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**Geochemical Data Including Mercury Speciation for Surface Waters at the Abandoned Greenwood
Mine Area, Prince William Forest Park, Virginia**

by

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ABSTRACT

This report presents water quality data for samples collected in May, 1998, aimed at understanding the geochemistry of mercury at the abandoned Greenwood mine area in Prince William Forest Park, Prince William County, Virginia. Data include temperature, pH, specific conductance, dissolved oxygen, alkalinity, flow, total acid soluble and dissolved major and trace element concentrations, and methylmercury and total mercury concentrations on filtered and unfiltered fractions of water from four sites around the mine workings and one site approximately 11 km downstream. Detailed interpretation of the data will be presented elsewhere.

SCOPE

The National Park Service acquired a 43-acre tract of land in Prince William County, Virginia for incorporation into Prince William Forest Park in July 1997 (Fig. 1). The abandoned Greenwood gold prospect is located within the tract. The U. S. Geological Survey conducted reconnaissance water sampling at the site in December 1997, exclusive of mercury. Also in December 1997, the National Park Service collected six samples in a reconnaissance soil geochemical survey at the site. During this survey, the National Park Service identified high mercury concentrations of over 40 mg/kg (Carol Pollio, N.P.S., personal communication, 1998) in soils adjacent to the shaft depressions. The elevated mercury values are probably related to the historic use of mercury amalgamation for gold extraction. On the basis of the December 1997 results, Seal and others (1998) suggested that the geochemical environment present in the shaft depressions at the mine site might be conducive to the production of methylmercury, a potent neurotoxin and the most hazardous form of mercury. In light of the geochemical environment and the high mercury concentrations in soils, the U.S. Geological Survey resampled the site in May 1998 to assess the impact of mercury on surface waters in the area.

The Greenwood mine is a gold property that is located in Prince William County at the northeastern end of the 175 km-long Virginia gold-pyrite belt (Pavlides and others, 1982). The deposits of the gold-pyrite belt are typically classified as low-sulfide gold-quartz deposits. These deposits generally consist of quartz veins with minor amounts of pyrite and gold (Goldfarb and others, 1995). The mine site is located at the headwaters of Quantico Creek, which flows past the reclaimed Cabin Branch mine, approximately 11 km downstream (Fig. 1). The deposit is hosted by the Ordovician (approximately 475 million year old) Lake Jackson pluton, a metamorphosed tonalitic

