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STREAM-WATER GEOCHEMISTRY AS A GUIDE TO SOURCES OF ACID-MINE DRAINAGE IN THE FORMER RAMBLER MINES AREA

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ABSTRACT

This paper describes the results of stream-water sampling in the South Brook watershed around the former Rambler Mines property on the Baie Verte Peninsula. The Rambler Mines produced primarily, Cu and lesser amounts of Au, Ag and Zn from five volcanogenic massive sulphide deposits. The ore was milled onsite, and a tailings compound and water-course diversions were built in an effort to prevent the generation of acid-mine drainage. Water sampling in 1993, 2000 and 2001 indicate that acid-mine drainage is prevalent and affects several streams, including the largest river in the area (South Brook) from the mining area downstream to its mouth at Baie Verte.

Comparison of data from the same sites over an eight-year period suggests that acidification and metal contamination of the affected streams is now the same or more severe than earlier. The major contaminants, with respect to impacts on aquatic life, are the high levels of Cu and acidification of affected streams. Stream-water geochemistry has identified three major sources of acid drainage. The largest source appears to be near the head of the North Diversion Ditch. The actual source or sources is unclear but may include leakage from the tailings compound and sulphidic waste-rock exposed in the catchment basin. A second source occurs in the vicinity of the Ming Mine as shown by high base-metal contents and acidification of the stream draining to the northwest from the former mine site. A third source is the Ming West Mine, which gives rise to a small stream having extremely high Cu contents flowing north into South Brook. More detailed sampling will be required to accurately delineate the sources of the metals.

INTRODUCTION

The former Consolidated Rambler Mines operation on the Baie Verte Peninsula (Figure 1) produced 4 300 000 tons of Cu, Au, Ag and Zn ore from five separate volcanogenic, massive sulphide orebodies during the period 1964 to 1982. An additional 150 000 tons were mined from the Ming West orebody by Ming Minerals Inc. from 1995 to 1996. Subsequent to the cessation of mining, acid-mine drainage from the property into the surrounding drainage system was recognized. Stream-water geochemistry is being used to identify and document the nature and sources of the acid-mine drainage that is being generated by the interaction of air and water, both with the tailings and with various sources outside the tailings compound (thought to be principally sulphide-bearing waste rock). This report summarizes the results of the current stream-water assessment.

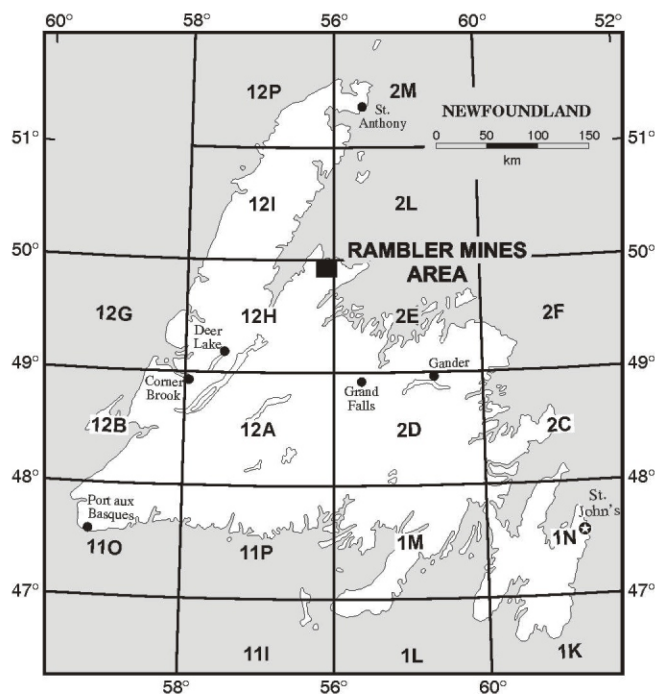

Figure 1. *Index map of the study area.*

PREVIOUS WORK

During an earlier project conducted in 1992 on the Baie Verte Peninsula to evaluate stream-water geochemistry as a mineral exploration tool, acid-mine drainage was recognized in the Rambler Mines area (Hall, 1993). As part of an exploration-focused project, several stream sites were sampled in the Rambler area during 1993 (McConnell, 1995). Results of that work indicated that waters in South Brook downstream of the tailings compound, as well as some sites on tributary streams, were very acidic and contained toxic levels of heavy metals, particularly Cu (McConnell, *op. cit.*). In 2000, several of the 1993 sites, as well as additional sites were sampled. Similar water chemistry to that analyzed in 1993 was found; some results of that study were published by Lee (2001). Most recently, Environment Canada conducted a mortality study of rainbow trout using water collected from the effluent stream from the tailings area pond. The test resulted in the complete mortality of the fingerlings. The tested water had a pH of 3.2 and analyzed 712 ppb Cu (Ronald Hunter, personal communication, 2001)

DESCRIPTION OF MINE WORKINGS

During the life of the mining operation, four major orebodies, and a small deposit east of Big Rambler Pond were developed and exploited. Ore was processed at a mill located near the Rambler Main Mine and tailings were discarded subaerially into a partially isolated compound created by diverting and damming existing streams and ponds in the area. Figure 2 shows details of the mining area, stream diversion structures and the water-sample sites within the detailed area. The mill was connected to the mining areas by gravel haulage roads, which in some cases were built with sulphide-bearing waste rock from the mining operations. The major drainage network in the area consists of South Brook and its tributaries, which form a drainage basin of approximately 120 km^2 and empty into the east side of Baie Verte, about 2.5 km northeast of the town of Baie Verte. To preserve the water quality of this watershed, an effort was made to isolate the tailings compound by excavating diversion ditches around the west and north sides of the compound and constructing a dyke across Little Rambler Pond to prevent the water of South Brook from gaining contact with tailings (Plate 1). Rambler Brook and England's Brook were also re-routed to avoid flowing into the tailings area. As with the haulage roads, sulphide-bearing waste rock was used in several locations to line the banks of the ditches. In the early 1990s, the western diversion ditch was reportedly dammed by beavers causing the newly created western half of Little Rambler Pond to breach and erode the dyke and re-route South Brook into the tailings compound. Removal of the beaver dam and work by the Mineral Lands Division of the provincial Department of Mines and Energy on the dyke has largely alleviated this problem with the possible exception of flood periods such as spring run-off.

