

THE APPROPRIATE GEOCHEMICAL MONITORING OF TOE SEEPAGE FROM A MINE-ROCK DUMP

Kevin A. Morin¹, Ian A. Horne², and David Flather³

¹ Morwijk Enterprises Ltd., Suite 703, 1155 Harwood Street, Vancouver, British Columbia V6E 1S1

² Island Copper Mine, P.O. Box 370, Port Hardy, British Columbia V0N 2P0

³ Rescan Environmental Services, 6th Floor, 1111 West Hastings Street, Vancouver, British Columbia V6E 2J3

ABSTRACT

Water passing through mine-rock dumps either enters the underlying groundwater system or exits at the toe. For the case of toe seepage, the water is often collected in ditches and diverted out of the area. In light of the variability in flow and chemistry expected in toe seepage, questions arise as to the appropriate monitoring program including, for example, the importance of variable sampling frequency. Alternatively, for many mines in British Columbia, the more important question is "Are we missing anything important by sampling on a routine basis such as monthly?". Rather than answering the question based on theory, this paper answers with actual data from a minesite in British Columbia.

At the Island Copper Minesite on Vancouver Island, British Columbia, an ambitious monitoring program of toe seepage took place over a six-month period. Eight stations were monitored basically either (1) once daily for flow and chemistry or (2) hourly for flow and every four hours for chemistry. Based on statistical analyses of data from selected stations, answers are provided for important technical questions, such as monitoring frequency, and for regulatory questions, such as permit limits. In essence, water chemistry can be viewed like hydrology where, for example, yearly concentrations of a 1-hour duration can be determined. This concept is expanded further in an accompanying paper at this symposium using standard monitoring data.

1. INTRODUCTION

The Island Copper Minesite (Figure 1) has been conducting intensive studies for several years for the eventual development of a detailed Decommissioning and Closure Plan. One of these studies has focussed on water chemistry in and around the mine-rock dumps (Figure 2). Over a six-month (semi-annual) period from October 1, 1991 to March 31, 1992, monitoring of eight stations (Figure 2, not including SUMP Station) followed schedules of either (1) daily mid-morning measurements of flow and chemistry [NWD, NDD, EDT], (2) hourly measurements of flow with sampling every four hours for chemistry [WME], or (3) a mixture of the two previous schedules [TED, EMO, EDD, PDW]. Full documentation of this monitoring program can be found in Rescan (1992).



FIGURE 1. Location of Island Copper

For this paper, we examine trends only at EMO, NDD, and WME. The EMO (Eastern Most Outcrops) Station is located at the end of the ditch which collects seepage from the northeastern extension of the North Dump. The EMO portion of the North Dump contains an estimated 5.5×10^6 metric tonnes of waste rock. The NDD (North Drainage Ditch) Station is located on the northwest corner of the Old North Dump, which is composed of an estimated 35% acid-generating rock and 65% acid-neutralizing till. The WME (Water Management East) Station is located at the midpoint of a culvert into which flows all drainage from the eastern and northern portions of the minesite. As a result, the chemistry at WME represents a composite of all drainages and, because lime is occasionally added at the top of the culvert, it also reflects the effect of alkaline water treatment.

Water samples from all stations were analyzed for pH, conductivity, alkalinity, acidity, sulfate, copper, zinc, cadmium, calcium, magnesium, and aluminum (Rescan, 1992). This paper is limited to copper and zinc with a minor examination of cadmium. Although both concentrations and loadings (flow multiplied by concentration) are available, only concentrations will be dealt with in this paper.

2. OBJECTIVES AND QUESTIONS

From a technical perspective, the objectives of this paper are:

- to determine the four statistical parameters of: mean, standard deviation, maximum (highest) value, and minimum (lowest) value for copper and zinc at EMO, NDD, and WME stations (cadmium was only considered at EMO for brevity); and
- to determine the aforementioned parameters at each station using (1) the entire database, (2) a quarterly subset (as explained below), (3) a monthly subset, (4) a weekly subset, and (5, for WME only), a daily subset.