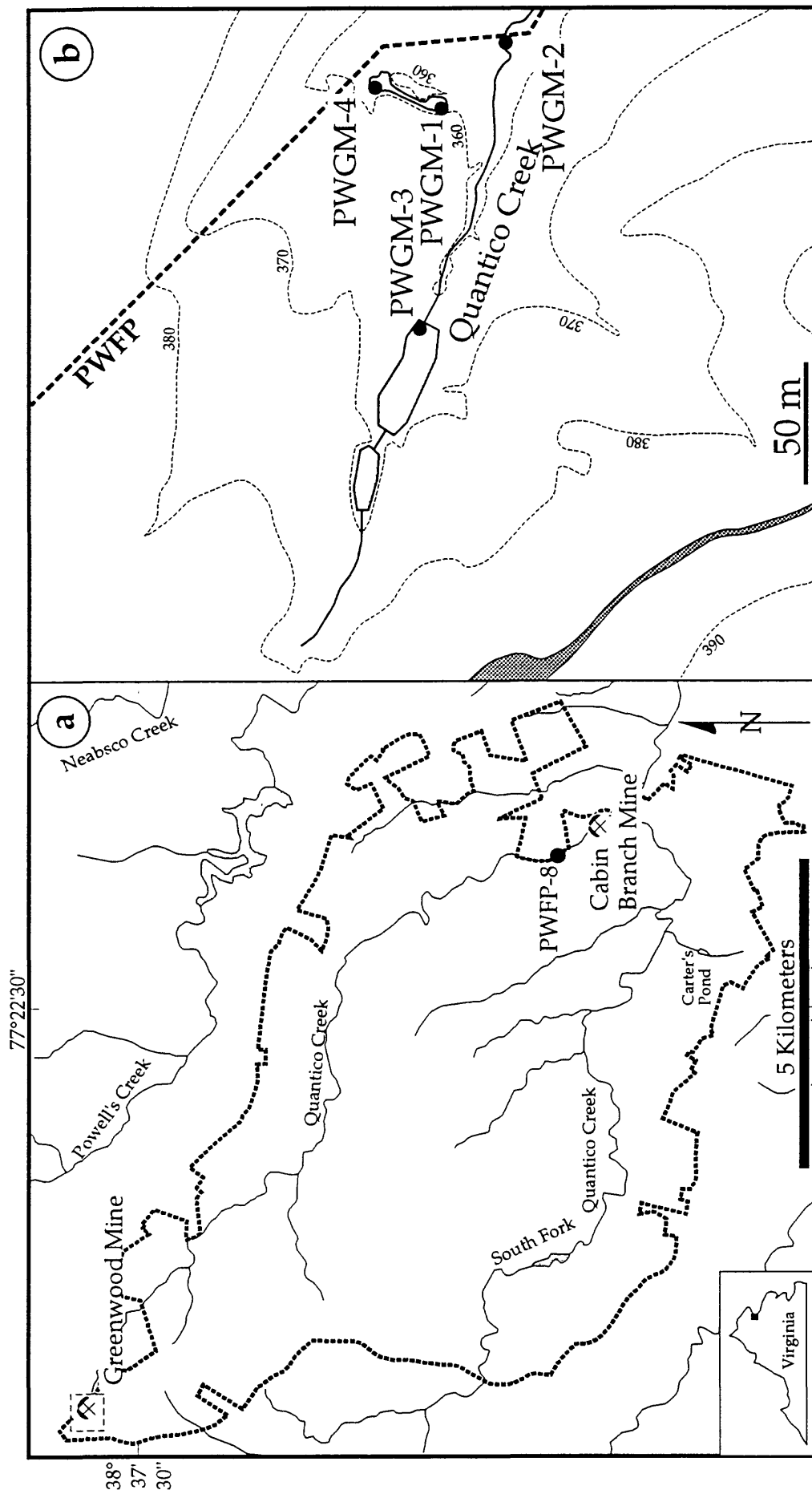


Figure 1. Maps of the study area. Heavy dashed line is the boundary of Prince William Forest Park including the new tract containing the Greenwood site. Streams are shown as thin solid lines. Ponds and lakes are shown as stippled patterns. The location of Fig. 1b is shown by the dashed rectangle. b: Map showing location of sample sites around the abandoned Greenwood mine. Road is shown as dark stippled pattern.

intrusion. Lonsdale (1927) reported that two vertical shafts were sunk, which are still identifiable. He also noted that the mine has been abandoned at least since 1907. Elsewhere in Prince William County, Pardee and Park (1948) described placer operations at the Crawford property on Neabsco Creek and its tributaries, located approximately 10 km east of the Greenwood mine. The placer was worked around 1935 and used copper-plate mercury amalgamation to extract gold. Although the details of the mineral processing techniques at the Greenwood site are not available, the use of copper-plate amalgamation at the nearby Crawford property suggests that the same process may have been used at Greenwood. Copper is the only heavy metal reported by Seal and others (1998) for the Greenwood site that exceeded U.S.E.P.A. (1996) standards for acute toxicity in freshwater aquatic ecosystems. This observation is significant because low-sulfide quartz-gold deposits are not expected to be highly enriched in copper (Goldfarb and others, 1995). The high concentration of mercury in soils at the site, assumed to be the result of the use of amalgamation, is likely to have been introduced either during the initial operation of the site or during later reworking of solid mine wastes when copper-plate amalgamation was used at the nearby Crawford property (ca. 1935).

Mercury amalgamation was a common technique that has been used globally in historic gold mining operations (Sweet, 1980; Lacerda, 1997). For small-scale operations, it offers the advantages of being cheap, reliable, and portable. Mercury is used to separate fine gold particles through amalgamation in both placer and hard-rock mining operations. The ore is first crushed, and then typically undergoes a gravimetric concentration step. The concentrate is then washed over mercury, or mercury amalgamated to a copper plate; the mercury readily alloys with gold. The alloy or amalgam is then typically roasted in open air to vaporize the more volatile mercury and leave the gold behind (Sweet, 1980; Lacerda, 1997). Contamination of the environment with mercury occurs during at least three stages of the process. First, some mercury is released in the water that is used to wash the ore concentrate over the mercury or copper-mercury plate. Second, some mercury adheres to the processed ore and is disposed with the solid mine waste. Third, mercury is released to the atmosphere during the roasting of the amalgam. At the abandoned Greenwood site, the greatest potential modern threat from mercury used in historic mining operations comes from the solid mine wastes that may have been disturbed around the site.