Plate 1. *Looking southwest from tailings pond across breach in dyke into Little Rambler Pond. Note the abundance of weathering, sulphide-rich, waste rock used in dyke construction.*

SAMPLE COLLECTION, PREPARATION AND ANALYSES

Sample collection and analytical procedures for results discussed here were similar to that described in previous years. In 2001, 45 samples were collected from 42 sites including 12 sites that were also sampled in 1993 and 2000. Two 250 ml, clean, nalgene bottles were filled at each site. One was used for conductivity and pH determinations. The content of the other was filtered through 0.45 µm filter paper and then acidified prior to analysis.

Conductivity measurement were made using a Corning meter with a conductivity sensor. Acidity (pH) determinations were made using a Corning meter having a combination electrode. Samples were analyzed for a suite of elements using two methods. The department's geochemical laboratory employed both inductively coupled plasma–emission spectrometry (ICP-ES) and inductively coupled plasma–emission spectrometry using an ultrasonic nebulizer (ICP-USN). The elements determined by each method are summarized in Table 1.

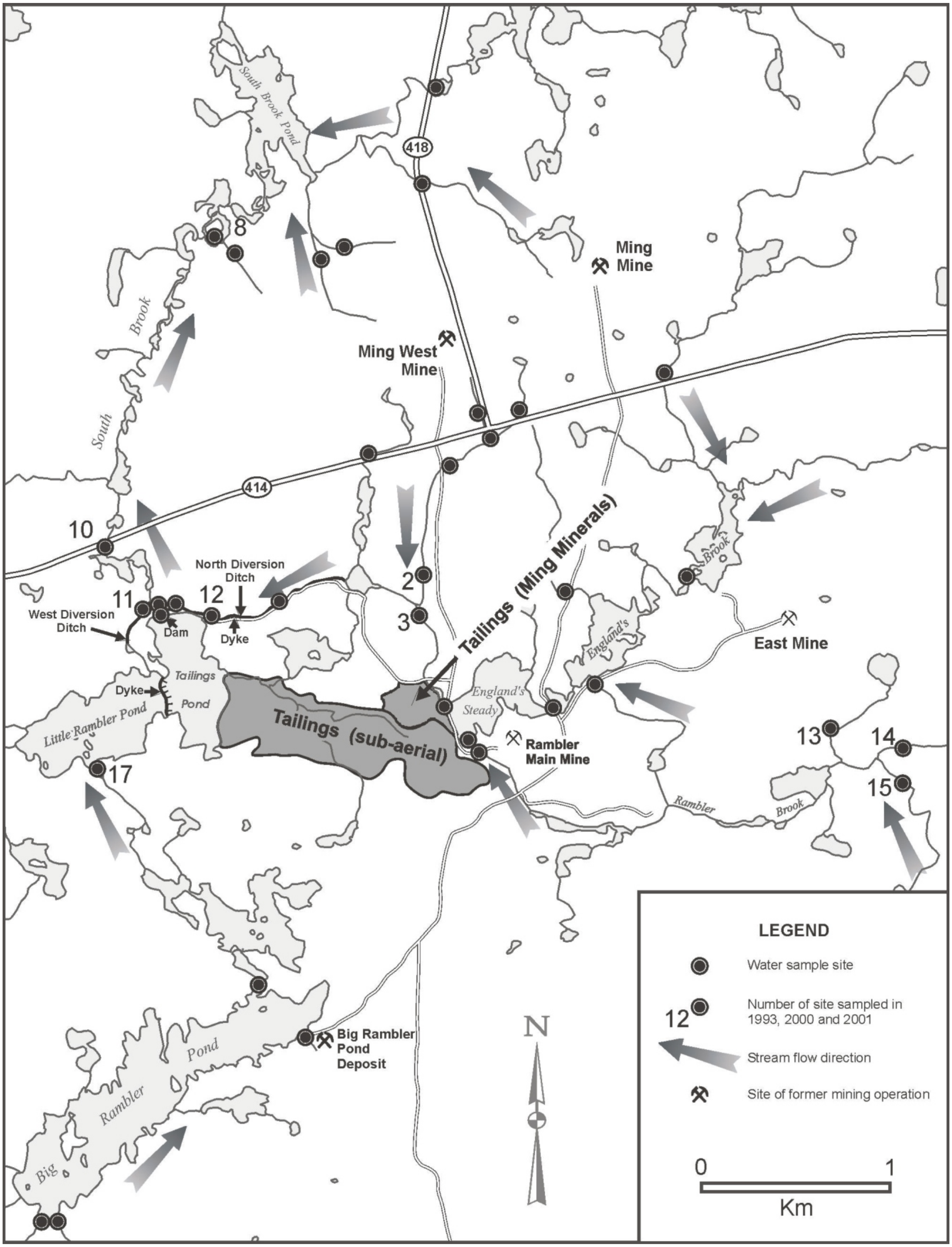

Figure 2. *Detailed map of mining operations, tailings area and water sample sites.*

