

UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Mines Special Publication SP 06A-94

***INTERNATIONAL LAND RECLAMATION
AND MINE DRAINAGE CONFERENCE***

AND

***THIRD INTERNATIONAL CONFERENCE
ON THE ABATEMENT OF
ACIDIC DRAINAGE***

Volume 1 of 4: Mine Drainage

Proceedings of a conference held in Pittsburgh, PA on April 24-29, 1994.
This conference served as the annual meeting for both the American Society for
Surface Mining and Reclamation and the Canadian Land Reclamation Association.

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HIGH-FREQUENCY GEOCHEMICAL MONITORING OF TOE SEEPAGE FROM MINE-ROCK DUMPS, BHP MINERALS' ISLAND COPPER MINE, BRITISH COLUMBIA¹

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Abstract: Recent studies of mine-rock dumps have shown that water can pass through a dump in hours to days. As this water initially flows downward and is focused into preferential channels within the dump, it collects dissolved metals from the rock. The water then either flows as surface seepage from the toe or enters the groundwater system beneath the dump. In the case of toe seepage, the water is often collected in ditches and diverted out of the area. Because of the variability in flow and chemistry expected in toe seepage, questions can arise as to the appropriate monitoring frequency.

This paper addresses monitoring frequency based on actual data from the Island Copper Mine in British Columbia. Data on flow and chemistry were repeatedly collected as frequently as every 15 minutes and every four hours, respectively, for six months in 1991-92 and again in 1992-93. The chemical parameters collected at 10 monitoring stations included pH, conductivity, alkalinity, acidity, sulfate, copper, zinc, cadmium, calcium, magnesium, and aluminum.

The combined database for this ongoing study currently contains tens of thousands of values and continues to grow. This paper presents some of the findings, correlations, and relationships noted to date. For example, distributions of the chemical data in 1991-92 and 1992-93 typically resemble lognormal or normal statistical distributions. The statistical analyses show that the results of hypothetical hourly sampling, for example, can be estimated from the actual results of weekly sampling. Based on this, a parallel is drawn with hydrology in which there is an annual peak chemical concentration of a particular duration. Also, relationships of chemical concentrations to both flow and time show the gradual depletion of reaction products that accumulated during summer months, as well as the later flushing of short-term accumulations that accrue between storm events. However, correlations of chemical parameters to flow alone are poor, reflecting the significant influence of other factors on chemistry. These factors are discussed further in other papers at this conference.

Additional Key Words: waste rock, mine rock, mine seepage, water chemistry, water quality, geochemistry.

Introduction and Objectives

Mine-rock dumps are recognized as physically and geochemically complex systems (e.g., Morin et al. 1991, Morin and Hutt 1994). In a general sense, precipitation and/or snowmelt initiates infiltration into a dump, the water is then focused into preferential channels as it collects metals and nonmetals from rock-particle surfaces, and the

¹Paper presented at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, USA, April 24-29, 1994.

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water with its chemical load exits into the underlying groundwater system or basal toe ditches. However, the specific details of this scenario of physical and chemical hydrogeology are difficult to monitor and define. As a result, there are currently two basic approaches for characterizing and predicting the effects of mine-rock dumps. The first is through internal studies of some dump processes that are thought to be most important (e.g., Gélinas et al. 1992, Morin et al. 1994a), which requires intensive long-term programs over several years. The second is seepage monitoring such as in basal toe ditches, which is more suited to short-term studies. The first approach describes a dump through internal monitoring of its behavior, whereas the second empirically describes a dump through monitoring of its cumulative effects at the base. This paper describes a study of the second type.

In the case of toe seepage, water leaving a dump is often collected in toe ditches and diverted from the area. Monitoring of toe ditches for chemistry and flow thus provides a detailed assessment of the cumulative effect of the dump and perhaps a suggestion of dominant processes operating within it. A major issue in this type of monitoring is the frequency at which the monitoring should be performed in order to obtain the necessary data for characterization and prediction. Frequency of monitoring has been addressed from theoretical and statistical viewpoints (e.g., Robertson 1990), but actual high-frequency data to test such theories are rare.