WATER QUALITY

Sample Sites and Samples

To date, eight surface-water samples from the Greenwood site and one surface-water sample from 11 km downstream, just above the reclaimed Cabin Branch site, have been collected and analyzed from Prince William Forest Park (Fig. 1). The four samples collected in December 1997 at the Greenwood site did not include mercury and sulfide analyses (Seal and others, 1998). The suite of samples from the present study included water within shaft depressions (PWGM-1, PWGM-4), a man-made pond upstream from the shafts (PWGM-3), the headwaters of Quantico Creek, immediately downstream from the shaft depressions (PWGM-2), and Quantico Creek, 11 km downstream from the Greenwood site (PWFP-8).

One shaft (PWGM-1) contained abundant organic debris (leaves, twigs) and the water in the shaft was dark brown and covered by an iridescent bacterial film. A distinct sulfurous odor was also noted. The other shaft (PWGM-4), north of the first along a shallow trench, was filled with light brown water with a less well developed bacterial film. A less distinct sulfurous odor was also noted.

At each site, two splits were collected for cation analysis; one split was unfiltered and the other split was filtered through a 0.45 μm filter. The collection of two splits was done to assess qualitatively the transport of heavy metals adsorbed on fine-grained suspended particulate matter. A separate split was also collected for mercury (Hg), which was filtered in the laboratory. Field and laboratory procedures are summarized in Appendix 1. Descriptions of the sampling sites are presented in Appendix 2.

Results

The waters sampled from within the shaft depressions are considerably different from the pond and stream samples. The pH values of all samples were near neutral and ranged from 6.3 to 7.0. The specific conductance ranged from 44.9 to 235.3 $\mu\text{S}/\text{cm}$, which corresponds to an approximate range of total dissolved solids of 30 to 150 mg/L. All dissolved oxygen levels were well below saturation. Dissolved oxygen values ranged from 3.7 to 7.4 mg/L for the stream and pond. Dissolved oxygen values for the waters in the shaft depressions were 0.93 and 1.3 mg/L, which are approximately 0.2 and 8 % of saturation, respectively. The low oxidation state of the waters from the shaft depressions is also reflected in the $\text{Fe}^{2+}/\text{Fe}_{\text{total}}$ ratios, where the shaft waters have values between 0.60 and 1.00. In addition, there is a broad negative correlation between $\text{Fe}^{2+}/\text{Fe}_{\text{total}}$ and dissolved oxygen (Fig. 2).

Dissolved sulfate values for the stream and pond average 4.8 mg/L, whereas the sulfate concentration of the shaft water at PWGM-1-1 was 2.5 mg/L and that at PWGM-4-1 was 16.0 mg/L. Total dissolved iron values are low in the stream and pond (<0.61 mg/L); the values from the water in the shaft depressions are higher (1.1 and 4.6 mg/L) and presumably reflect a combination of the greater solubility of reduced iron (Fe^{2+}) compared to oxidized iron (Fe^{3+}) and the greater solubility of total iron due to complexation with dissolved organic carbon (DOC) compounds. The brown color of the shaft waters is consistent with high DOC. Dissolved aluminum (up to 0.11 mg/L), and total base metals (copper + zinc + nickel + cobalt + cadmium + lead; up to 0.03 mg/L) values are generally low compared to waters around the Cabin Branch mine site (Seal and others, 1998). Alkalinity values range from 12.3 to 98.6 mg/L CaCO_3 for all samples. Hardness values for all samples vary between 13.0 and 74.9 mg/L CaCO_3 equivalent, where hardness (CaCO_3 equivalent mg/L) = $2.5 \cdot \text{Ca}$ (mg/L) + $4.1 \cdot \text{Mg}$ (mg/L). Complete analyses, with the exception of mercury species, for all water samples collected in May 1998 are presented in Appendix 3.