Table 1. Analytical methods for stream-water samples

ANALYSIS	METHOD	PREPARATION
pH	Corning combination pH electrode	None
Conductivity	Corning conductivity sensor	None
Ca, Fe, K, Mg, Mn, Na, Si, So_4	ICP-emission spectroscopy[1]	Filtration (0.45 µm) and HNO_3 acidification
Al, Ba, Be, Co, Cr, Cu, Li, Mo, Ni, P, Pb[2], Sr, Ti, Y, Zn	ICP ultrasonic nebulizer[1]	Filtration (0.45 µm) and HNO_3 acidification

[1] Finch, C.J., 1998.
[2] 2001 analyses only

DESCRIPTION AND DISCUSSION OF RESULTS

STATISTICAL SUMMARY

Histograms provide a visual depiction of the distribution of data for a given population. Histograms of data from the 42 sites sampled in 2001 are presented for pH, Cu, SO_4 and Zn (Figure 3). Note that the X-axes have an exponential scale. All four plots produce bimodal populations where SO_4 and pH have particularly sharp separations. The most populous intervals for Cu and Zn analyses are below their respective detection limits giving misleading spikes in the lowest intervals. The histogram of pH suggests a population break at pH=5; for Cu, a break is suggested at about 5 ppb; for SO_4, at about 3.2 ppm and for Zn, at about 2 ppb.

Since Cu is the most biotoxic element in the streams, its distribution is used as a means of dividing the sites into two groups for comparison purposes. Those having Cu >5 ppb are regarded as being from streams affected by acid-mine drainage and those <5 ppb are from stream not affected by acid-mine drainage (background streams). Table 2 shows summary statistics for data from the 2 populations. Variables are listed in order of decreasing value of the "enrichment ratio", determined by dividing the median value of the the mine-affected streams by the median value of the background streams. These ratios should be regarded as order-of-magnitude estimates, particularly for Zn, Cu, Co and Ni, which have several analyses less than the detection limit. Nevertheless, this table provides a guide to the relative enrichment of several elements in the mine-affected streams relative to the background streams in the area. Acidity (pH) is treated differently in Table 2. The value of pH is the negative logarithm of the hydrogen ion concentration, hence the corresponding enrichment ratio is calculated by dividing the antilog of the median background by the antilog of the median mine-affected value.

DATA DISTRIBUTION MAPS

Distribution of Cu, pH, Zn and SO_4 in stream water are discussed here. Loadings in Cu and pH are likely causing the greatest damage to the biotic environment. Copper contents in water above 2 to 8 ppb, depending on water hardness, are lethal to most aquatic life including the many microscopic organisms at the base of the food chain on which fish and other aquatic and avian life depend (Ministry of Environment, Lands and Parks, 2001). Low pH values promote the dissolution of heavy metals, and pH values below 4.5 produce lethal effects on aquatic life (*ibid*). Zinc in high concentrations is also toxic to aquatic life, and like Cu, its toxicity is a function of water hardness. Water hardness can be regarded primarily as a measure of the dissolved calcium and magnesium ions. Using the equation $CaCO_{3equivalent}$= (2.497*Ca + 4.116*Mg), hardness values were calculated for the water samples collected from 42 sites in 2001. The resulting values ranged from 4.52 to 500.4 mg/L having a median value of 27.6 mg/L. Thirty-eight of the 42 samples had values <65 mg/L. If a value of 65 mg/L is assumed for all samples, the highest non-lethal level for Cu is 8.1 ppb. This is derived from the equation Cu_{max}=(0.094 (hardness) + 2) = ((0.094*65) + 2).

The distribution of Cu in water is shown in Figure 4. The range of Cu values associated with each symbol is shown on the cumulative frequency plot. The bimodal nature of the distribution is clearly shown by the sharp break in the curve. Most samples fall into one of two groups – those having Cu values >100 ppb and those <5 ppb. The