As part of closure studies at BHP Minerals' Island Copper Mine in British Columbia, the short-term peaks in flow and chemistry from the mine's dumps were identified as major issues for closure planning. Consequently, a high-frequency monitoring program was designed and initiated during the wet season from October 1991 to March 1992 (Rescan, 1992), with flow and chemistry measured as frequently as every 15 minutes and every four hours, respectively. This program was repeated from September 1992 to June 1993, and is again underway in 1993-94.

The first objective of this paper is to describe the results of the monitoring program. Due to the large number of analyses and values, results can only be presented through statistical summary parameters and distributions. As a second objective, the statistical distributions are used in predictive mode to estimate concentrations between and beyond monitoring events. This reflects the "hydrology-like" behavior of chemical concentrations at Island Copper, which means that there is an annual peak concentration, for example, of one hour duration. Another objective is to examine ditch flow over a selected period of time and to correlate flow with chemistry. All of these objectives provide a glimpse of the database and the interpretations that are leading to a closure plan in 1994.

Minesite Layout and Monitoring Program

Island Copper Mine is located on the northern end of Vancouver Island in British Columbia (fig. 1). This minesite contains several dumps from which toe drainage is carried by ditches to the Water Management Pond (fig. 2). For example, toe drainage from the Old North Dump is initially intercepted at Monitoring Station NDD, then carried along the upper rim of the pit past Station TED, and joins flow passing by Station EDT. This combined flow is carried past Station WME to the Water Management Pond.

The monitoring study involves eight stations: EDD, EDT, EMO, NDD, NWD, PDW, TED, and WME. Two new stations, TCR and TMP, have recently been added, but are not intensively monitored. During the 1991-92 hydrology study, ditch flows and water samples were obtained as frequently as every 15 minutes and every four hours, respectively, with automated equipment (Rescan 1992). Chemical analyses usually included pH, conductivity, alkalinity, acidity, sulfate, copper, zinc, cadmium, calcium, magnesium, and aluminum. However, sampling



Figure 1. Location of the Island Copper Minesite in British Columbia.

limitations, laboratory overload, and equipment breakdowns precluded extended periods of highest-frequency monitoring at most stations. Several stations were only monitored once a day through grab samples for chemistry and staff-gauge observations for flow.

As the final monitoring point before water treatment, WME is of greatest interest for closure studies and has the most extended period of highest-frequency monitoring. Consequently, this paper focuses on WME and only discusses other stations in a cursory manner.

Results for Water Chemistry

Statistical Distributions

Each year of intensive monitoring at Island Copper has generated thousands of values at each monitoring station for the chemical parameters mentioned above. The results can be presented graphically (e.g., fig. 9), but a more informative and concise presentation is through statistical summary parameters such as means and standard deviations.

The concept behind standard deviations is valid for statistically normal distributions. Therefore, we visually examined the frequency distributions of all parameters at all stations in all years. Normal and lognormal distributions (Morin et al., 1993) were often generally seen in the distributions (figs. 3 and 4), although bimodal distributions (fig. 5) and other types were also noted (fig. 6). The values of the means and standard deviations based on lognormal distributions were found to generally repeat yearly (table 1), suggesting that the internal processes within the dumps remain relatively consistent over a period of at least a few years. This annual repetition has also been noted at other sites (Morin et al. 1994a and 1994b).