Total mercury values for unfiltered samples reached a high of 124.0 ng/L in the stream immediately below the shaft depressions; methylmercury values for unfiltered samples reached a high of 34.6 ng/L in a shaft depression (Table 1). In general, methylmercury concentrations (both filtered and unfiltered) are highest within the shaft depressions. Both total mercury and methylmercury are lowest 11 km downstream from the Greenwood site (PWFP-8-GM2).

DISCUSSION

Comparison with Water Quality Standards

The water samples from the present study are all below U.S.E.P.A. (1996) criterion maximum concentration (CMC) for acute toxicity in freshwater aquatic environments for the heavy metals cadmium, chromium, copper, lead, nickel, silver, and zinc. For chronic toxicity limits (criterion continuous concentration; CCC), two samples (PWGM-1-2 and PWGM-3-2) are slightly above the limit for lead, and one sample (PWGM-1-2) is above the limit for copper. From the previous sampling, Seal and others (1998) found only one sample, PWGM-1-1, exceeded the acute toxicity limit (CMC) for copper.

For mercury ($\text{Hg}(\text{II})$), the established limits for acute and chronic toxicity are based on total recoverable mercury. For the present study, all of the samples are below the acute toxicity limits (Table 1). For chronic toxicity effects, the total Hg (unfiltered) values for three samples, PWGM-1-2, PWGM-2-2, and PWGM-4-2, exceed the limit.

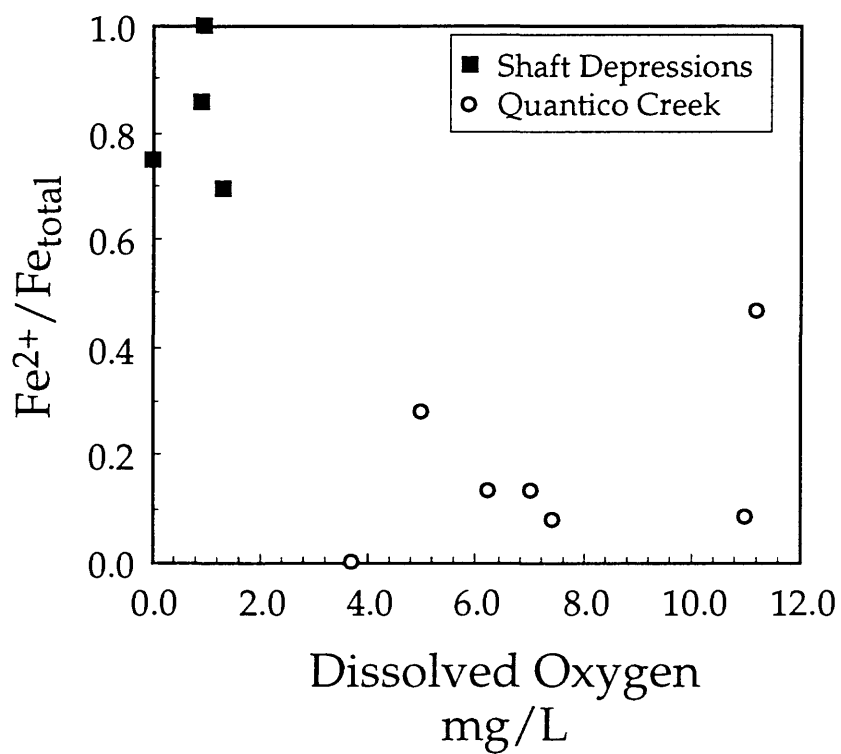


Figure 2. Plot of $\text{Fe}^{2+} / \text{Fe}_{\text{total}}$ vs. dissolved oxygen. Plot includes data from present study and from Seal and others (1998). Quantico Creek data include samples from the pond (PWGM-3).

TABLE 1. Mercury speciation and concentrations and selected other parameters in surface waters around the abandoned Greenwood mine site. CMC and CCC values for freshwater aquatic systems are for total recoverable mercury.