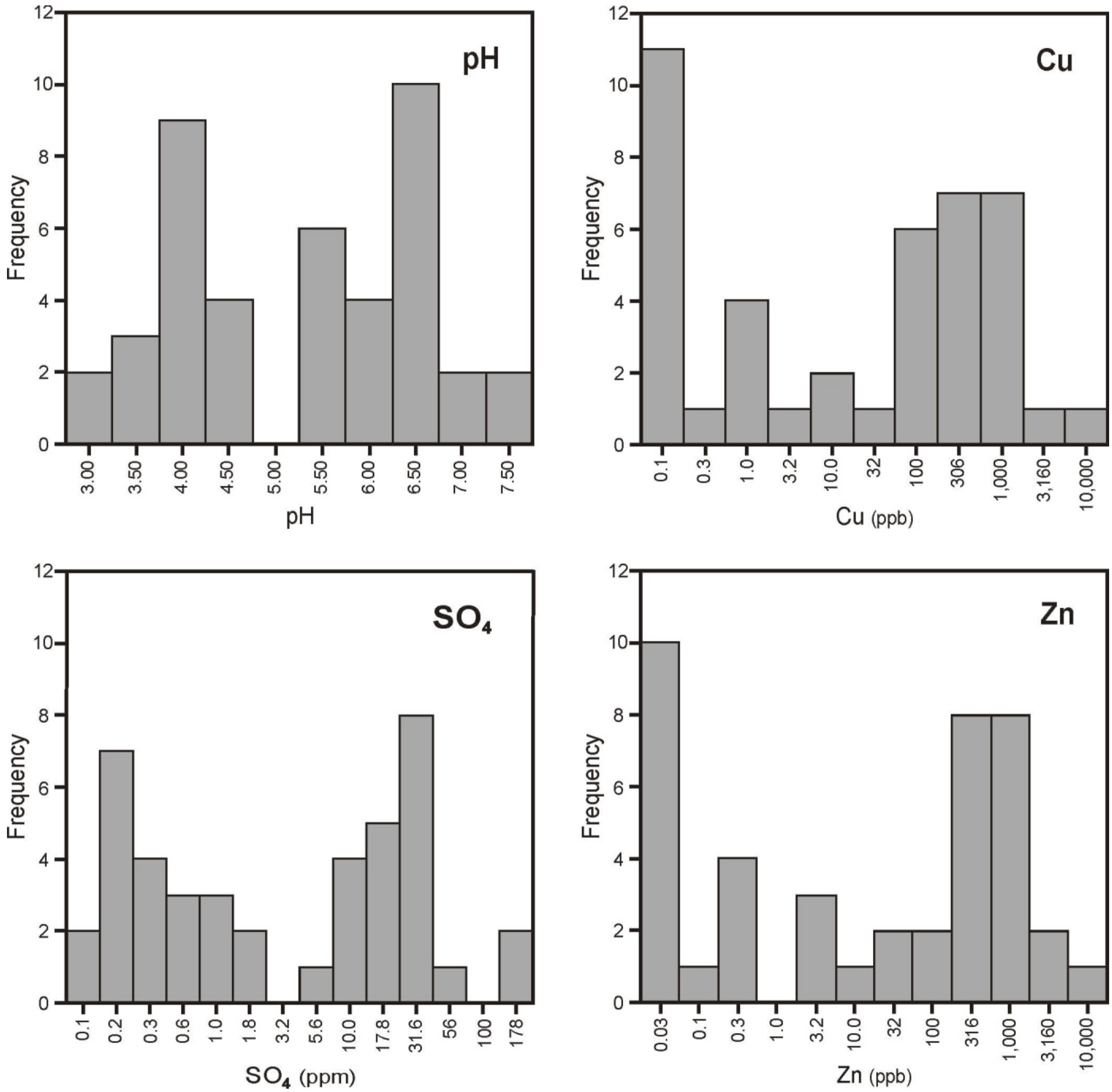

Figure 3. *Histograms of pH, Cu, SO_4 and Zn in 2001 water samples.*

blue and green symbols reflect Cu levels that are non-toxic to aquatic life. Orange and red dots and red stars reflect sites that have lethal Cu contents. The most serious toxic values are streams indicated with red stars, in which Cu contents range from 800 to 7000 ppb. The 7000 ppb site is located 900 m northwest of the Ming West Mine. Another serious problem is in the stream crossing Highway 418 (2200 ppb Cu) that drains the area of the Ming Mine.

Perhaps the most serious problem with Cu levels is found in the North Diversion Ditch, which carries high volumes of water and drains England's Steady, the pond into

Table 2. Summary statistics for data from background (N=17) and mine-affected (N=25) streams

	Background (<5 ppb Cu)			Mine-affected streams(>5 ppb Cu)			Enrichment Ratio*
	median	minimum	maximum	median	minimum	maximum	
Zn	0.1	0.1	2.93	500	5.54	5760	5000
Cu	0.1	0.1	2.90	254	6.2	7066	2540
pH	6.36	5.4	7.43	4.18	2.86	6.73	151**
Co	0.1	0.1	2.71	11.7	0.1	134	117
Ni	0.1	0.1	2.54	10.7	0.1	86.2	107
SO_4	0.21	0.11	1.60	16.1	0.34	214	76.7
Mn	16	8	349	581	4	6775	36.3
Y	0.01	0.01	0.23	0.27	0.01	2.71	27.0
Pb	0.1	0.1	0.5	2.1	0.1	173	21.0
Al	83	13	323	949	66	5284	11.4
Fe	269	70	676	1994	177	62480	7.4
Cr	0.11	0.10	1.08	0.71	0.10	8.45	6.5
Conductivity	34	20	77	213	39	1475	6.3
Mg	0.76	0.46	1.74	2.98	0.88	38.54	3.9
Ca	3.22	1.02	10.13	12.34	2.42	177.6	3.8
Li	0.22	0.22	0.50	0.61	0.22	9.54	2.8
Si	0.43	0.18	0.99	1.09	0.49	5.94	2.5
Sr	6.84	4.19	20.9	16.6	6.72	176.8	2.4
K	0.25	0.11	0.52	0.53	0.16	4.18	2.1
Ba	3	1.5	6.3	6.1	2.0	26.9	2.0
Na	2.83	2.17	4.87	4.05	2.81	17.94	1.4
Ti	0.09	0.05	3.90	0.05	0.05	4.28	0.6
V	0.14	0.05	2.20	0.07	0.05	1.72	0.5
P	10.1	6.3	23.6	0.5	0.5	83.7	0.05

All element values in ppb except SO_4, Mg, Ca, Si, K and Na which are ppm. Conductivity is expressed in µS.

* ratio of (background median)÷ (mine-affected median)

** pH is a negative log value, hence the ratio was determined by dividing the anti-log of the median background by the anti-log of the median mine-affected value.

which England's Brook discharges (Figure 2 and Plate 2). The five samples collected along the ditch range from 560 to 1000 ppb Cu and the highest values occur in the first 2 sites, downstream of the pond. The largest stream flowing into the pond has a content of 2.9 ppb. The content at the discharge site from the pond is 808 ppb. The only other stream flowing into the pond at the south end has elevated Cu values (110 and 135 ppb) but does not account for the extreme values leaving the pond. The pond is flanked on the west by the subaerial tailings pile and by a mine-access road. It seems likely that the principal sources of Cu include groundwater flow from the tailings, interaction of stream water with bank material, contributions from the southern stream and possibly leaching from sulphide-rich rock used in the road construction. Water leaving the tailings pond over the spillway is also high in Cu (1110 ppb) however the flow rate is relatively low because the net addition to the Cu load in South Brook is less significant than that from the North Diversion Ditch.