Predictions Based On Statistical Results

The observations that valid means and standard deviations could be calculated for some parameters and that these values generally repeat on a yearly basis led to the realization that (1) concentrations between the frequent monitoring events could be estimated and (2) future concentrations should reflect the same statistical distributions at least in the short term unless independent variables such as pH change significantly (Morin et al. 1994b). For example, copper as $\mu\text{g/L}$ at WME has a two-year-average mean and standard deviation as logarithmic values of 1.76 and 0.435, respectively (table 1). Based on the application of normal probability levels to a yearly period, the peak annual concentration of one-hour duration is +3.85 standard deviations above the mean (Morin et al. 1994a). For

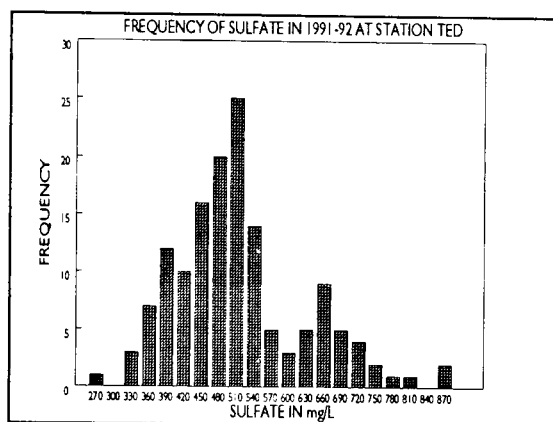


Figure 3. Example of a normal distribution.

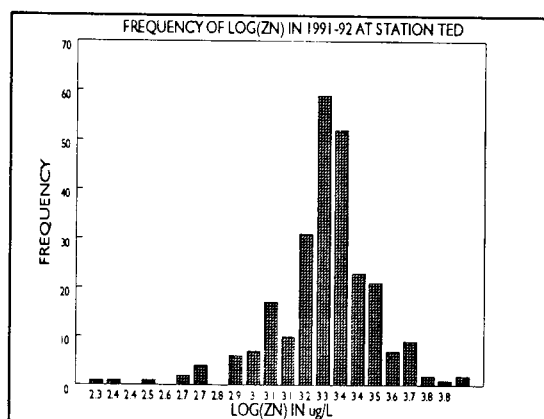


Figure 4. Example of a lognormal distribution.

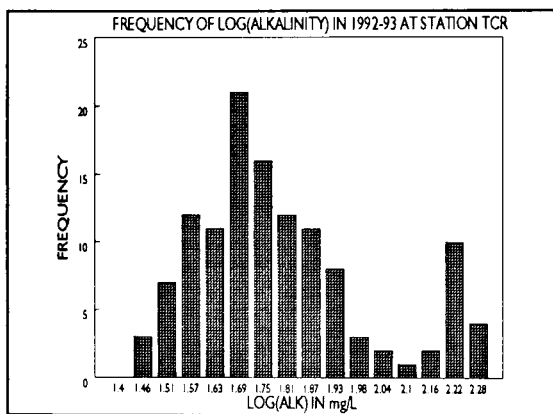


Figure 5. Example of a bimodal lognormal distribution.

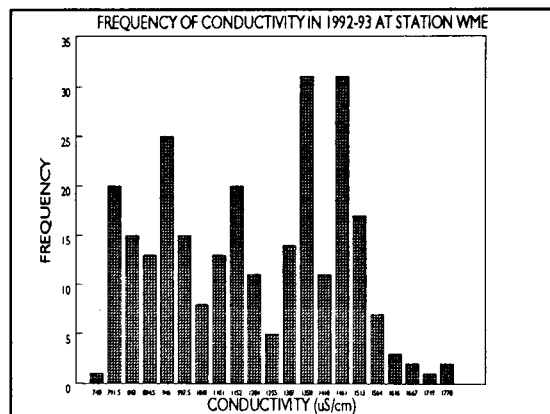


Figure 6. Example of an irregular distribution (step-like?).

Table 1. Logarithmic Means and Standard Deviations for Station WME.

