

PREDICTION OF FUTURE WATER CHEMISTRY FROM ISLAND COPPER MINE'S ON-LAND DUMPS

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ABSTRACT

Island Copper Mine will close shortly and one part of closure planning involved predictions of water chemistry from the on-land waste-rock dumps over decades to centuries. The approach used to create the predictions entailed a statistical assessment of existing monitoring data, involving analyses of more than 5,800 drainage samples over 24 years. The results showed that aqueous concentrations have followed regular, predictable trends as pH evolved from pH-neutral to acidic conditions. As long as these acidic conditions persist, ranges of concentrations similar to those already measured are expected to continue. After acidic conditions dissipate and pH eventually returns to near-neutral levels, the predictable trends should again be followed. These trends were defined by empirical equations and were compiled into a "predictive water-chemistry model". This model predicts that copper in acidic water, for example, should have a mean annual concentration around 0.73 mg/L with low-high monthly averages of 0.14 and 3.7 mg/L.

INTRODUCTION

BHP Canada's Island Copper Mine is located on the northern end of Vancouver Island in British Columbia. This mine has operated for nearly 25 years and is about to close (Horne, 1993; Island Copper Mine, 1994). For several years, various physical, chemical, biological, and engineering studies have been undertaken in and around the minesite to identify optimal closure strategies. Some studies have focussed on the on-land waste rock dumps (Figure 1), namely the Northwest Dump, West Dump, South Dump, and North Dump, including its westernmost reaches known as the Old North Dump and its EasternMost Outlopes (EMO). Other studies have examined the Beach Dump built into Rupert Inlet, but this dump is not discussed here.