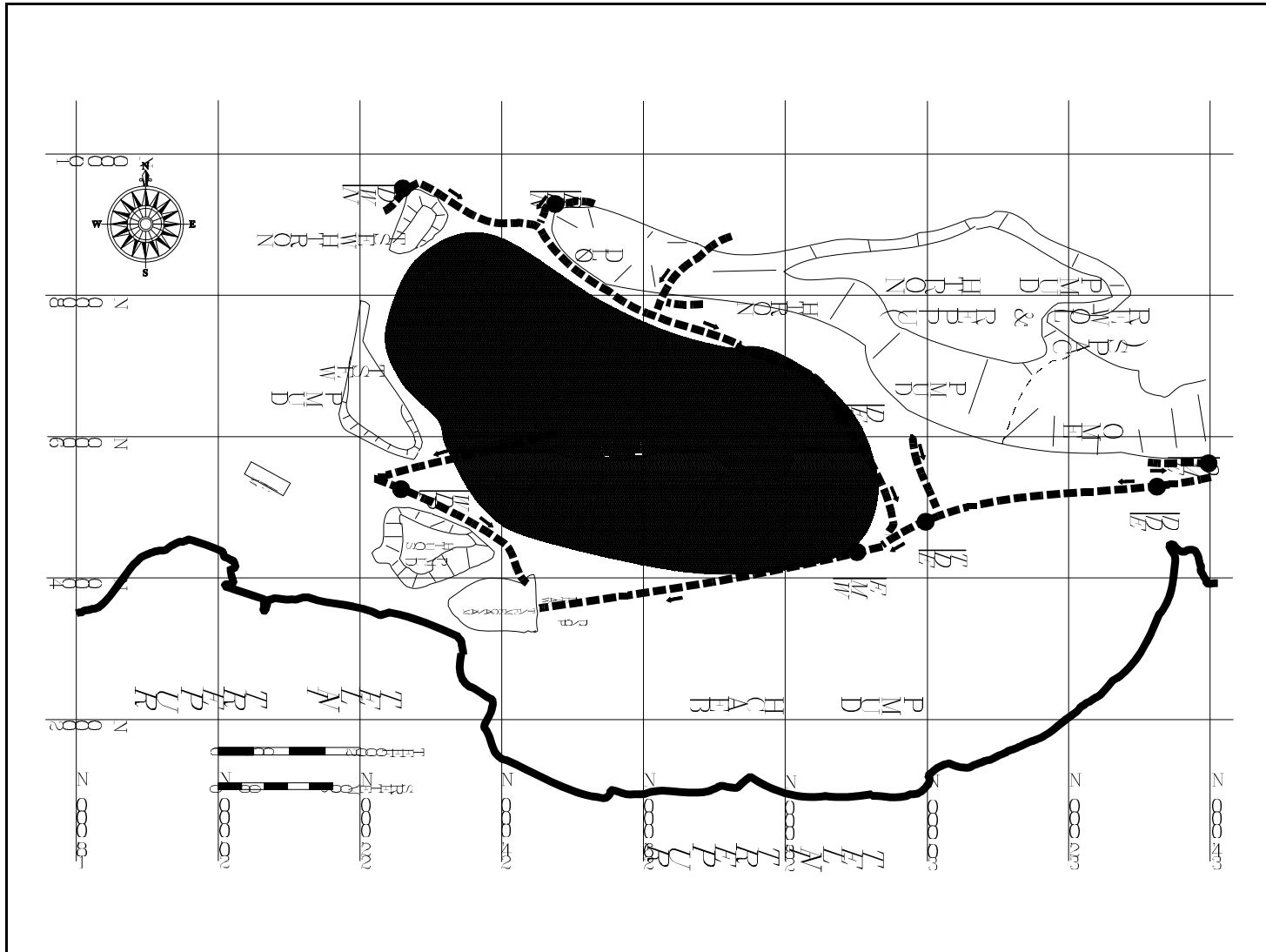


FIGURE 2. Map of Island Copper Minesite and locations of Monitoring Stations

Relevant questions that arise from the statistical calculations include:

- if only quarterly or weekly sampling had been performed, how would the values of their statistical parameters compare to those of the entire database?
- how accurately can daily or hourly concentrations be predicted from quarterly or monthly data?
- what is the maximum concentration of each metal that flowed past each station over the semi-annual period, even if it was not directly measured?

In order to fulfill the objectives and answer the questions, we used the following approach and terminology. (The terminology below within quotation marks is critical in understanding the later discussion and diagrams.) Basically, all data at each station had to be normalized to a semi-annual period extending from October 1 to March 31. Beginning with the EMO database, which essentially consisted of daily measurements of flow and concentration, the "real" semi-annual values of the statistical parameters were calculated from the entire database (October 1 to March 31). Then another set of semi-annual statistical values (labelled "quarterly midpoint values") was calculated from the one mid-day sample on November 15 (midway between October 1 and December 31) and the one mid-day sample on February 14 (midway between January 1 and March 31). The use of just these two datapoints to represent the entire semi-annual period obviously would not provide accurate values of, for example, the mean when compared to that of the entire database. However, the concept behind this paper is to compare the "quarterly midpoint mean" to the "real semi-annual mean" in order to discover how representative quarterly sampling would have been.