Parameter	Log ₁₀ Mean		Log ₁₀ std dev	
	1991-92	1992-93	1991-92	1992-93
pH pH units (n=401 & 265)	0.826	0.836	0.055	0.043
Conductivity . uS/cm (n=365 & 265)	3.058	3.056	0.075	0.098
Alkalinity mg CaCO ₃ /L (n=245 & 260)	1.795	1.575	0.666	0.314
Acidity . . mg CaCO ₃ /L (n=34 & 13)	1.438	1.513	0.303	0.239
Cu μg/L (n=578 & 265)	1.906	1.609	0.445	0.424
Zn μg/L (n=625 & 265)	3.373	3.432	0.305	0.231
Cd μg/L (n=581 & 265)	1.217	1.268	0.234	0.228
Sulfate mg/L (n=215 & 256)	2.875	2.889	0.089	0.067
Ca mg/L (n=338 & 265)	2.334	2.413	0.057	0.050
Mg mg/L (n=336 & 265)	1.427	1.553	0.146	0.046
Al mg/L (n=313 & 265)	-0.676	-0.517	0.339	0.342

copper at WME, this one-hour peak would be 2720 μg/L ($10^{1.76 + 3.85 \cdot 0.435}$), which can be compared to the measured four-hour peak of 580 μg/L in 1991-92 and 650 μg/L in 1992-93. It is possible that 2720 μg/L may not be possible at WME due to secondary-mineral precipitation, which would limit the maximum concentration. This effect of mineral precipitation also likely accounts for the observed truncation of upper values in some data distributions (e.g., fig. 5), and this potential for mineral precipitation will be checked at a later time against estimates from the geochemical program, MINTEQ.

Implications for Less-Frequent Monitoring

One primary objective of the 1991-92 monitoring at high frequency was to obtain sufficient information to determine the appropriate frequency for long-term monitoring. As explained above, the most important goals for monitoring are to obtain representative means and standard deviations. Thus, the basic question becomes "How frequently must monitoring be performed to obtain representative means and standard deviations?"

In order to answer the question on appropriate frequency, the entire 1991-92 databases for Stations WME, NDD, and EMO were used to calculate means and standard deviations for copper and zinc (for convenience called the "real values"). These values were then compared to those calculated under the assumptions that sampling had only occurred during the midpoint of each day, each week, each month, and each quarter. Additionally, the real values were compared with values obtained from a random-number generator that selected a random sample from each daily period for calculations of means and standard deviations, from each weekly period, etc. The random-number sampling was performed 25 times for each time-interval period (Morin et al. 1993) to determine statistically how accurately the various frequencies would have provided the "real" mean and standard deviation. For example, the mean values for copper in the 25 random runs using one sample from each quarter displayed a wide range from 20 to 600 $\mu\text{g/L}$, whereas the 25 runs with one sample from each day showed little variation and were within 25% of the "real" mean of the entire database (fig. 7). Similarly, the standard deviations for copper from the 25 runs converged to the "real" value as sampling frequency increased (fig. 8). Based on these results, sampling frequency at WME during 1992-93 was reduced from every four hours to daily. The frequency will be reduced further after 1993-94 data are similarly evaluated.

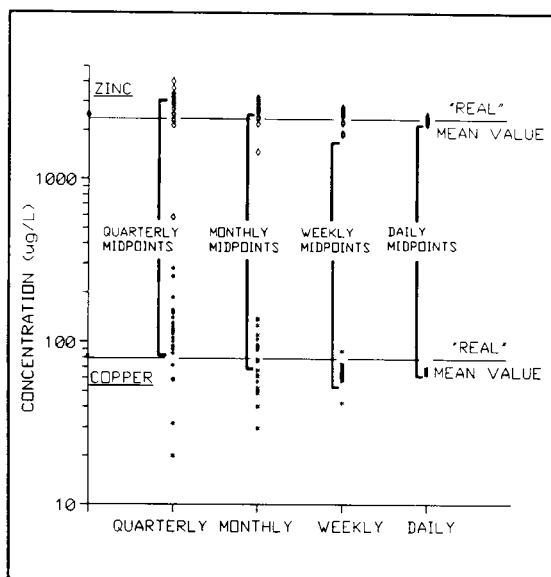


Figure 7. Mean values for copper and zinc at WME, including 25 random runs at each sampling frequency.