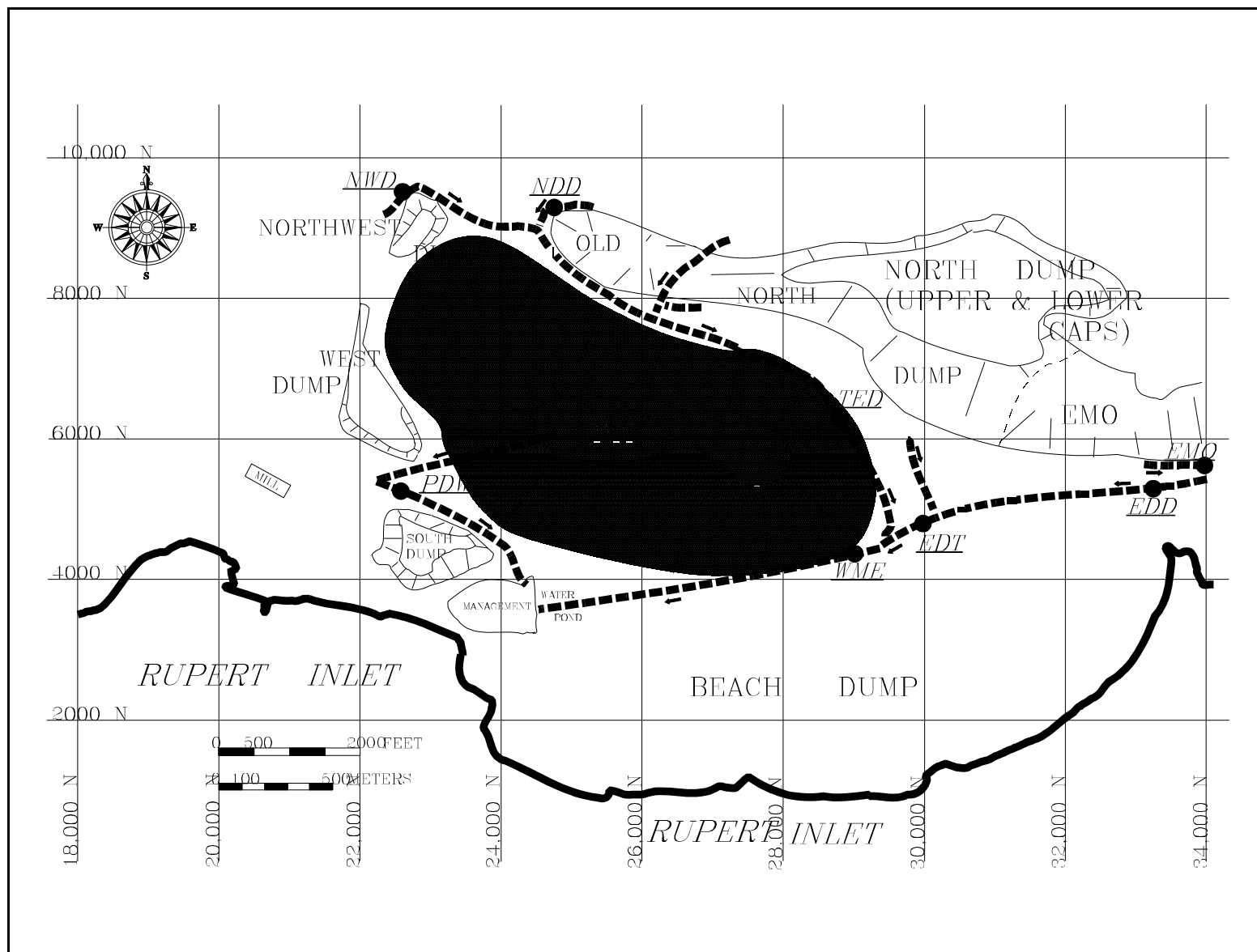


FIGURE 1. Schematic Layout of Island Copper Mine with Water Monitoring Stations.

For almost 25 years, chemical analyses have been routinely conducted on drainage from the waste rock and the pit at Island Copper. The drainage samples were collected at well-established stations (Figure 1), such as NDD (North Dump Drainage), EMO (EasternMost Outsoles), WME (Water Management East), and Pit DeWatering (PDW). The resulting database contains almost 60,000 values from analyses of more than 5,800 samples. Trends in pH and chemistry over the last 25 years should, and do, provide predictions for future water chemistry. These predictions are the topic of this paper.

As part of closure studies, intensive monitoring of drainage chemistry from the waste-rock dumps has been conducted as frequently as every four hours over several months (Rescan, 1992). At the same time, flow rates in toe ditches have been measured as frequently as every 15 minutes (Rescan, 1994). This information led to the ability to delineate the optimum frequency of monitoring and the maximum short-term concentrations that are not detected during monitoring (Morin et al., 1993; Morin and Hutt, 1994a; Morin et al., 1994). This work has shown that drainage concentrations behave like climatic and hydrologic events with, for example, one-hour peak values over one-year and multiple-year periods. This knowledge plays a role in predictions of future drainage chemistry, but the focus here is on average long-term chemistry over decades to centuries.

Around 1985, about 15 years after the start of mining at Island Copper, acidic drainage was identified. However, this onset of drainage acidification was not drastic or widespread. Several monitoring stations still report pH-neutral to alkaline conditions today.

At stations now acidic, the onset of net acidity was erratic over a period of several years (e.g., Figure 2) and was preceded by two-fold increase in sulfate concentrations approximately two years before the first measured acidic pH. In any case, static and kinetic tests used for the assessment and prediction of acidic drainage confirm that widespread acidic conditions should be expected to develop in waste rock and persist for at least several decades (Lister, 1994; Li, 1991). As a result, most waste-rock drainage that is currently pH-neutral is expected to become acidic in the future. The widespread acidic conditions should then persist until the leaching of acidity and metals slows through time and becomes negligible.

THEORY

The prediction of future drainage chemistry at mines has often been based on various static tests, such as acid-base accounting, and kinetic tests, such as humidity cells. In recent years, detailed analysis