Similar to the semi-annual "quarterly midpoint" calculations, a random number generator was used to select one sample anytime within the first quarter (October 1 to December 31) and one sample anytime within the second quarter (January 1 to March 31). The resulting "random quarterly" mean, standard deviation, high, and low could then be compared to the "real" semi-annual values. In fact, 25 random quarterly runs were performed for comparison, which is physically equivalent to replaying the semi-annual period 25 times and having the opportunity to sample differently during each replay.

As with the quarterly runs, a "midpoint" run and 25 random runs were also made for monthly, weekly, and (for WME) daily partitions of the database. In other words, the "weekly midpoint mean" is the semi-annual value calculated from the 26 samples, each taken at the midpoint of a week, over the semi-annual period (although data were not available for all weeks). Similarly, the "monthly random standard deviation" is the semi-annual value calculated from the 6 values randomly chosen anytime within each month over the semi-annual period.

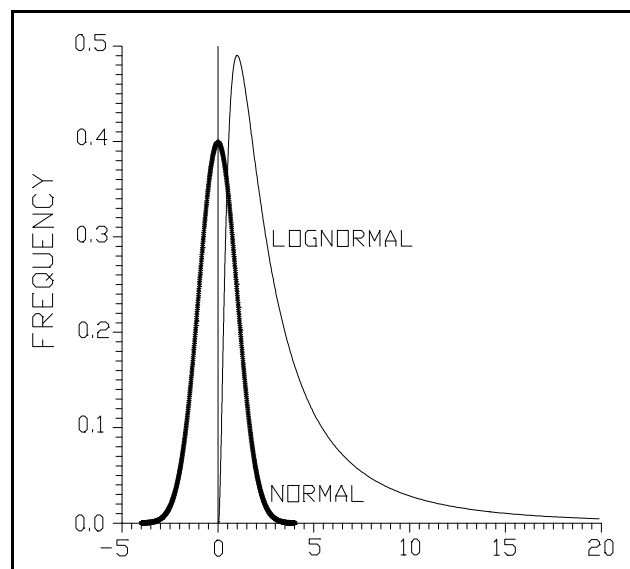


FIGURE 3. Examples of Normal and Lognormal Distributions on an Arithmetic Scale

In order to validly calculate statistical parameters such as means and standard deviations, the data must display a "normal" distribution (Figure 3). If data do not display this distribution, the data must be mathematically transformed into a normal distribution or alternative complex techniques must be implemented. A common mathematical transformation for geochemical data is logarithmic (Davis, 1986). An analysis of our database indicated the data often did not display a normal distribution (Figure 4a), but could be transformed through logarithms to approximate the distribution (Figure 4b). This is discussed further in another paper at this symposium (Morin and Hutt, 1993), but an important observation here is that the standard deviation must remain as a log value. For example, if a calculated logarithmic mean and standard deviation were 2 ($10^2 = 100$ ug/L) and 0.2 log cycles, respectively, then + 1 standard deviation is $10^{[2 + (0.2*1)]}$, or 158 ug/L, and + 2 standard deviations is $10^{[2 + (0.2*2)]}$, or 251.