Plate 2. *Looking north down South Brook at the confluence of North Diversion Ditch (right) and South Brook (left). Analyses at this location in 2001 from South Brook included Cu: <1 ppb and pH: 5.6; analyses of the North Diversion Ditch were Cu: 565 ppb and pH: 3.7.*

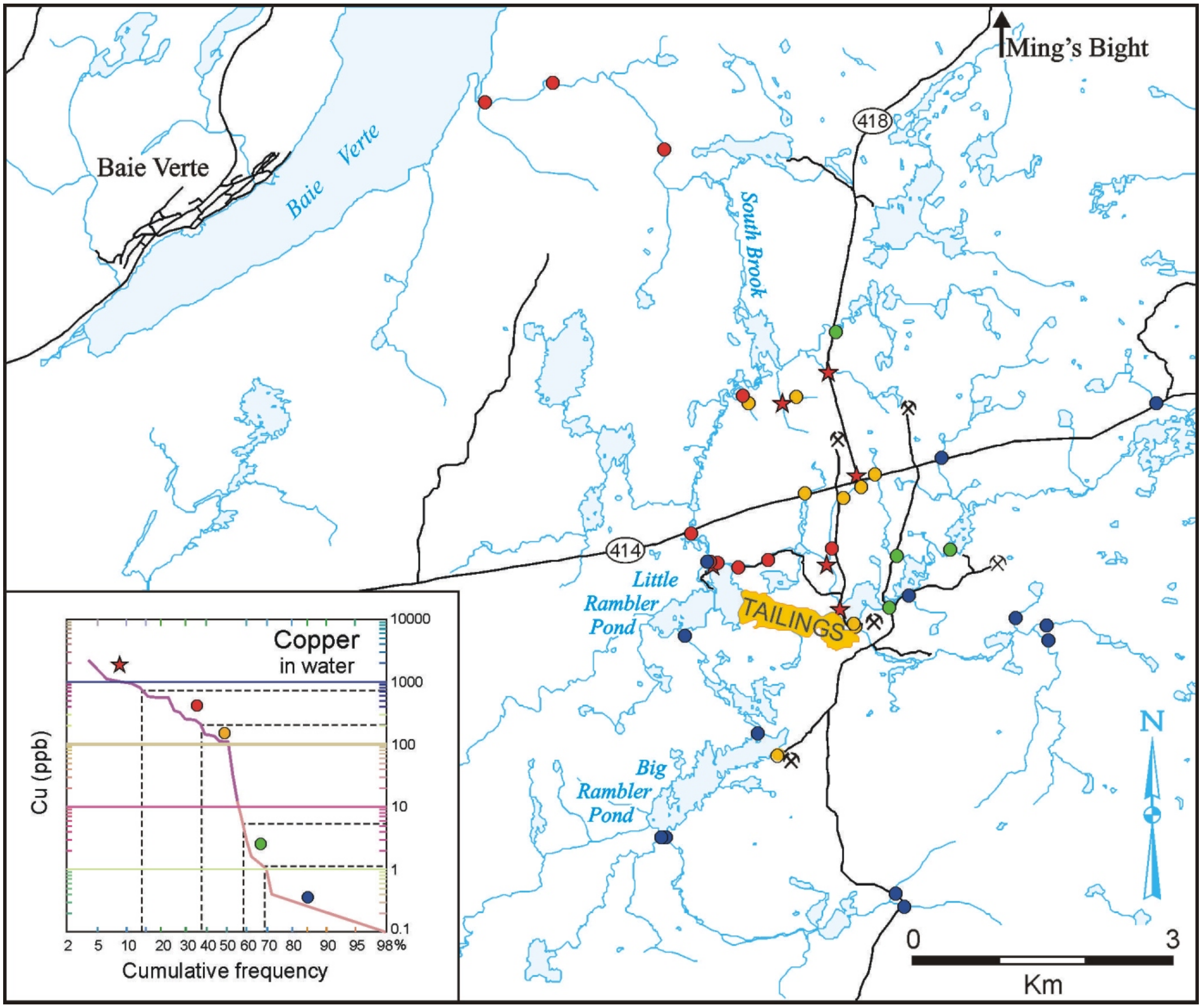

Figure 4. *Cu in stream water. Data from 2001 water samples. See text for explanation of symbols.*

Water acidity in streams is shown by the map of pH (Figure 5). Values of pH <7 are increasingly acidic and values >7, increasingly alkaline. The values are logarithmic so that a 1 unit difference in pH represents a 10-fold difference in acidity. The distribution pattern of pH is similar to that of Cu with a few distinct differences. As with Cu, blue and green symbols reflect water quality that supports aquatic life (pH>4.5). As with Cu, all streams above the mining activities are permissive of aquatic life whereas most streams below the start of the North Diversion Ditch, and below the confluence of the ditch with South Brook, are not. The problem areas are the North Diversion Ditch, South Brook between the tailings pond and Baie Verte and the stream draining to the northwest from the Ming Mine. The stream with 7000 ppb Cu is only moderately acidic (pH=4.2). The sources of this acid drainage are likely the same sources producing high Cu levels in the streams

The distribution of Zn in streams is shown in Figure 6. The distribution pattern is nearly identical to that of Cu. One minor difference is that the Zn contents in the stream entering the south end of the England's Brook pond are proportionately higher than the Cu contents.

