Virginia Journal of Science
Volume 45, Number 3
Fall 1994

Spectral Characterization of Acid-Mine and Neutral-Drainage Bacterial Precipitates and Their Relationship to Water Quality in a Piedmont Watershed

John E. Anderson, Research Biologist, U.S. Army Corps of Engineers, Topographic Engineering Center,
Fort Belvoir, Virginia 22315

ABSTRACT

Mining residues have an enormous impact on water quality; however, not all associated red, orange, and yellow drainage precipitates indicate acid conditions. Recently, preliminary work in a Virginia Piedmont stream affected by mine drainage demonstrated that a passive spectral technique may exist to differentiate between acid and neutral drainages. *In-situ* spectral reflectance measurements (350 to 900 nm) were collected on bacterial precipitates in Contrary Creek, near Mineral, Virginia. Spectra also were collected on bacterial precipitates in a neutral tributary stream. Each drainage had associated with it different water quality and bacterial communities. For each of the stream precipitates evaluated in this study, different spectral reflectances were recorded which were strongly associated with specific conductivity levels. Spatial and temporal changes did not influence the reflectance values as the acid precipitate reflectances were an average 44% brighter than the neutral precipitates.

Key words: spectral reflectance, acid mine drainage, bacterial precipitates, water quality

INTRODUCTION

Acid drainage from active and abandoned mines is a major water-quality concern (Bureau of Mines, 1994). Where iron is present, the impact is highly visual -- precipitates of yellow, orange, and red colors line the creeks and rivers (Lackey, 1938). The Virginia Piedmont is characterized by iron-bearing rocks weathering under a humid, temperate regime. Coal and metals actively have been mined there since European settlement (Wilkes, 1988). The mineral pyrite, which occurs in the coal and as veins in crystalline rocks, is the major source of acidity (Poole, 1973).

The bacteria that participate in the production of iron precipitates or flocculates in acid waters usually are classified under the name of the most easily cultured member of a complex consortium, *Thiobacillus* (Ehrlich, 1990). The acidophilic thiobacilli are autotrophs, which means that this species actually derives energy from oxidizing the iron or the sulfur in pyrite (Singer and Stumm, 1970). This oxidation results in the production of sulfuric acid and precipitates that appear orange to yellow in the visible spectrum. These precipitates are commonly called "yellow boy."

In contrast, neutral waters that bear iron contain a different group of bacteria. The so-called "iron depositing bacteria" predominate where anoxic ground water transports ferrous iron (Fe^{2+}) and discharges it into oxygen-rich surface waters (Pringsheim, 1949). Their precipitates appear more red to red-orange in the visible spectrum. This consortium includes facultative anaerobes, microaerophiles, and aerobes that proliferate at the redox boundary (Ehrlich, 1990). Some, such as Gallionella, actually get energy from the oxidation of iron; such autotrophy has not been proven for the other members of the iron bacteria consortium. For these bacteria, iron oxidation may be a byproduct reaction (Ehrlich, 1990). Where the dried precipitates of these iron bacteria have been studied, ferrihydrite is the resulting iron-oxide mineral phase (Chukrovet al., 1973; Ferris et al., 1989). One of the consortium, *Leptothrix discophora*, forms oily films that spread out across the surface of the water (Ghiorse, 1984) and become redder through time. It is suggested that the color change is the result of dehydration reactions as ferrihydrite mineralizes to hematite (Robbins, 1994).

Yellow and red flocculates are colorful but look menacing (Chapelle, 1993). The menace is real where acids and soluble metals of acid drainage kill aquatic life and river bank vegetation. All such colors in waters are considered to be a problem to those untrained in the differences between the acid and neutral iron-oxidizing bacteria.

This investigation seeks to demonstrate that the precipitates of acid-mine and neutral bacteria have different spectral reflectance properties that can be associated with different water qualities. Similar approaches have been used to evaluate water quality using chlorophyll spectra from algal biomass and suspended sediments (Dierberg and Carriker, 1994). The end product of such a technique has translated into remote-sensing strategies for water-quality monitoring. Historically, applying remote sensing to evaluating mine wastes has been attempted since the ERTS 1 generation of sensors (Alexander et. al., 1973). Additionally, correlations between spectral data and water-quality data have only recently been investigated with studies involving the evaluation of various sensors for water-quality monitoring (Carboni and Moreau, 1990).