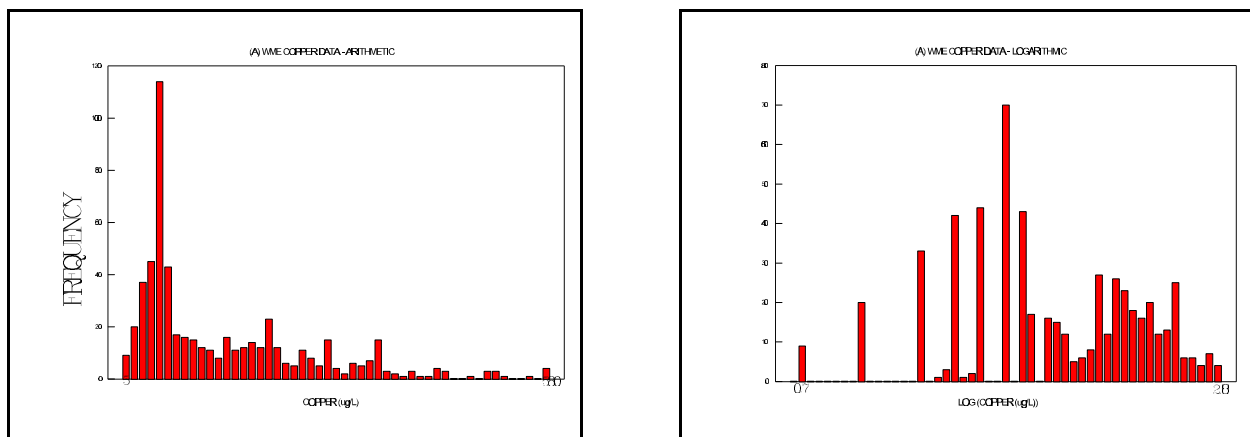


FIGURE 4. Frequency Distribution of Copper at WME on (a) Arithmetic and (b) Logarithmic Scales

3. RESULTS

3.1 Mean Values

The "real" mean values for zinc, copper and cadmium at EMO, based on the logarithmic transformation of the entire semi-annual database, were 16960, 1840, and 80 ug/L, respectively. The means of the quarterly midpoints, which were based on one sample each from the midpoint of each quarter (Section 2), provided reasonable estimates of the real means at values of 15500, 2220, and 89 ug/L (Figure 5a). However, the 25 random quarterly runs (Section 2) show that these reasonable estimates were a coincidence and that an error of up to 0.2 log cycles (Figure 5a; a factor of roughly 2) would usually be encountered if quarterly sampling was used to calculate "real" means for copper and iron. If an error of a factor of 2 is acceptable for the mean, then quarterly sampling would usually be sufficient at EMO for zinc and copper.

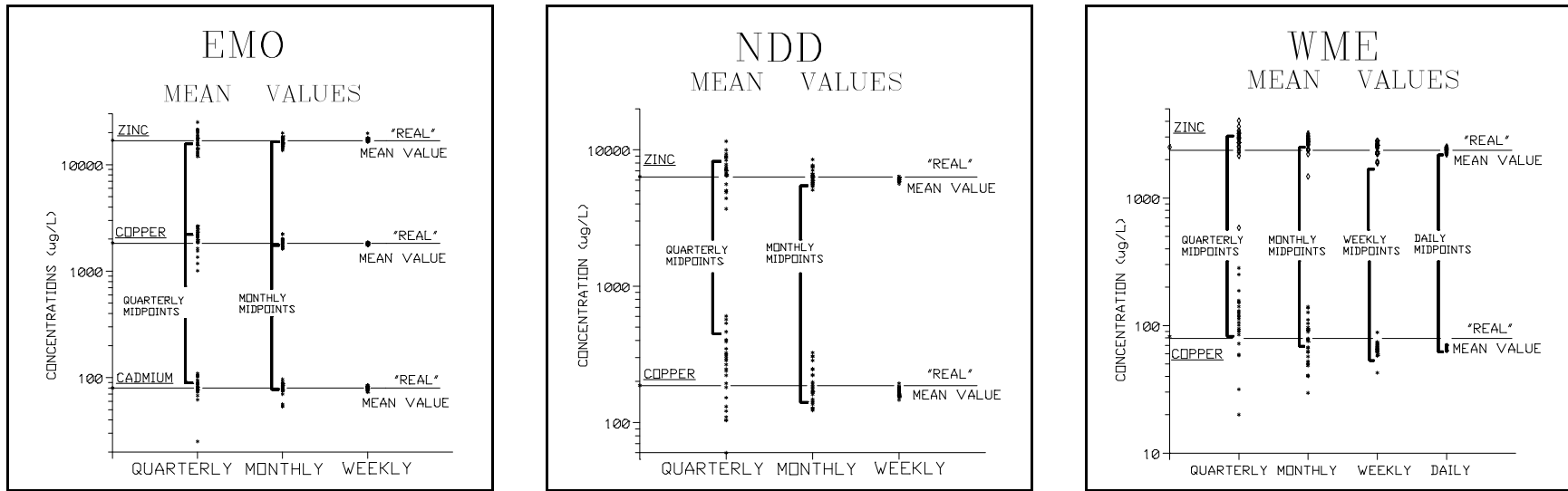
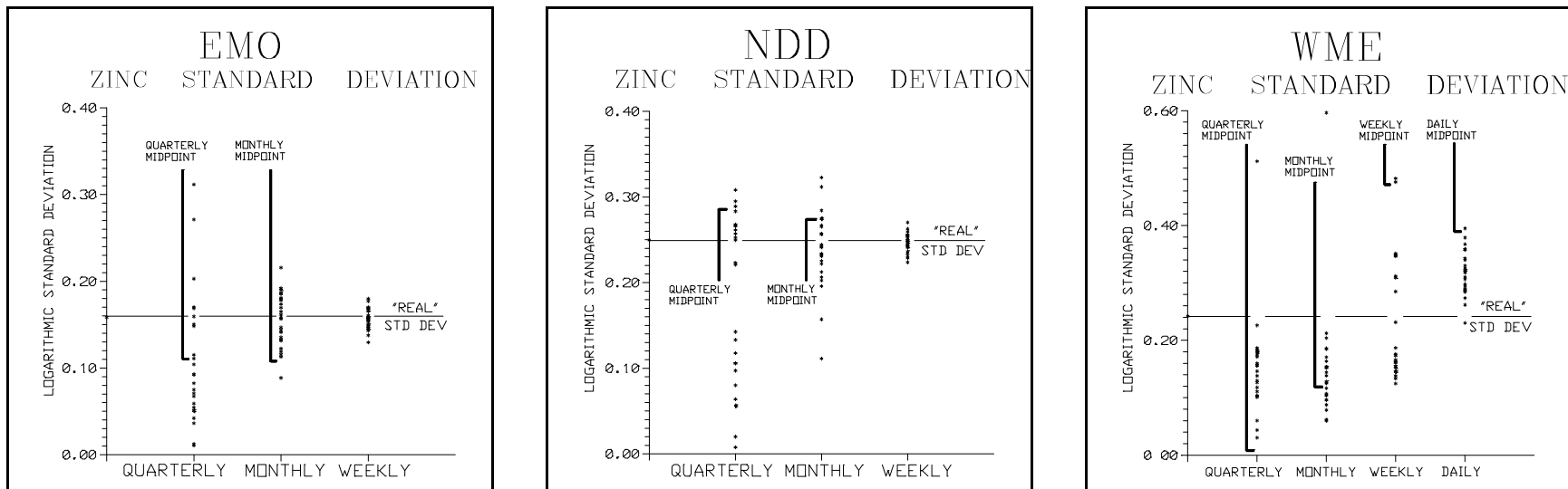