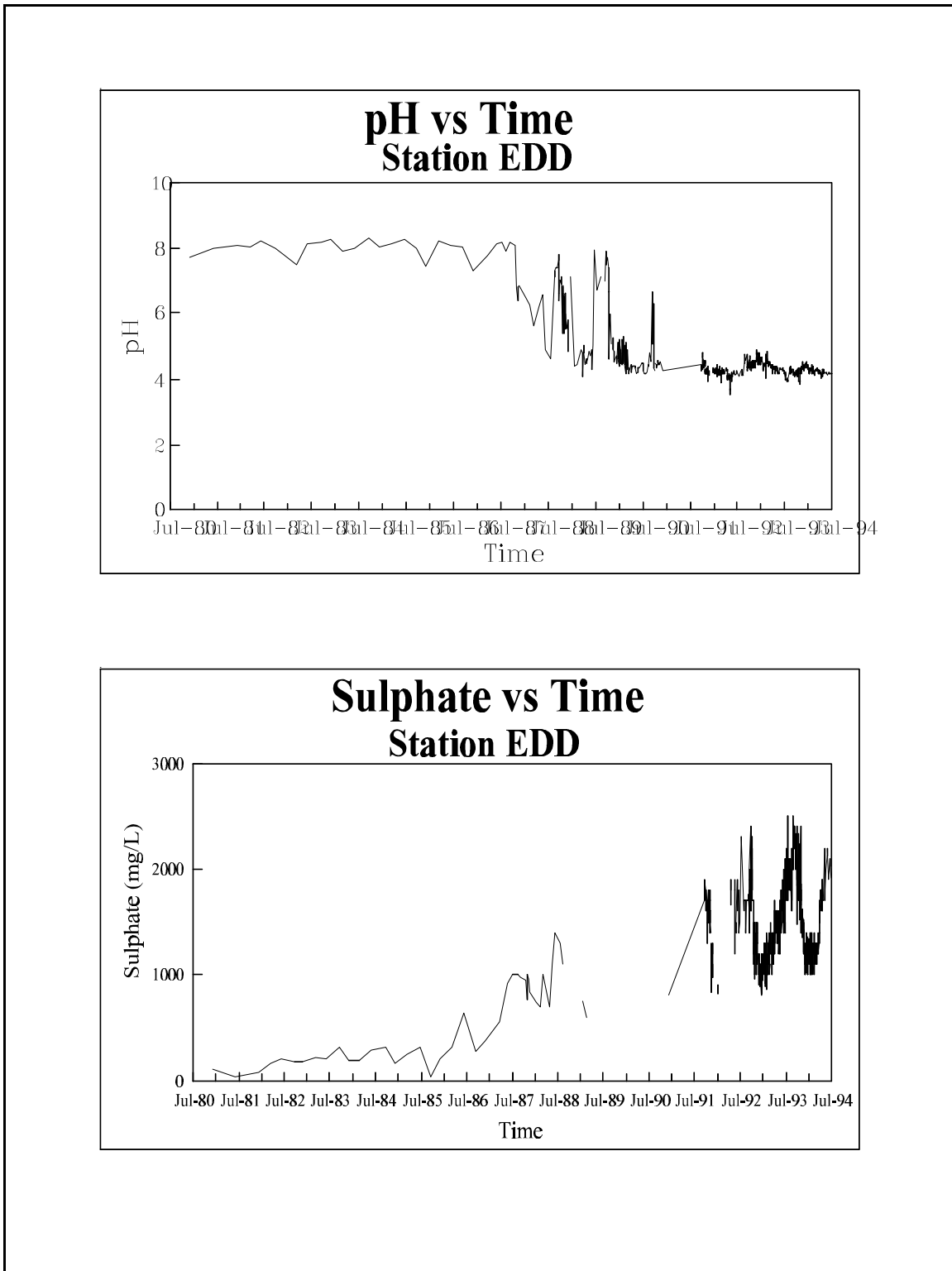


FIGURE 2. Aqueous pH and sulfate at EDD through time.

of field monitoring data has shown that these tests sometimes overestimate leaching rates in the short term and underestimate them in the long term. The implications of this are (1) short-term water quality will not be as poor as thought and (2) long-term water quality will be worse than expected. In technical terms, significant quantities of acidity and/or leached metals, up to 95% of annual production, can be retained year after year, only to be released much later (Morin and Hutt, 1994b; Morin et al., 1995a). This has also been noted in walls of pit mines and underground workings (Morin and Hutt, 1995).