METHODS

For this investigation, a creek was chosen having neutral ground-water seeps and acid-producing mine runoff in the same watershed. Contrary Creek (Figure 1) near Mineral, in Louisa County, Virginia, drains five pyrite deposits that were actively mined in the 1840s and 1850s (Poole, 1973). The host rock of the mineralization is the Chopawamsik chlorite biotite schist; individual pyrite veins are as thick as 200 meters. The study site is located north of Mineral, Virginia at the intersection of the US 522 bridge and Contrary Creek. The U.S. Geological Survey gaged the creek at the US 522 bridge from 1989-1992 and measured pH values which ranged from 2.9 to 4.8 (B.J. Prugh, Jr., written commun., 1994). Dissolved sulfate was measured at 110 mg/L. In mg/L, total iron was 15, dissolved iron 11, dissolved Mn 0.87, and Zn 1.9. For this study, water-quality measurements including pH, specific conductivity, dissolved oxygen, and temperature were recorded monthly from March to October 1994 at the Contrary Creek site using hand-held instruments. These measurements were collected to assess temporal variations in water quality which may influence the spectral signatures of the precipitates (Figures 2-5). Coincident with water quality measurements, spectral

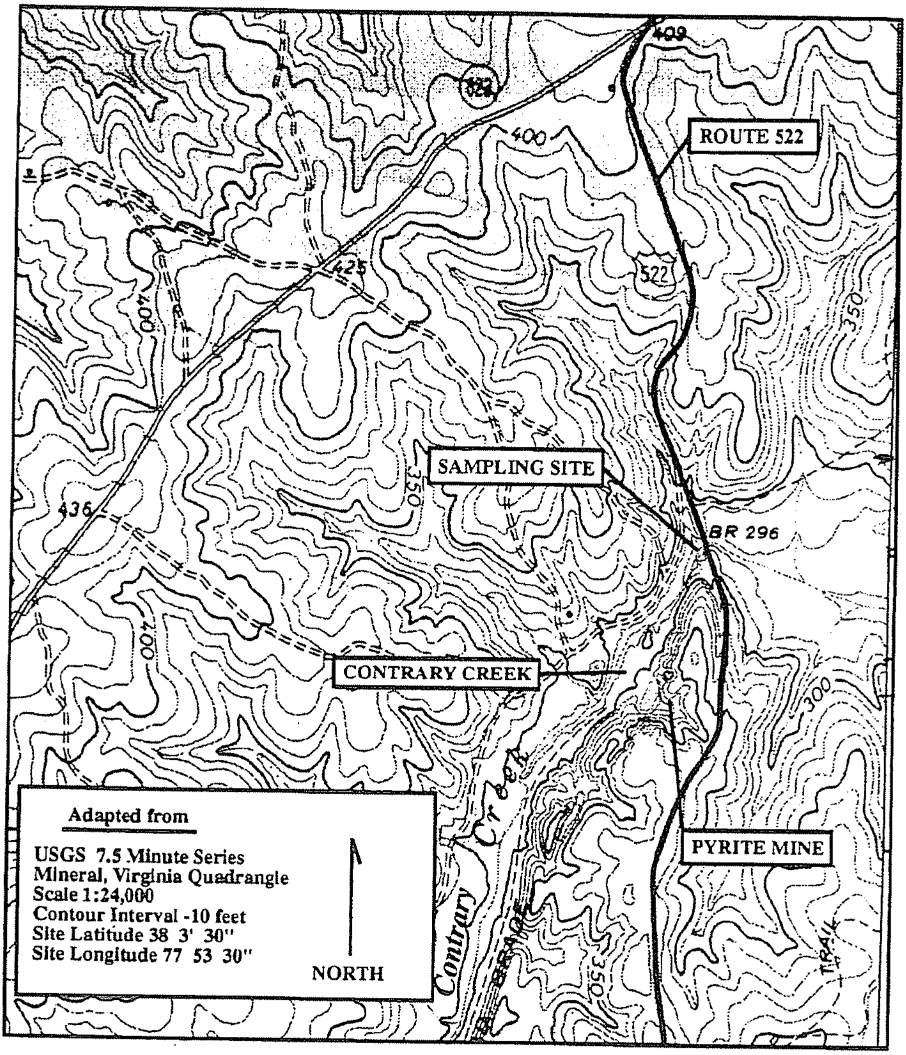

FIGURE 1. Location of sampling site along the Contrary Creek watershed near Mineral, Virginia.