FIGURE 5 (above). Mean Values for Zinc and Copper at (a) EMO (including Cadmium), (b) NDD, and (c) WME

FIGURE 6 (below). Log Standard Deviations for Zinc at (a) EMO, (b) NDD, and (c) WME



However, if better accuracy of the real mean is required, then monthly sampling would usually provide errors of less than 0.1 log cycles (about a factor 1.25 or 25%) or 0.2 cycles for cadmium (Figure 5a). Weekly analyses would only be required for highly accurate geochemical work and would not be justified relative to analytical accuracy which is often considered to be approximately 10% (0.04 log cycles).

The quarterly midpoints for zinc and copper at NDD (Figure 5b) are poorer estimates of the "real" means than those for EMO (Figure 5a). Nevertheless, the 25 random quarterly runs show that the midpoints are not the worst estimates that could be obtained. Overall, weekly sampling at NDD would be required to generally obtain the same accuracy that monthly sampling would provide at EMO. This discrepancy reflects the cumulative differences between the two areas, including factors such as greater pH variations and the presence of till in the adjacent rock at NDD.

The water chemistry at WME represents the composited chemistries from all rock on the east and northside of the minesite (Section 2 and Figure 2). As a result, greater scatter can be expected for mean values calculated from the random quarterly runs which is in fact observed (Figure 5c). If an accuracy better than 50% is required in the estimate of the "real" mean value, then weekly or more frequent sampling is required.

3.2 Standard Deviations

As explained in Section 2, the lognormal distribution of the data required logarithmic transformations of the values. This carries important implications for the standard deviation, which is maintained as a log value and added to the log of the mean as required (Section 2). The importance of the standard deviation is significant and is discussed further in Section 4.