The distribution of sulphate (SO_4) in water is shown in Figure 7. The shape of the cumulative frequency plot is strongly bimodal and similar to those of the metals and pH. The distribution pattern of the values is also similar to the others.

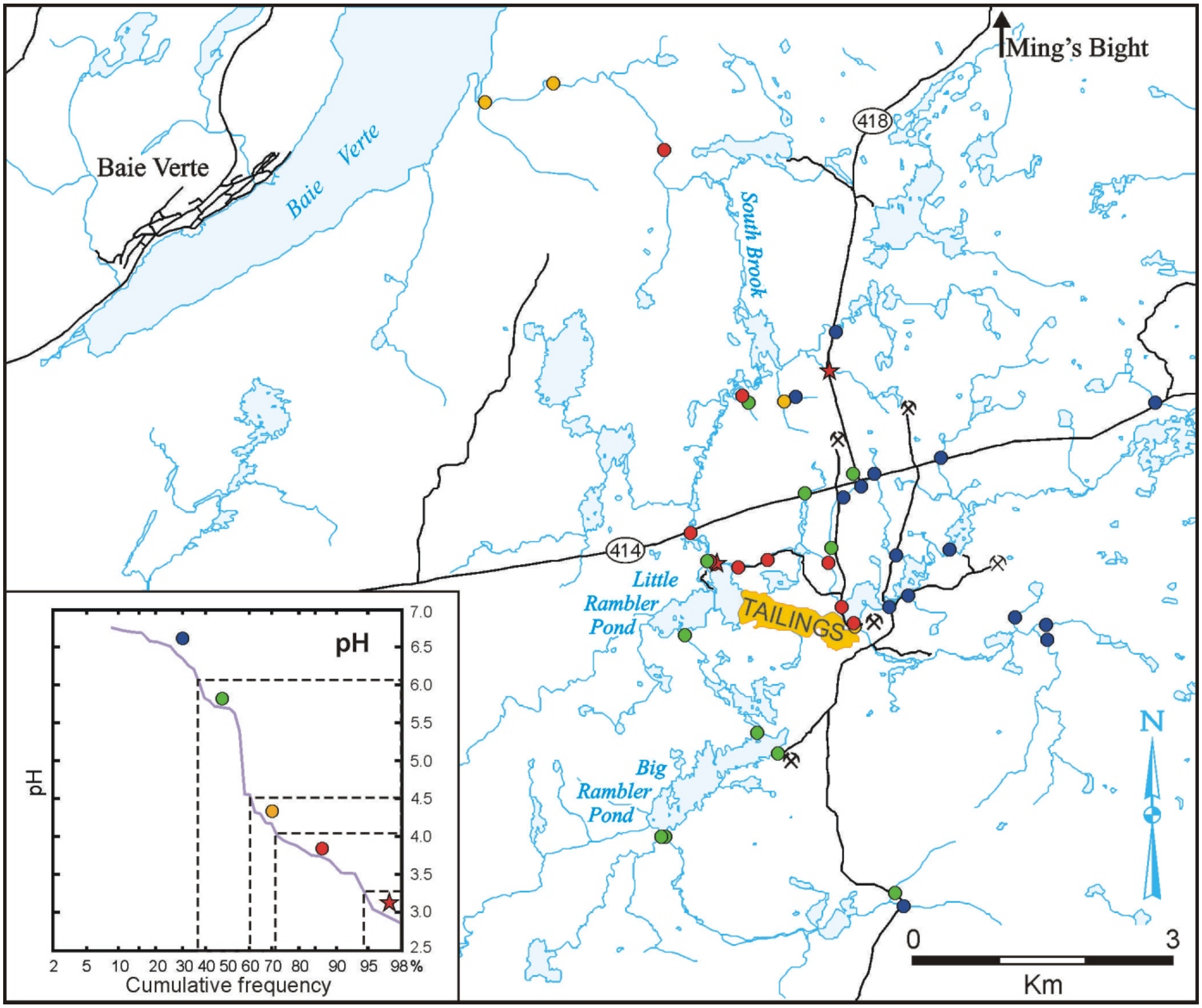

Figure 5. *pH in stream water. Data from 2001 water samples. See text for explanation of symbols.*

Site Duplicates

Copper analyses are available from 12 sites that were sampled in 1993, 2000 and 2001. Determinations of pH from 1993 are not regarded as reliable and are not included. These data may be used to monitor changes in water chemistry over time. Figures 8 and 9 plot the results for Cu and pH, respectively. For ease of comparison, data are sorted by increasing value of the 2000 data. Locations of site duplicates falling within the detailed map area are shown in Figure 2. The Cu plot indicates that Cu levels in the mine-affected sites (>10 ppb Cu in Figure 8) were very similar in 1993 and 2000 but considerably higher in the most recent sampling. The lower values for the background streams in the 2001 data likely result mostly from a lowered analytical detection limit in the new data. The sites with high Cu are also the same sites with low pH values (<5.0). The pH analyses from the 2001 samples are similar to the 2000 data for the background streams but are considerably more acid in five of the six mine-affected samples. These five samples are all from the North Diversion Ditch or from various sites along South Brook – drainages that carry most of the mine-affected stream water. The sixth site is from a south-draining tributary of the North Diversion Ditch. This lowering of pH levels in the most recent sampling and the corresponding increased metal levels, indicates that the problem with acid mine drainage is not improving with time.