Morin et al. (1995a) explained this retention through a series of reaction rates (Figure 3). $RATE_1$ from Reservoir #1 (sulfide and oxide minerals) is obtained from typical kinetic tests. However, except under very acidic conditions, most of the metals and/or acidity are retained as Reservoir #2 ($RATE_2 >> RATE_3$). As a result, relatively little of $RATE_1$ from the kinetic tests is often released

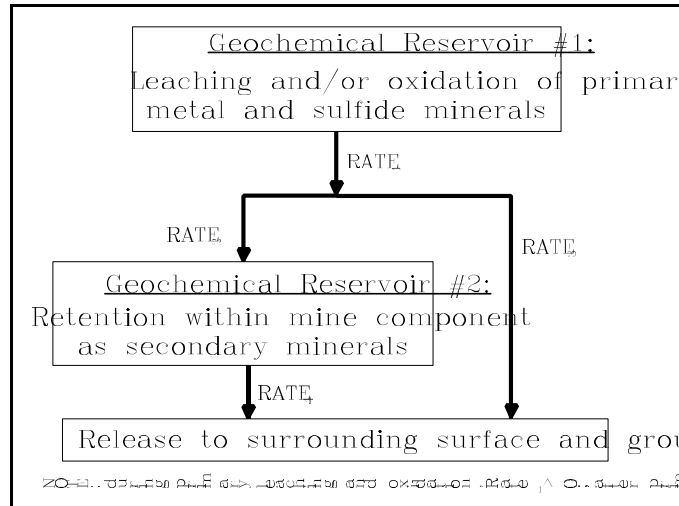


FIGURE 3. Geochemical Rates and Reservoirs Affecting Drainage Water Chemistry.

from waste rock into the environment ($RATE_3$). Instead, $RATE_4$, the release rate from Reservoir #2, controls water chemistry.

$RATE_4$ is typically much less than $RATE_1$ during active sulfide oxidation and metal leaching, and $RATE_4$ does not change with the size of Reservoir #2 because it is controlled by equilibrium chemistry (discussed below). As a result, the size of Reservoir #2 grows quickly as Reservoir #1 is depleted. $RATE_4$ then continues for many more years than $RATE_1$, determining long-term drainage chemistry. Therefore, for long-term predictions of water chemistry at some mines, the behavior of Reservoir #2 should be predicted, rather than the behavior of Reservoir #1, as long as $RATE_4 << RATE_1$ in the short term.

Studies of drainage chemistry at several mines in Canada have shown that concentrations of metals ($RATE_4$) are regulated by the solubility of secondary minerals such as sulfates and carbonates (Morin and Hutt, 1993; Morin et al., 1995a). As a result, Reservoir #2 is composed of these secondary minerals, which accumulate as the sulfide and oxide minerals of Reservoir #1 react. Although $RATE_1$ can vary over

a few orders of magnitude at a particular pH (Morin et al., 1995b), $RATE_4$ typically varies by roughly one order of magnitude at a particular pH (Morin et al., 1995a). As a result, predictions of future chemistry become easier and probably more reliable when controlled by Reservoir #2.

Equilibrium chemistry of mineral solubility requires the same amount (number of milligrams) of a mineral to instantaneously dissolve into each liter of water in contact with the mineral. Therefore, concentration in each liter is identical. As with any theory, there are complications and, in this case, temperature, aqueous complexation, analytical errors, variable pH, and many other factors cause one liter to have different concentrations than others. Through analysis of monitoring data, pH has been found to have the greatest effect and thus mathematically removing its effect leads to relatively constant concentrations at a particular pH. The detailed procedures and theory behind this approach are discussed in Morin and Hutt (1993) and Morin et al. (1995a). They are currently being tested by the federal MEND Program as an empirical approach for modelling drainage chemistry from waste-rock dumps. The application of this approach to Island Copper fills the remainder of this paper.

PREDICTION OF FUTURE WATER CHEMISTRY

The approach of Morin and Hutt (1993) and Morin et al. (1995) calls for three steps in predicting future water chemistry using past monitoring data. The first step is to search for a regular statistical distribution. At Island Copper, like most other sites examined this way, lognormal distributions provide reasonable matches to monitoring data and thus logarithms of concentrations are used in predictions.