As with mean values (Figure 5), the accuracies of the standard deviations for zinc (Figure 6) and copper (Figure 7) improve greatly as sampling frequency increases. For zinc at EMO (Figure 6a), the random quarterly runs show that the calculated standard deviations can range from essentially 0 log cycles (constant values) to almost 0.32 log cycles (a factor of 2) in comparison to the "real" value from the entire database of 0.158 (a factor of 1.44). Nevertheless, this is not a significant error and at a weekly frequency, the typical error in the calculated standard deviation is less than 0.03 log cycles (less than 10%). A similar behavior is noted for zinc at NDD (Figure 6b), but zinc at WME (Figure 6c) deviates from the trend.

At WME, the zinc standard deviation for the quarterly and monthly runs appear to converge on a value less than the "real" value (Figure 6c). At weekly and daily frequencies there is a distinct shift towards higher standard deviations which converge on a value greater than the "real" standard deviation. This behavior is a consequence of the lime that is occasionally (rarely) added above this station: it raises aqueous pH above 11.0 and sharply decreases metal concentrations. Because the quarterly and monthly runs did not detect these rare additions of lime, no particularly low values were encountered which resulted in relatively high "minimum" values (not shown) and relatively low standard deviations. As sampling frequency increased, the rare additions of lime were detected which resulted in relatively low "minimum" values and relatively

high standard deviations as seen in Figure 6c. The "real" standard deviation from the entire database obviously lies between these two extremes.

The trends in standard deviations for copper (Figure 7) follows those noted for mean values (Figure 5) and for standard deviations for zinc (Figure 6). As the sampling frequency increases, the scatter in the random runs converges on the "real" value based on the entire database. The importance of this convergence lies in this conclusion: if the required degree of accuracy of the mean and standard deviation are identified (e.g., comparable to analytical accuracy), then the appropriate sampling frequency at random or at predetermined times can be identified. While there is obviously some value in this exercise, a more important issue for mining companies and regulatory agencies alike is usually the maximum concentration or: are we exceeding permit levels at any point in time?

3.3 Highest Measured Concentration

Permit levels are typically written so that a particular value cannot be exceeded or a violation has occurred. From this perspective, the maximum or highest measured value becomes a major concern. This section discusses the observations from the databases at EMO, NDD, and WME. Then Section 4 explains how important the preceding means and standard deviations are in estimating the true highest concentration that was even missed by the frequent sampling in this study.

At EMO, the quarterly midpoints for zinc, copper, and cadmium provide maximum concentrations that are consistently less than the highest values in the database (Figure 8a). Similarly, the 25 random quarterly runs fail to yield the "real" maximum value, except for one run with zinc. However, at monthly frequency, several runs did return the highest value in the database, showing that this highest value in the database is not rare. Even for the runs that do not detect the "real" highest value, the maximum values are often within 0.3 log cycles (a factor of 2) below it. At weekly frequency, most maximum values were less than 0.12 log cycles (a factor of 1.35 or 35%) below the "real" highest value.

At NDD (Figure 8b), at least one run from each set of 25 detected the "real" highest value in the database, including the quarterly and monthly midpoints for copper. However, the scatter among a set of 25 random runs is greater than that for EMO (Figure 8a) and thus the chances of obtaining the real value at any sampling frequency is actually less than at EMO. Similar trends are noted at WME (Figure 8c), although the daily random runs at WME, which are not available for EMO and NDD, show that the scatter does decrease to 0.1 log cycles (25%) at that frequency.

4. DISCUSSION AND CONCLUSIONS

Monitoring programs for water chemistry are often driven by the desire to protect the environment and to meet operating/closure permit specifications. This study has shown that various sampling frequencies often provide values for means, standard deviations, and maximum