SUMMARY

The mining operation at the Rambler Mines property produced primarily Cu and lesser amounts of Au, Ag and Zn

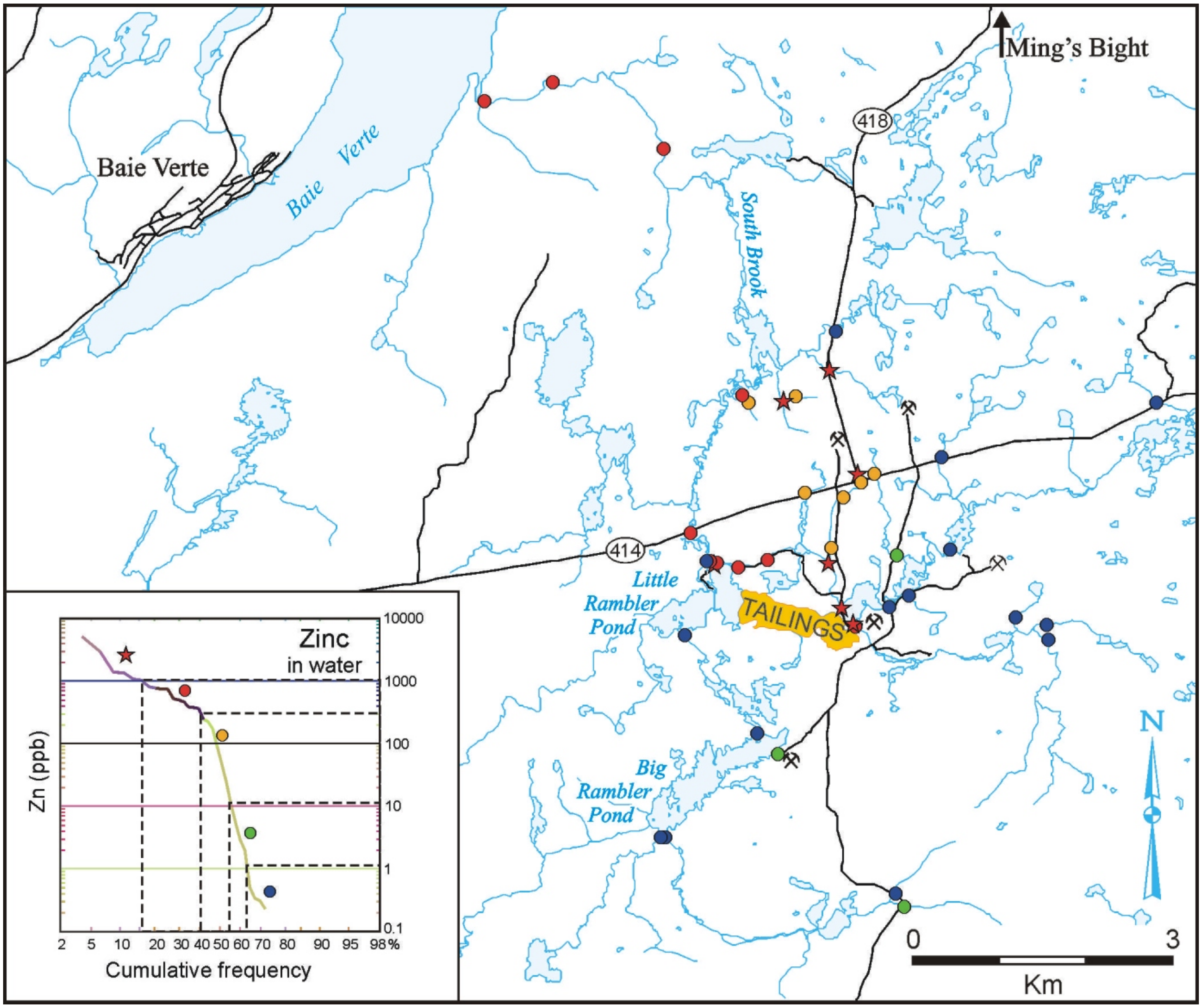

Figure 6. *Zn in stream water. Data from 2001 water samples. See text for explanation of symbols.*

from five volcanogenic massive sulphide deposits. The ore was milled onsite and a tailings compound and water-course diversions were built in an effort to prevent the generation of acid mine drainage. Water sampling in 1993, 2000 and 2001 of streams in the area indicate that acid mine drainage is prevalent and affects several streams including the largest river in the area (South Brook) from the mining area downstream to its mouth at Baie Verte. Comparison of data from the same sites over an eight-year period suggests that acidification and metal contamination of the affected streams is now the same or more severe than earlier. The major contaminants, with respect to impacts on aquatic life are high levels of Cu and acidification of affected streams. Stream-water geochemistry has identified three major sources of acid drainage. The largest source appears to be near the head of the North Diversion Ditch. The actual source or sources is unclear but may include leakage from the tailings compound and sulphidic waste rock exposed in the catchment basin. A second source occurs in the vicinity of the Ming Mine as shown by high base-metal contents and acidification of the stream draining to the northwest from the former mine site. A third source is the Ming West Mine that gives rise to a small stream having extremely high Cu contents flowing north into South Brook. More detailed sampling in the Rambler Mines area will be required to further delineate the sources of the metals.