The second step is to remove numerical effects of major variables to reduce standard deviations. This is often best accomplished by creating scatterplots of aqueous concentrations against pH and by identifying the best-fit equations that predict mean logarithmic concentrations from pH (Figures 4a, 5a, and 6a). The geochemical model, MINTEQ (Allison et al., 1990), indicates that the best-fit equations for zinc and cadmium around neutral pH, for example, reflect the pH-dependent solubility of the secondary minerals, zinc carbonate and otavite ($CdCO_3$). The standard deviation, calculated from the variability diagrams (Figures 4b, 5b, and 6b; measured value minus calculated value at a particular pH), allows the prediction of seasonal and short-term variations about the mean if wanted.

The third and last step is to identify temporal cycles. At Island Copper, annual mean concentrations have remained generally constant, and have varied annually within the same range, over

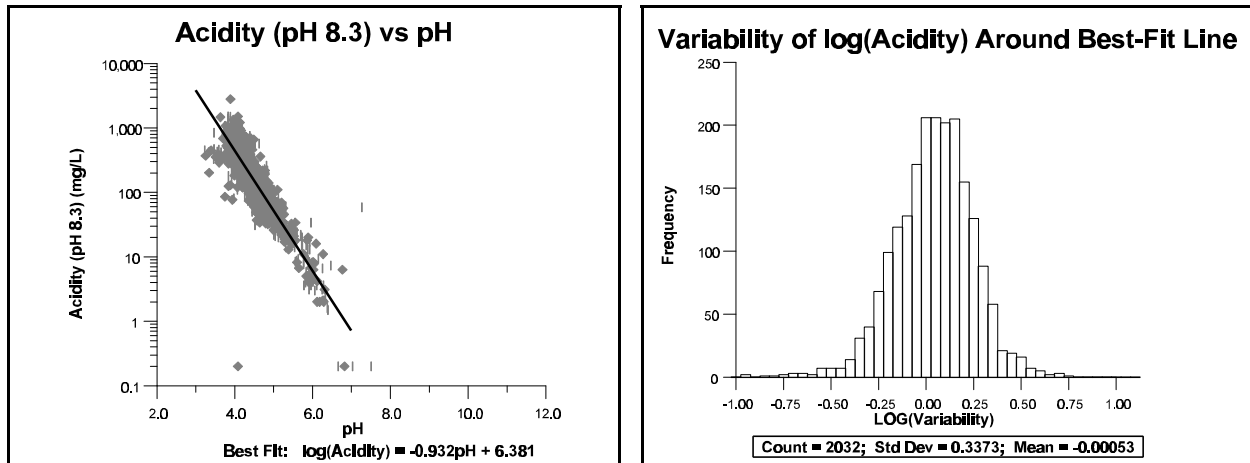


FIGURE 4. (a) Scatterplot of Log(Acidity) vs. pH; (b) Variability of Data About Best-Fit Equation.

