text{-}A}$
4	$SF_{contact}$,SF_{temp}, $SF_{O2\text{-}B}$

Table 4 *Model Simulations Using Various Scaling Approaches.*

- Maximum predicted concentrations for all modeled parameters are within the expected range for copper porphyry deposits when both the channelization ($SF_{contact}$) and temperature (SF_{temp}) scaling factors are applied for both climate scenarios.
- If anSF_{O2} factor of 0.5 ($SF_{O2–B}$) is applied with the channelization ($SF_{contact}$) and temperature (SF_{temp}) factors, copper, iron and zinc concentrations are within the expected range for copper porphyry deposits for both climate scenarios.
- When a lower oxygen content scaling factor ($SF_{O2–B}$ = 0.2) is applied with the channelization ($SF_{contact}$) and temperature (SF_{temp}) factors, the maximum predicted concentration of copper is below the expected range for copper porphyry deposits for both climate scenarios.
- Depending on the selection of scaling factors, model results can vary by almost two orders of magnitude.

Discussion and Conclusions

Selection of an appropriate scaling method can be challenging because site-specific information may not be available when scaling factors need to be determined. Therefore, professional judgement is used to select scaling factors based on the available information and the current understanding of the system being modeled. Depending on site conditions, some scaling factors may be inappropriate, while others are necessary to develop a reasonable representation of the system.

To evaluate whether water quality model results are reasonable, they can be compared to the range of drainage water quality from similar deposit types (Plumlee *et al.* 1999) or to analogous mine sites. Plumlee *et al.* (1999) presents a range of natural drainage chemistries from mineralized zones of several deposit types. While this information does not directly represent the operational drainage water quality from a mine site, it provides a useful benchmark to assess the reasonableness of model results in the absence of site-specific water quality.

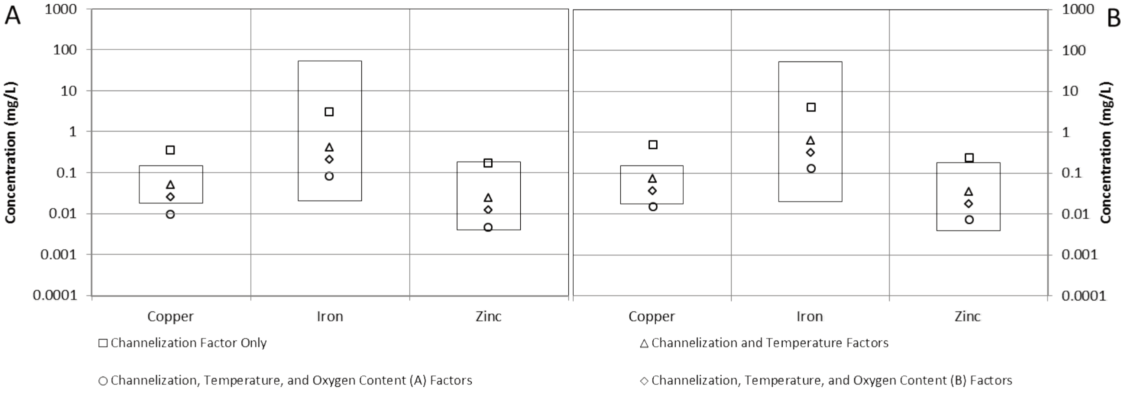

Fig. 1 *Maximum predicted metal concentrations in TSF collection pond water for climate scenarios A (net surplus, left) and B (net evaporative, right). Results are compared to expected concentration ranges for circum-neutral drainage presented in Plumlee et al. (1999) for copper porphyry deposits (boxes).*

A comparison of application of different scaling factors indicates that model results can be sensitive to the use of different scaling factors. When only a channelization factor ($SF_{contact}$) was applied to scale loading rates, predicted maximum concentrations of copper and zinc were above the expected range of concentrations for porphyry copper deposits (Fig. 1). As expected, simulated concentrations decrease as additional scaling factors (*i.e.* SF_{temp} and SF_{O2})are applied.

Due to the sensitivity of water quality model results to scaling factors (Fig. 1), it is the role of the modeler to exercise professional judgement, not only when selecting which factors to apply, but also when determining the value for each scaling factor. For example, when an $SF_{O2}$of 0.5 was applied to HCT loading rates, maximum copper and zinc concentrations were within the expected range for copper porphyry deposits (Plumlee *et al.* 1999). However, concentrations of copper and zinc were less than the minimum concentrations for this deposit type when the $SF_{O2}$was decreased to 0.2 (Fig 1). Based on the model assumptions, both of these factors would be considered reasonable (Kempton 2012).

Given the large range of possible model results (*i.e.* orders of magnitude) that can result from the use of different scaling factors, the results of such an exercise can be presented as a sensitivity analysis when there is uncertainty about which rate to apply. In doing so, the modeler can present the most plausible realizations or results as being “likely”, whereas upper and lower bounds can be presented as “unlikely” or “possible”. Mine water managers can thus be made aware of the uncertainty inherent in such model predictions, and decisions regarding monitoring and mitigation will be more well informed.

Model development is an iterative process. Water quality models are often initially developed using conservative assumptions and if the model results indicate that the projected water quality is unreasonable, further refinement to the model assumptions is required. This is usually addressed through the modification of scaling factors. However, it is not the purpose of scaling to adjust model results until they match an expected water quality but rather, to generate reasonable and conservative representations of systems being modeled. Water quality models should be frequently updated throughout the life of mine with operational water quality monitoring results. This way, the results can be validated or corrected through refinement of model input assumptions, such as scaling factors that are often initially selected based on professional judgement.

It has been shown, using a water quality model for a hypothetical TSF, that use of inappropriate scaling factors can lead to unrealistically high or low water quality results when compared to the range of drainage water quality for a copper porphyry deposit (Plumlee *et al.* 1999). Despite limited site information, a reasonable scaling approach can be selected using professional judgement. Even in the absence of site-specific, field measurements, this approach can be used to produce realistic and conservative water quality results which can be used to inform decision making processes in planning and permitting of mining projects.

References

GoldSim (GoldSim Technology Group) (2010) GoldSim User’s Guide.Version 10.5.

Herrell MK, Salzsauler K, McRae C (2012) A Practical Application of Mass-Balance Methods for Predicting Mine Drainage Water Quality – Climate Influences and Best Practices. Proceedings of the9th International Conference on Acid Rock Drainage (ICARD), Ottawa, Ontario, Canada, May 20 – 26, 2012.

Kempton H (2012) A Review of Scale Factors for Estimating Waste Rock Weathering from Laboratory Tests. Proceedings of the 9th International Conference on Acid Rock Drainage (ICARD), Ottawa, Ontario, Canada, May 20 – 26, 2012.

Mine Effluent Neutral Drainage Network (MEND) (2006) Update on Cold Temperature Effects on Geochemical Weathering. MEND Report 1.61.6, October 2006.

Plumlee GS, Smith KS, Montour MR, Ficklin WH, Mosier EL (1999) Geologic Controls on the Composition of Natural Waters and Mine Waters Draining Diverse Mineral-Deposit Types. In: Reviews in Economic Geology, Society of Economic Geologists (SEG), 1999, pg. 373 -407.