reflectance measurements in the 350 to 900 nanometer bandpass (visible to near infrared) of acid-mine and circumneutral bacterial precipitates were collected monthly at the Contrary Creek site. This bandpass was selected because it covers the entire visible as well as a large part of the near-infrared portion of the electromagnetic spectrum. Spectral reflectance data are collected in-situ along a

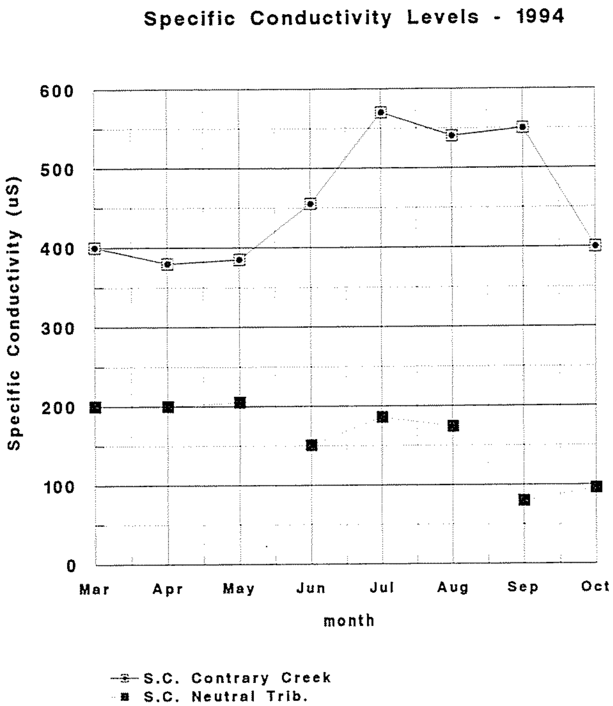

FIGURE 2. Specific conductivity levels at Contrary Creek and the neutral tributary.

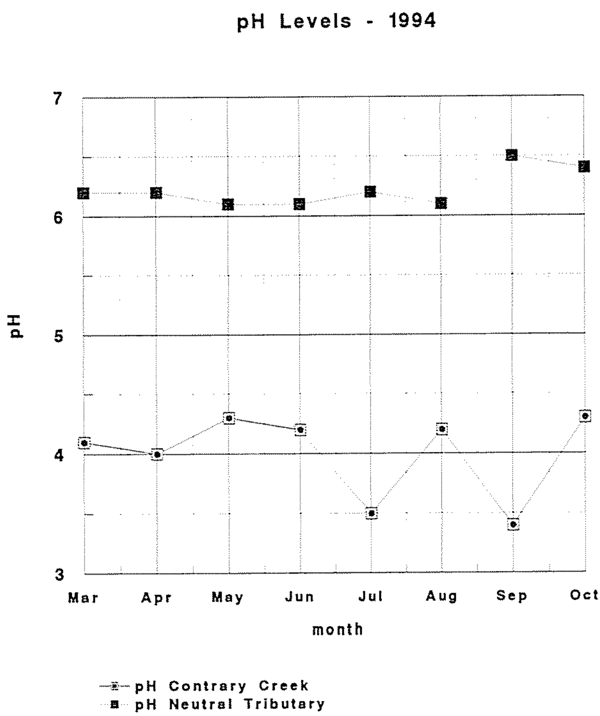

FIGURE 3. pH levels at Contrary Creek and the neutral tributary.

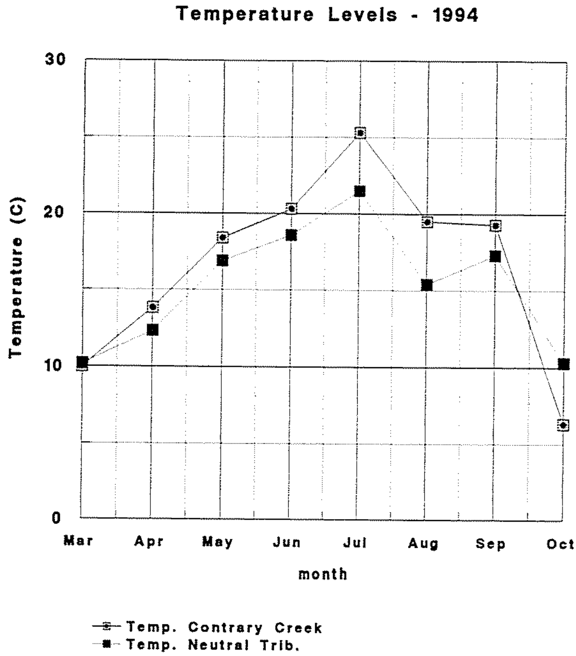

FIGURE 4. Temperature levels at Contrary Creek and the neutral tributary.