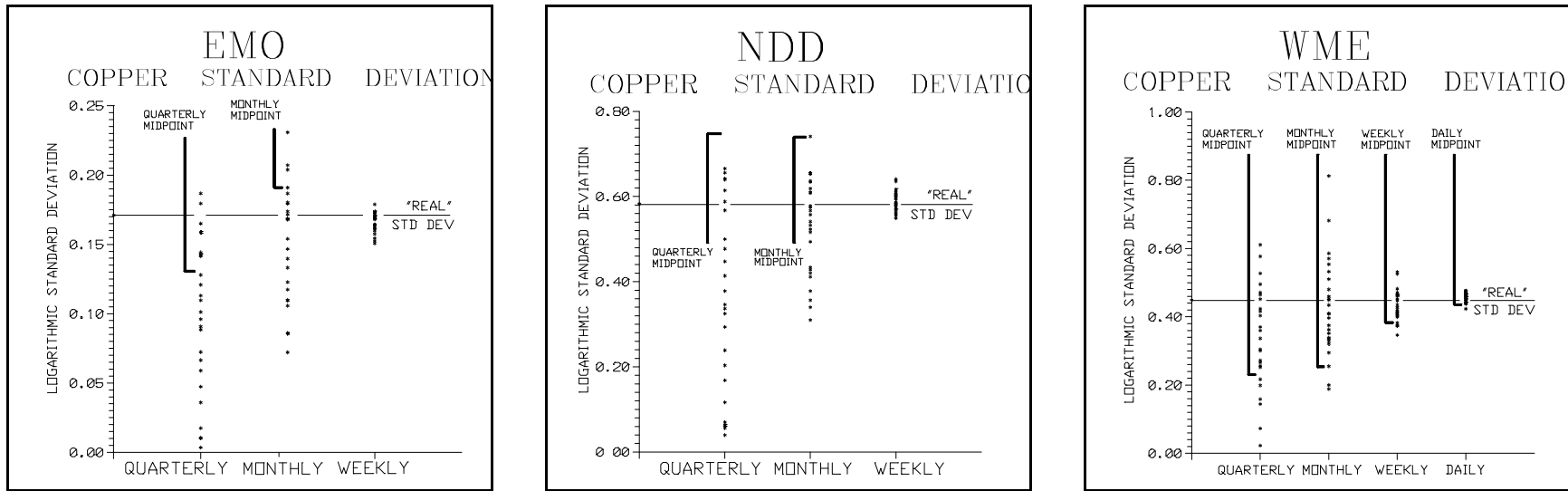
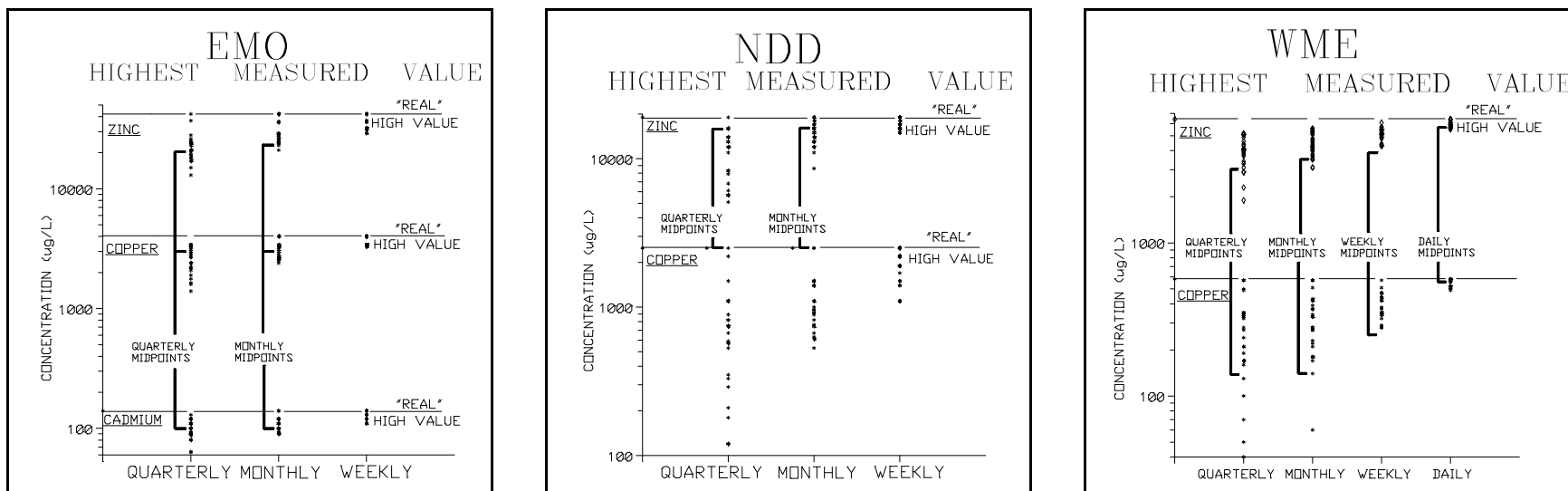


FIGURE 7 (above). Log Standard Deviation for Copper at (a) EMO, (b) NDD, and (c) WME

FIGURE 8 (below). Highest Values for Zinc and Copper at (a) EMO (including Cadmium), (b) NDD, and (c) WME



values that are within specific ranges of the "real" highest values in the databases. If the desired degree of accuracy is selected, then the appropriate monitoring frequency (random or set-time) can be identified. This fulfills the two objectives of this paper and answers the first two of three questions of Section 2. To answer the third question, further discussion of maximum values is needed.