SAMPLE	PWGM-1-2	PWGM-2-2	PWGM-3-2	PWGM-4-2	PWFP-8-GM2
Description	Shaft	Stream	Pond	Shaft	Stream
pH	6.3	6.7	6.9	6.7	5.9
Dissolved O ₂ mg/L	1.30	3.70	6.21	0.93	7.4
SO ₄ mg/L	2.5	3.3	6.4	16.0	4.6
S ⁼ mg/L		0.041		0.598	
Fe ²⁺ /Fe _{Total}	0.69	0.00	0.13	1.00	0.08
Total Hg, unfiltered, ng/L	91.6	124.0	10.3	15.1	2.47
Total Hg, filtered, ng/L	50.1	36.3	7.57	10.1	1.27
Methyl Hg, unfiltered, ng/L	34.6	1.84	0.857	10.0	0.188
Methyl Hg, filtered, ng/L	30.9	1.46	0.539	8.52	0.149
CMC, Hg (II), ng/L	2,100.0	2,100.0	2,100.0	2,100.0	2,100.0
CCC, Hg (II), ng/L	12.0	12.0	12.0	12.0	12.0

Comparison with Other Gold Mining Areas

Mercury data, particularly methylmercury concentrations, from gold mining areas are limited, but span several orders of magnitude (Fig. 3). Nriagu and others (1992) reported dissolved and total mercury concentrations for rivers from gold mining areas in Brazil that ranged up 33.2 ng/L. Callahan and others (1994) found mercury concentrations in waters from mining districts in North Carolina to be less than 200 ng/L. Bonzongo and others (1996) reported mercury speciation data for the Carson River, Nevada, which empties an area where mercury amalgamation was used in the latter half of the 19th century. Their total dissolved mercury and dissolved methylmercury values ranged from 2.46 to 56.46 ng/L, and 0.129 to 1.597 ng/L, respectively. The Greenwood site is distinctive because of the high methylmercury concentrations even though the total mercury concentrations are in the middle of the range for the other areas (Fig. 3).

RECOMMENDATIONS

Future work at the site, and downstream, should evaluate the seasonal variation of the speciation of dissolved mercury to determine methylmercury concentrations. Mercury concentrations of fish (whole-body and (or) liver) at the site and downstream may be useful in determining the extent of contamination. Assuming that the mercury contamination is due to mercury amalgamation used in gold recovery, then long-term problems may be associated with residual mercury in solid mine wastes around the site. To assess the nature and extent of the problem, soil sampling survey on a grid around the site should be conducted to determine the mineralogy and geochemistry of the soils.

ACKNOWLEDGMENTS

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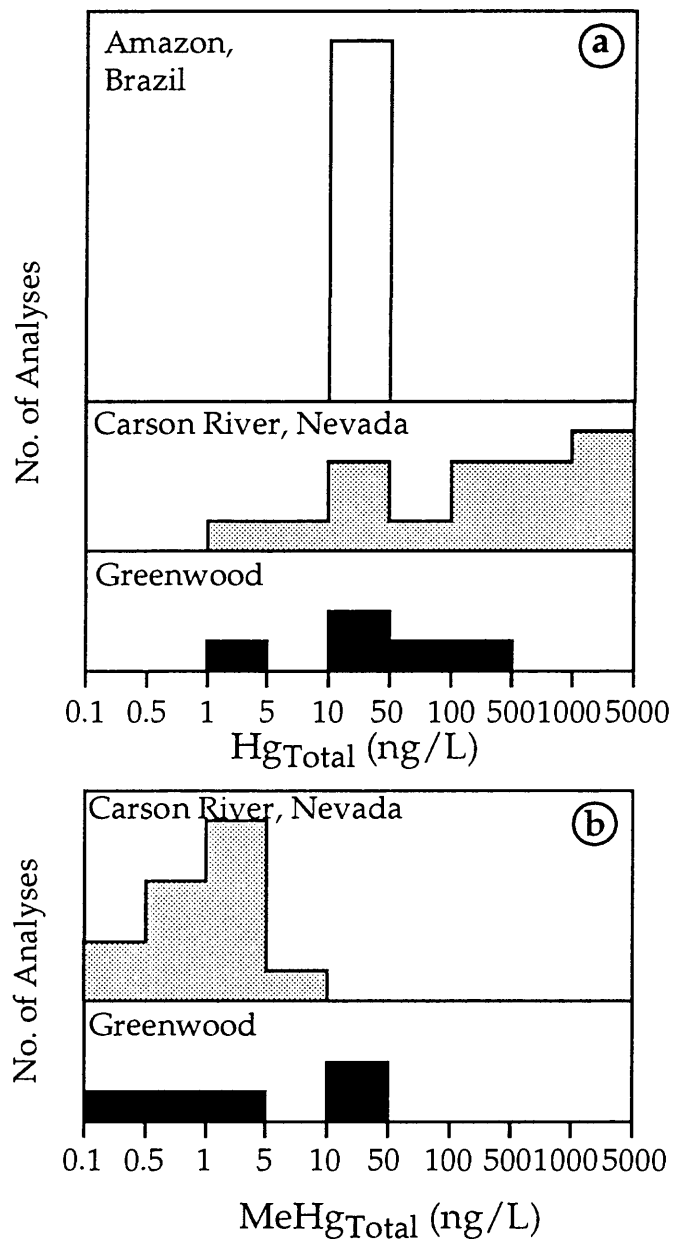