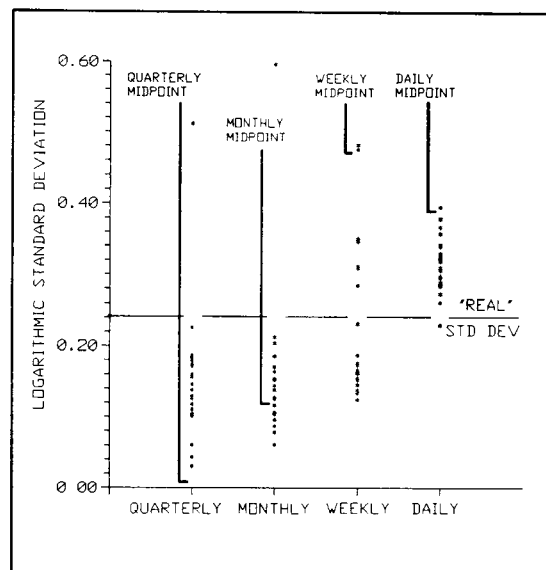


Figure 8. Log_{10} std. deviation for copper at WME, including 25 random runs at each sampling frequency.

Ditch Flow and Its Effect on Chemistry

Flows in the ditches at the various monitoring stations were measured with pressure transducers located at weirs and with staff gauges. Measurements with the transducers at frequencies up to every 15 minutes were

compared to flows occasionally calculated from the staff gauges to ensure accuracy and to allow recalibration of the transducers. Electronic drift in the transducers sometimes required significant corrections, and many of the transducer data are being carefully evaluated. Meanwhile, there is confidence in most WME readings, and these readings are available for a nearly continuous period extending from mid-December 1991.

The general trends in aqueous copper and zinc from October 1991 to March 1992 reveal initially sharp increases in concentrations, peaking by November, then decreasing over the next four months (fig. 9; alkaline samples caused by the addition of lime at WME have been filtered out). Copper particularly decreased in concentration and then generally stabilized by late December, which would be consistent with the depletion of reaction products that accumulated during summer months. These trends in chemistry before mid-December cannot be closely correlated with trends in flow because high-frequency flow measurements are not available until mid-December. The more frequent data after this date then account for the appearance of frequent peaks in flow in fig. 9 (enlarged in fig. 10).

WME provides an opportunity to inspect the high-frequency temporal trends in copper (fig. 11) and zinc (fig. 12) with flow during the period from 10 December 1991 to 10 February 1992. For example, copper concentrations show "background" values of 20 to 80 $\mu\text{g/L}$, but reach peak values of several hundred $\mu\text{g/L}$ before late December and peaks usually below 200 $\mu\text{g/L}$ after late December. Since the source of most copper and zinc to late December is thought to be the depletions of summer accumulations, storm events could cause a dilution in concentration as the removal progresses. This effect can be seen in the first two storm events in figs. 11 and 12. After the accumulated products are removed and the rock is only generating new products, storm events could cause an increase in concentration as the water removes products accumulated over the short time intervals between the storms. Such increases can be seen in storm events on figs. 11 and 12 after the first two events.

Despite the aforementioned relationships between flow and chemistry, scatterplots of flow against copper (fig. 13) and zinc (fig. 14) do not reveal good correlations. This lack of correlation holds for both the entire 1991-92 dataset (figs. 13 and 14) and the data between 10 December 1991 and 10 February 1992 (not shown). Initially, this may be surprising in view of the previous temporal relationships; however, there is more than the one variable of flow that determines chemistry. Other variables are discussed by Morin and Hutt (1994) and Morin et al. (1994b).