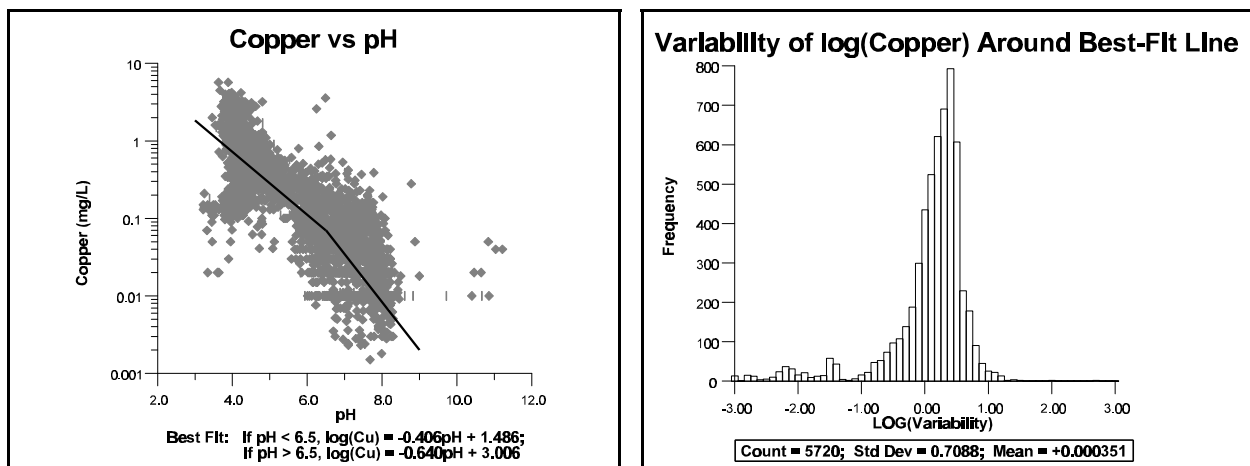


FIGURE 5. (a) Scatterplot of Log(Copper) vs. pH; (b) Variability of Data About Best-Fit Equation.

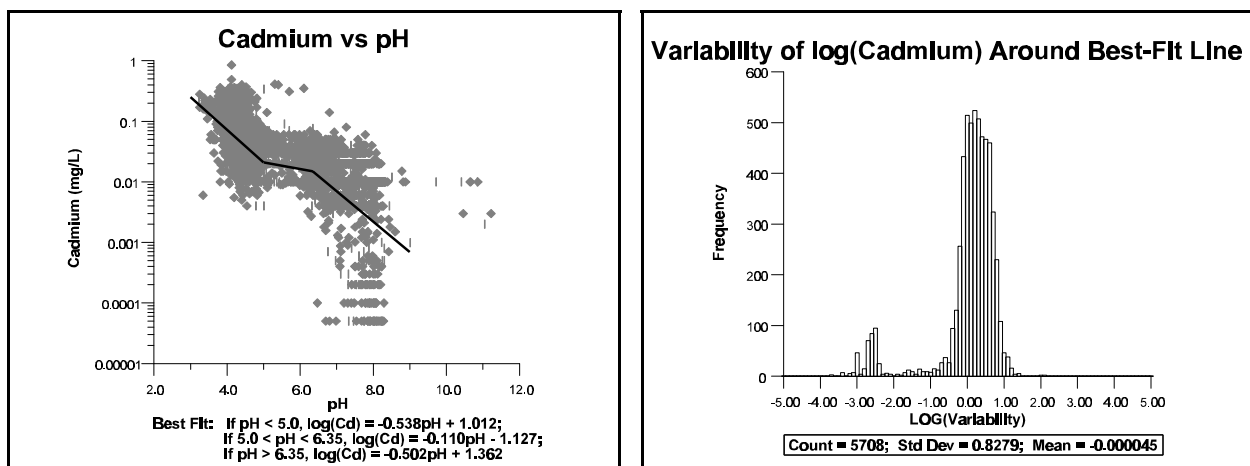


FIGURE 6. (a) Scatterplot of Log(Cadmium) vs. pH; (b) Variability of Data About Best-Fit Equation.