The "real" highest values in the databases are not actually true maximum values. At EMO and WME, the "real" highest value in the database is simply the highest value measured in instantaneous grab samples around mid-morning of each working day. At WME, the "real" highest value is the maximum instantaneous sample collected over four-hour intervals. Obviously, there could have been even higher concentrations that were not detected by the monitoring programs. These observations show that the last question of Section 2 can actually be divided into three more specific questions:

- if the highest concentrations in the databases (Section 3.3) were not the true maximum values, how close were they to the maximum?
- how long did the highest concentrations in databases persist or how frequently will they occur?
- what were the true maximum concentrations?

Obviously we cannot obtain the answers based on measured data because even this intensive study could not provide the information. Therefore, we will have to calculate the answers based on statistics, particularly means and standard deviations. This study has shown that as sampling frequency increases the calculated means and standard deviations converge on constant values. Perhaps the databases did not provide the true value, but Figures 5 through 8 show that the "real" values from the databases are likely to be within 10% of true values. Based on this observation, calculations can now be made.

A statistically normal distribution allows the calculation of probability levels (e.g., Pollard, 1977) in which, for example, 84.1% of all values will lie at or below + 1 standard deviation above the mean. The worst-case monthly concentration is defined as the highest composite concentration that persists for a total of one month over a year. During this month (1/12 or 8.3% of a year), one-half (4.3% of a year) of the instantaneous concentrations could be expected to be higher than the composite value and one-half to be less. With the composite probability of 4.3%, the monthly composite concentration would be 1.73 standard deviations above the mean (Table 1). Other time intervals are also tabulated in Table 1.

TABLE 1					
PROBABILITY LEVELS AND CORRESPONDING TIME INTERVALS					
TIME INTERVAL	1 YEAR	1 MONTH	1 WEEK	1 DAY	1 HOUR
PROBABILITY	100%	8.3%	1.9%	0.27%	0.011%
NO. OF STD DEV ABOVE MEAN ¹	+ 0.00	+ 1.73	+ 2.34	+ 3.00	+ 3.85

¹ Obtained from normal-distribution tables (e.g., Pollard, 1977) after dividing probability by 2

As an example of this approach, the highest measured zinc concentration at EMO was 42000 ug/L (log value of 4.62), the logarithmic mean was 4.23 (16960 ug/L), and the log standard deviation was 0.1584 log cycles. Consequently, the highest measured value was 2.4 standard deviations above the mean $[(4.62-4.23)/0.16]$ which corresponds to a 1 week time interval (Table 1). In other words, this concentration is expected to occur for a duration (continuous or discontinuous) of 1 week over 1 year. If this reasonable, then weekly sampling at EMO should usually detect this "highest" concentration whereas monthly and quarterly would not typically do so, which is confirmed by Figure 8a.

A pertinent question would now be the highest zinc concentration at EMO with a total duration of 1 hour in 1 year. This concentration is expected to be 70150 ug/L $[10^{4.23 + (0.16*3.85)}]$, or 67% greater than the highest measured value in the database. From this perspective, water chemistry can be viewed in a manner similar to storm events and hydrology flows with a 1-hour-duration concentration that occurs yearly. There is reason to expect higher 1-hour-duration concentrations that may occur every 100 years, but our semi-annual database is not sufficient to assess this possibility. Nevertheless, this procedure provides the answers to the last question of Section 2 and those in this Section.

Further discussion of this approach using long-term standard monitoring data can be found in Morin and Hutt (1993). Meanwhile, further evaluation of the Island Copper databases continue.

REFERENCES

- Davis, J.C. 1986. Statistics and Data Analysis in Geology, Second Edition. John Wiley & Sons, Toronto. 646 p.
- Morin, K.A., and N.M. Hutt. 1993. The use of routine water-chemistry monitoring data for assessment and prediction of water chemistry. 17th Annual Mine Reclamation Symposium (these proceedings), May 4-7, Port Hardy, British Columbia.
- Pollard, J.H. 1977. A Handbook of Numerical and Statistical Techniques. Cambridge University Press. 349 p.
- Rescan Consultants Inc. 1992. Hydrological and Metal Loadings Study, Phase 1 Report. Mine Report for Island Copper Mine, BHP Minerals Canada Limited.