Figure 3. Histograms of mercury species data for waters from gold mining areas. Brazilian data are from Nriagu and others (1992); Carson River data are from Bonzongo and others (1996). a. Total mercury (all species, dissolved + particulate). b. Total methylmercury (dissolved + particulate).

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APPENDIX 1: FIELD AND ANALYTICAL METHODS

Water samples were collected in one-liter high-density polyethylene bottles that were doubly-rinsed with sample water prior to collection. Samples were divided into four splits for chemical analysis: two for cation analysis, one for anion analysis, and one for alkalinity determination. The cations splits included filtered (dissolved) and unfiltered (total acid soluble) aliquots. Samples were filtered through 0.45 μm nitrocellulose filters. Cation splits were stored at ambient temperature in acid-washed (10 % HCl) high-density polyethylene bottles and preserved with 1 drop of ultra-pure nitric acid per each 10 ml of sample. Anion and alkalinity splits were stored high-density polyethylene bottles that were not acid-washed and were refrigerated until the time that they were analyzed.

On-site measurements at the time of collection included air temperature, water temperature, pH, specific conductance, dissolved oxygen, dissolved ferrous iron, dissolved total iron, dissolved sulfate, dissolved nitrate, and water flow. The pH was measured using an Orion 230A pH meter with a 91-07 probe, calibrated with pH = 4.00 and 7.00 buffer solutions. Specific conductance was measured with an Orion 135 specific conductance meter. Dissolved oxygen concentrations were determined with Chemetrix high-range ampoules or with an Orion 250A meter with an Orion 97-08-99 oxygen electrode. Dissolved total iron, ferrous iron, sulfate, and nitrate concentrations were determined in the field using a Hach DR2000 spectrophotometer. Alkalinity samples were analyzed by Gran titration with 0.18 N H_2SO_4 .

Cations were analyzed at U.S. Geological Survey (Central Mineral Resources Team) laboratories in Denver, CO by inductively-coupled plasma mass spectrometry (ICP-MS). Anions were analyzed at U.S. Geological Survey (Water Resources Division) laboratories in Ocala, FL by ion chromatography (chloride, and sulfate) and by ion-selective electrode (fluoride).

Total mercury and methylmercury were analyzed by Frontier Geosciences (Seattle) by cold-vapor atomic fluorescence spectrometry (CVAFS). Total mercury was determined by using oxidation with a 1% BrCl solution, and methylmercury was determined by using distillation and ethylation processes prior to CVAFS analysis (Bloom and Crecelius, 1983; Bloom, 1989; Horvat and others, 1993).

APPENDIX 2: DESCRIPTIONS OF SAMPLE SITES

PWGM-1-2 (NPS GM002): 38° 37.8' N, 77° 26.0' W; Water in main mine shaft at Greenwood Mine; deep brown color and iridescent bacterial film on surface; abundant organic debris in water; sulfurous odor. Same site as PWGM-1-1 from Seal and others (1998).

PWGM-2-2: 38° 37.8' N, 77° 26.0' W; Quantico Creek downstream from Greenwood Mine area; water had clear appearance and no odor; flow rate = 2.7 L/min. Same site as PWGM-2-1 from Seal and others (1998).

PWGM-3-2: 38° 37.9' N, 77° 26.8' W; Lower pond upstream from Greenwood Mine area; flow rate = 2.7 L/min. Same site as PWGM-3-1 from Seal and others (1998).