Conclusion

This paper has presented the results of high-frequency measurements of dump-drainage flow and aqueous chemistry at the Island Copper Mine in British Columbia. Flow and chemistry were measured as frequently as every 15 minutes and every four hours, respectively. The chemical results allow several useful assessments including that of (1) statistical distributions and summary parameters, (2) the estimation of concentrations between and beyond the monitoring events, and (3) the decreased frequency of monitoring that would still provide representative values of the required statistical parameters. The flow results showed the influence of storm events which cause short-term peaks in flow. These peak flows were accompanied by either a decrease or an increase in aqueous concentrations of copper and zinc. The decreases in concentration were attributed to the depletion of accumulated reaction products during summer months and the later increases were attributed to flushing of short-term accumulations between storm events. These findings are applicable to other minesites as discussed in Morin et al (1994a and 1994b).

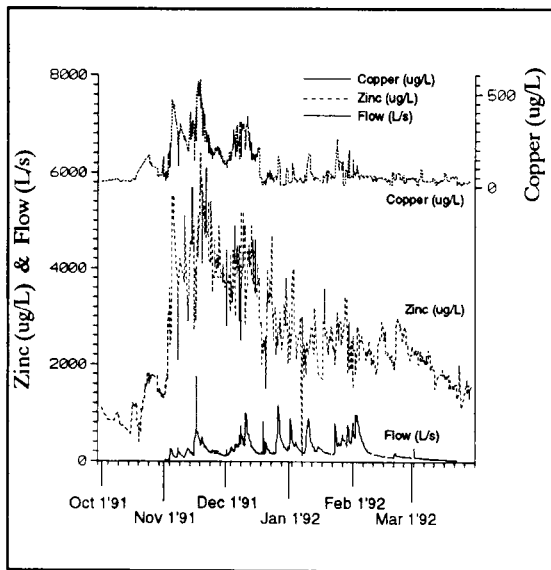


Figure 9. Temporal trends of flow, copper, and zinc at WME from 01 October 1991 to 31 March 1992.

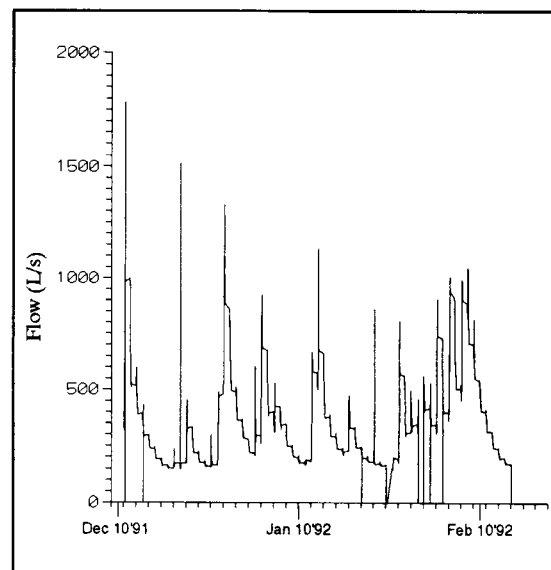


Figure 10. Temporal trend of flow at WME from 10 December 1991 to 10 February 1992.

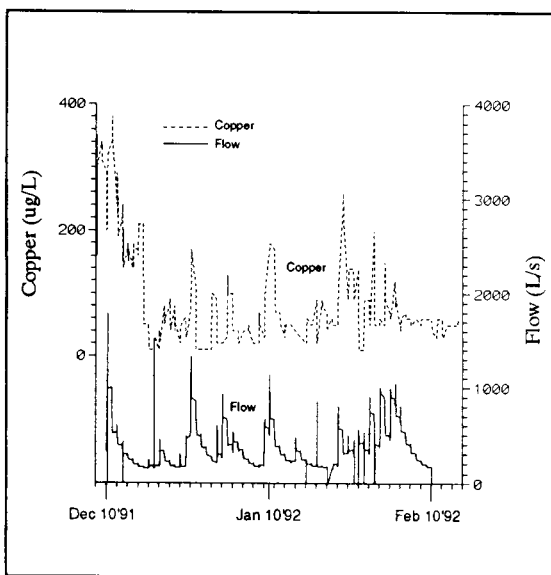


Figure 11. Temporal trend of copper at WME From 10 December 1991 to 10 February 1992.