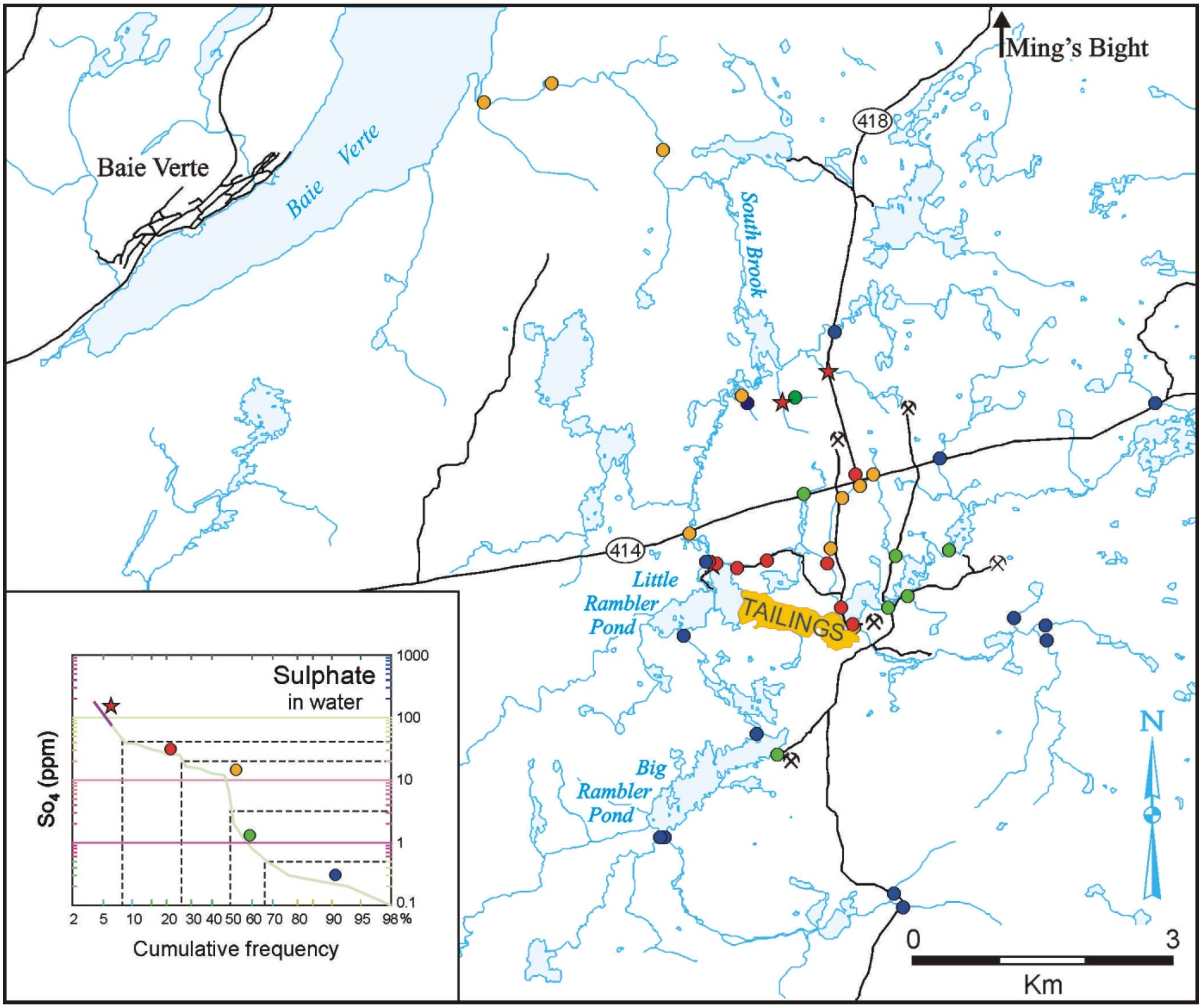

Figure 7. *SO_4 in stream water. Data from 2001 water samples. See text for explanation of symbols.*

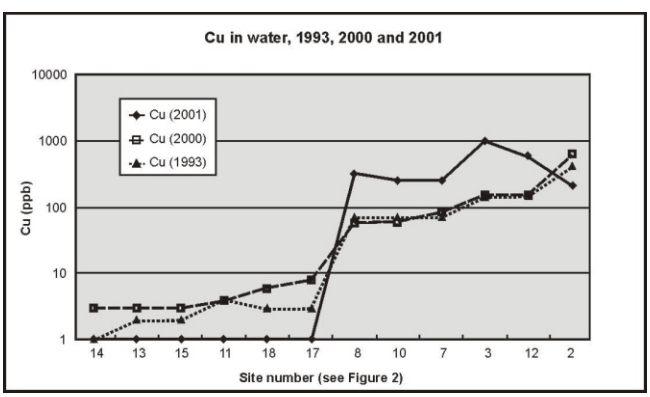

Figure 8. *Cu in site duplicates. From 1993, 2000 and 2001 data.*

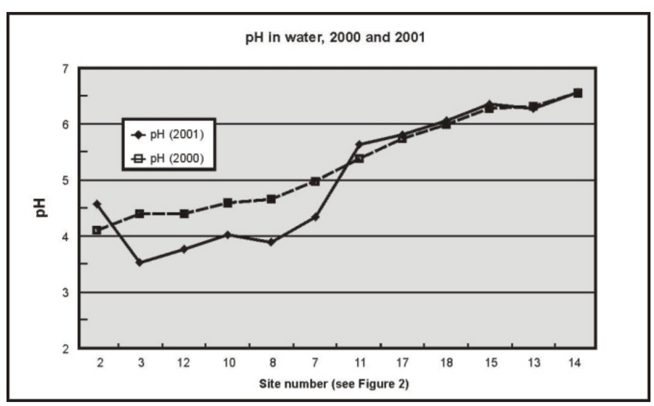

Figure 9. *pH in site duplicates. From 2000 and 2001 data.*

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