PWGM-4-2 (NPS GM001): 38° 37.9' N, 77° 26.0' W; Water in small mine shaft north of main shaft; brown color, less distinct sulfurous odor compared to PWGM-1-2, and abundant leaves. Same site as PWGM-4-1 from Seal and others (1998).

PWFP-8-GM2: 38°34.798'N, 77°21.312'W; Quantico Creek, 11 km downstream from the Greenwood site, and just upstream from the reclaimed Cabin Branch site.

APPENDIX 3: WATER-QUALITY DATA

SAMPLE NUMBER	PWGM-1-2	PWGM-2-2	PWGM-3-2	PWGM-4-2	P-VFP-8-GM2
Description	Shaft	Stream	Pond	Shaft	Stream
NPS Location	GM002			GM001	
Collection Date	5/20/1998	5/20/1998	5/20/1998	5/20/1998	5/20/1998
Field Parameters					
Air Temperature °C	22	21.7	26.7	22.1	25.8
Water Temperature °C	14.6	17.9	24	19.1	21.2
pH	6.3	6.7	6.9	6.7	7.0
Specific Conductance µS/cm	44.9	152	96.5	235.3	46.7
Dissolved O ₂ mg/L	1.3	3.7	6.2	0.93	7.4
Dissolved (<0.45 µm) Concentrations					
Alkalinity mg/L CaCO ₃	12.3	50.7	35.8	98.6	13.8
NO ₃ mg/L					
SO ₄ mg/L	2.5	3.3	6.4	16	4.6
F mg/L					
Cl mg/L	1.1	17	4.5	7.1	3.7
Li µg/L	0.8	1.3	0.9	2.8	1.2
Be µg/L	0.09	0.06	0.08	0.06	< 0.05
Na mg/L	1.6	16	8.6	17	3.4
Mg mg/L	1.1	4.0	3.0	7.3	1.8
Al µg/L	110	42	110	27	10
SiO ₂ mg/L	12	22	11	35	14
K µg/L	1100	1300	990	1100	970
Ca mg/L	3.4	9.2	7.5	18	2.8
Sc µg/L	0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ti µg/L	0.5	0.5	1.7	0.8	< 0.1
V µg/L	0.2	0.6	1	0.6	0.3
Cr µg/L	2	2	2	2	< 1
Mn µg/L	230	450	82	130	44
Fe µg/L	4600	370	610	1100	260
Fe ²⁺ mg/L	3.19	0.00	0.08	2.03	0.02
Co µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ni µg/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Cu µg/L	2	2	2	< 0.5	0.7
Zn µg/L	10	20	3	2	2
Ga µg/L	0.03	< 0.02	0.02	< 0.02	< 0.02
Ge µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
As µg/L	< 0.2	< 0.2	0.4	< 0.2	< 0.2
Se µg/L	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Rb µg/L	2.1	1.9	1.3	0.99	1.8
Sr µg/L	25	62	43	140	20
Y µg/L	0.76	0.59	0.87	0.3	0.3
Zr µg/L	0.09	0.1	0.5	< 0.05	< 0.05
Nb µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Mo µg/L	0.2	0.2	< 0.02	< 0.02	0.04
Ag µg/L	< 0.01	< 0.01	0.06	< 0.01	< 0.01
Cd µg/L	0.02	< 0.02	< 0.02	< 0.02	< 0.02
In µg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sn µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Sb µg/L	3.8	0.09	0.1	0.2	0.1
Te µg/L	< 2	< 2	< 2	< 2	< 2
Cs µg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