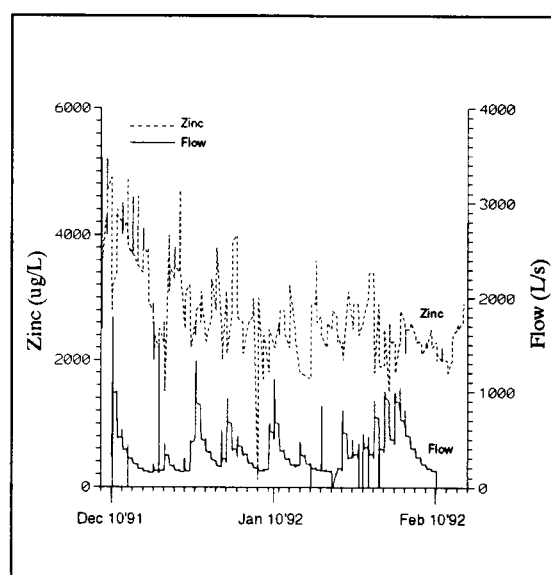


Figure 12. Temporal trend of zinc at WME From 10 December 1991 to 10 February 1992.

Acknowledgements

Obviously a study of this magnitude required contributions from many people. We would particularly like to thank Maged Said and the staff of Island Copper's laboratory who were deluged with samples and data, staff at Rescan including Clem Pelletier, David Flather, and Diane Howe who designed and initiated the hydrology study, and Nora Hutt of Normar Enterprises who assisted in data management and graphics. We also thank the three anonymous reviewers who helped to improve the quality and clarity of this paper and the coordinators of this conference who carefully managed manuscript submission and printing.

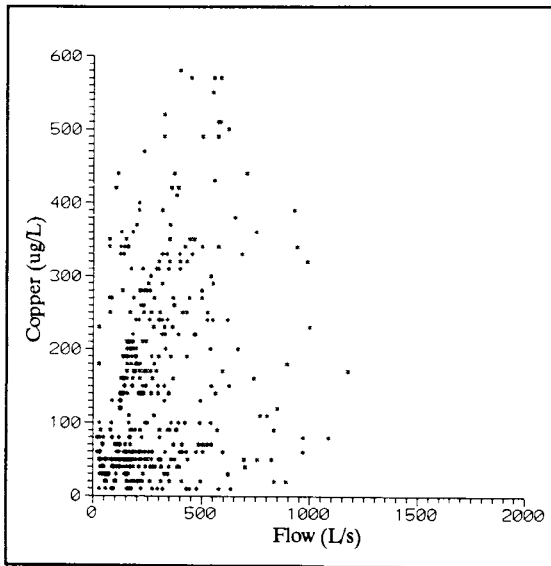


Figure 13. Scatterplot of flow and copper at WME for the 1991-1992 dataset.

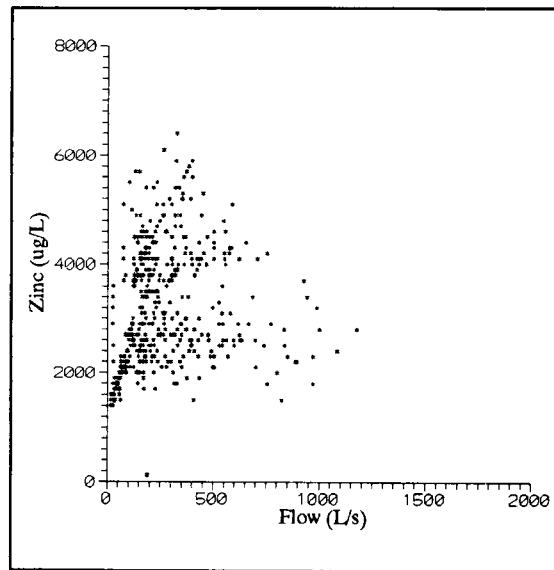


Figure 14. Scatterplot of flow and zinc at WME for the 1991-1992 dataset.

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