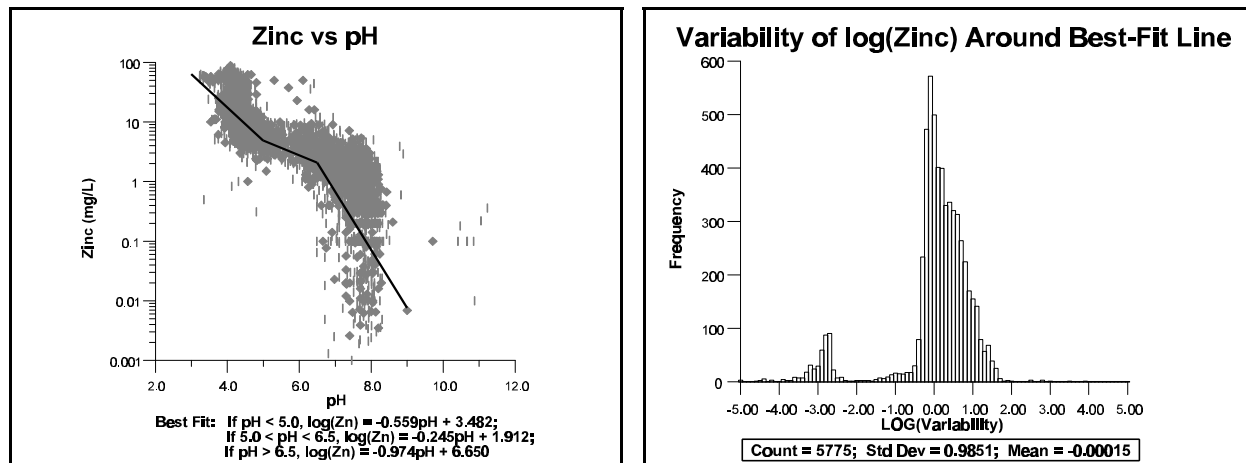


FIGURE 7. (a) Scatterplot of Log(Zinc) vs. pH; (b) Variability of Data About Best-Fit Equation.

the years when pH has remained constant (Morin and Hutt, 1994a). However, when pH has evolved to acidic levels, concentrations have risen, but the increase has followed the best-fit equations. As a result, the best-fit equations remain valid for any station as it becomes acidic. Similarly, the equations should remain valid as acid generation decreases decades into the future and pH is eventually restored to near-neutral values.

Based on this information, the best-fit equations can be compiled (Table 1) and used as a "predictive water-chemistry model" that should remain valid for decades to centuries until Reservoir #2 (Figure 3) is depleted. To use the predictive model, an average annual value of pH is required. Based on monitoring data (Figures 2 and 4 to 6) and observations at other mines, pH at an acid-generating mine tends to cluster around a site-specific typical neutral value and a typical acidic value. For Island Copper, these values are 7.0 and 4.0. Since most of the waste rock is predicted to become acidic at some time, drainage from most of the dumps is thus expected to be at pH 4 for decades to centuries. As a result, copper concentrations, for example, are expected to be at an annual average value of 0.73 mg/L with monthly averages between 0.14 and 3.7 mg/L based on Table 1.

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TABLE 1			
PREDICTIVE WATER-CHEMISTRY MODEL FOR ON-LAND DUMPS AT ISLAND COPPER MINE			
Parameter (<u>mg/L</u>)	Valid pH <u>Range</u>	Predictive Equation <u>for Mean</u>	Standard Deviation <u>from Mean</u>
Conductivity (: S/cm, N= 5010)	pH # 4.5	= -0.475 pH + 5.237	0.1568
	pH > 4.5	= + 3.099 (set value)	
Alkalinity (CaCO ₃ , N= 2309)	4.5 < pH # 6.5	= + 0.730 pH - 3.120	0.3062
	pH > 6.5	= + 0.370 pH - 0.780	
Acidity (to pH 8.3, N= 2032))	pH < 8.0	= -0.932 pH + 6.381	0.3373
Copper (N= 5720)	pH # 6.5	= -0.406 pH + 1.486	0.7088
	pH > 6.5	= -0.640 pH + 3.006	
Zinc (N= 5775)	pH # 5.0	= -0.559 pH + 3.482	0.9851
	5.0 < pH < 6.5	= -0.245 pH + 1.912	
	pH \$ 6.5	= -0.974 pH + 6.650	
Cadmium (N= 5708)	pH # 5.0	= -0.538 pH + 1.012	0.8279
	5.0 < pH < 6.35	= -0.110 pH - 1.127	
	pH \$ 6.35	= -0.502 pH + 1.362	
Sulphate (N= 4105)	pH # 4.75	= -0.348 pH + 4.587	0.2148
	pH > 4.75	= -0.030 pH + 3.077	
Calcium (N= 4507)	pH # 4.5	= -0.294 pH + 3.665	0.3141
	pH > 4.5	= 2.342 (set value)	
Magnesium (N= 4503)	pH # 4.8	= -0.284 pH + 2.929	0.3790
	pH > 4.8	= -0.083 pH + 1.963	
Aluminum (N= 4186)	pH # 5.65	= -1.341 pH + 6.908	1.3156
	pH > 5.65	= -0.068 pH - 0.285	

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