SAMPLE NUMBER	PWGM-1-2	PWGM-2-2	PWGM-3-2	PWGM-4-2	PWFP-8-GM2
Dissolved (<0.45 µm) Concentrations (cont.)					
Ba µg/L	26	29	22	35	18
La µg/L	0.82	0.4	0.65	0.2	0.2
Ce µg/L	1.7	1.1	1.3	0.70	0.51
Pr µg/L	0.30	0.1	0.2	0.06	0.06
Nd µg/L	1.1	0.52	0.69	0.25	0.26
Sm µg/L	0.27	0.08	0.1	0.05	0.05
Eu µg/L	0.02	0.02	0.02	0.005	< 0.005
Tb µg/L	0.02	0.01	0.02	0.006	0.009
Gd µg/L	0.17	0.11	0.16	0.03	0.058
Dy µg/L	0.12	0.097	0.12	0.04	0.050
Ho µg/L	0.02	0.02	0.03	0.006	0.009
Er µg/L	0.088	0.071	0.066	0.02	0.02
Tm µg/L	0.008	0.01	0.007	< 0.005	< 0.005
Yb µg/L	0.09	0.06	0.06	0.01	0.02
Hf µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ta µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
W µg/L	0.03	0.04	< 0.02	0.1	< 0.02
Re µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Au µg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Tl µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Pb µg/L	1.0	0.57	1.2	0.1	0.08
Bi µg/L	< 0.01	< 0.01	0.04	< 0.01	< 0.01
Th µg/L	0.36	0.04	0.14	0.03	< 0.005
U µg/L	0.03	0.05	0.09	0.03	0.01
Total Acid Soluble Concentrations					
Li µg/L	0.8	1.1	1.2	2.7	1.0
Be µg/L	< 0.05	< 0.05	0.06	< 0.05	0.05
Na mg/L	1.3	16	8.7	17	3.4
Mg mg/L	1.1	4.0	3.0	7.2	1.8
Al µg/L	170	80	160	42	38
SiO ₂ mg/	12	22	11	35	14
K µg/L	1100	1200	1000	1000	950
Ca mg/L	3.6	9.2	7.6	18	2.8
Sc µg/L	0.2	< 0.1	< 0.1	< 0.1	< 0.1
Ti µg/L	1.1	0.6	1.9	1.1	0.6
V µg/L	0.4	0.9	1	1	0.6
Cr µg/L	2	2	2	3	< 1
Mn µg/L	240	470	97	130	61
Fe µg/L	7200	760	800	1900	660
Co µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ni µg/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Cu µg/L	4	3	2	< 0.5	0.7
Zn µg/L	10	22	6	0.6	4
Ga µg/L	0.03	< 0.02	0.02	< 0.02	0.02
Ge µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
As µg/L	< 0.2	0.3	0.4	0.3	< 0.2
Se µg/L	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Rb µg/L	2.1	1.8	1.4	0.97	1.8

SAMPLE NUMBER	PWGM-1-2	PWGM-2-2	PWGM-3-2	PWGM-4-2	PWFP-8-GM2
Total Acid Soluble Concentrations (cont.)					
Sr µg/L	26	61	44	140	19
Y µg/L	0.98	0.72	0.99	0.4	0.60
Zr µg/L	0.1	0.1	0.50	< 0.05	< 0.05
Nb µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Mo µg/L	0.1	0.1	0.02	< 0.02	0.05
Ag µg/L	< 0.01	< 0.01	0.02	< 0.01	< 0.01
Cd µg/L	0.03	0.02	< 0.02	< 0.02	< 0.02
In µg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sn µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Sb µg/L	0.1	0.04	0.06	< 0.02	< 0.02
Te µg/L	< 2	< 2	< 2	< 2	< 2
Cs µg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ba µg/L	31	33	23	38	19
La µg/L	1.2	0.70	0.81	0.4	0.59
Ce µg/L	2.6	1.7	1.7	1.1	1.2
Pr µg/L	0.44	0.2	0.21	0.1	0.2
Nd µg/L	1.7	0.80	0.85	0.43	0.68
Sm µg/L	0.31	0.2	0.1	0.06	0.1
Eu µg/L	0.04	0.02	0.03	0.008	0.03
Tb µg/L	0.04	0.02	0.03	0.01	0.02
Gd µg/L	0.28	0.14	0.18	0.090	0.11
Dy µg/L	0.20	0.12	0.16	0.050	0.11
Ho µg/L	0.03	0.02	0.03	0.01	0.02
Er µg/L	0.081	0.059	0.099	0.04	0.061
Tm µg/L	0.01	< 0.005	0.01	< 0.005	0.006
Yb µg/L	0.09	0.06	0.08	0.04	0.04
Hf µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ta µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
W µg/L	< 0.02	0.04	0.1	0.03	< 0.02
Re µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Au µg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Tl µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Pb µg/L	2.6	1.0	1.1	0.2	0.3
Bi µg/L	0.02	< 0.01	0.01	< 0.01	< 0.01
Th µg/L	0.40	0.07	0.16	0.03	0.01
U µg/L	0.04	0.05	0.11	0.04	0.02