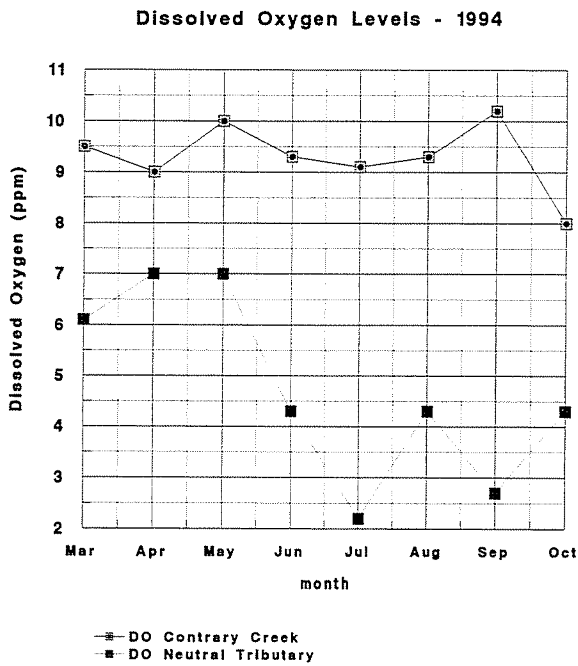

FIGURE 5. Dissolved oxygen levels at Contrary Creek and the neutral tributary.

transect in the stream channel using an Analytical Spectral Devices (ADS) PS II Spectroradiometer. Data collection followed the procedure outlined by Satterwhite and Henley, 1989. A five-degree field-of-view (FOV) is used to gather spectra in an eight centimeter sampling spot at a distance of one meter.

All spectra were collected at a nadir viewing angle in direct sunlight and referenced to a halon (Spectralon) standard. Three spectra were collected for each sample and then averaged. Late winter, summer and fall spectral reflectance data were analyzed to determine the seasonal spectral characteristics for acid and neutral bacterial precipitates (see Figures 6 & 7). Bacteria were collected and studied using non-standard microbial ecology methods. The precipitates were collected with an eyedropper and vial as well as by placing microscope slides into the creek and tributary stream. Light microscope observations of morphology were supplemented with standard microbial testing (broth tubes) for thiobacilli by Mark Stanton of the U.S. Geological Survey.

RESULTS

Acid stream bacteria in the orange-yellow precipitates within Contrary Creek included motile rods, non-motile cocci and short rods, and empty sheaths of filamentous bacteria resembling *Leptothrix ochracea*. Broth tube cultures were positive for NO_3 and Fe utilization, which is characteristic of *Thiobacillus*.

The spectroradiometric properties recorded for these precipitates (Figure 6.) show distinct and seasonally fluctuating waveform reflectance characteristics. Averaged spectral reflectance values for March through October showed that acid bacterial precipitates were 44% brighter than neutral bacterial precipitates. For the acid precipitates, reflectance peaks ranged from 750nm (March) to 711nm (September) over the course of the sampling period. This suggests a shift to shorter wavelengths from late winter to summer. Percent reflectances of 29 to 45 were also recorded. The highest reflectance values were measured over the late summer during August and September. At this time, pH levels were at their lowest point while specific conductivity levels were at their highest. Lower precipitate reflectance values for the bacteria were recorded during October, possibly in response to cooler temperatures and increased stream flow. Seasonal water quality measurements in the past suggest that Contrary Creek has had wide seasonal fluctuations in pH, temperature and conductivity. Our water quality measurements appear to be consistent with past gage station data.

Bacteria in the red precipitates occupying the neutral tributary were dominated by *Siderocystis* spp. in March. In April, *L. ochracea* dominated, *Toxothrix trichogenes* was next in abundance. *Gallionella ferruginea* also was present, but only weakly colored by thin iron-oxide precipitates in both March and April. Non-motile and motile cocci and colorless filaments were also present. The spectral properties of this neutral precipitate (Figure 7) exhibited reflectance peaks of 710nm (March) to 770nm (September) which are more red to far red spectrally. These values may suggest a shift to longer wavelengths from winter to summer. In addition, lower fluctuating reflectance values of 12 (March) to 25.5 (September) were measured. Again, the percent reflectance was seasonally dynamic with the brightest levels recorded during the summer and a decline in the fall. Water quality in the neutral drainage (pH, specific conductivity, and temperature) did not vary

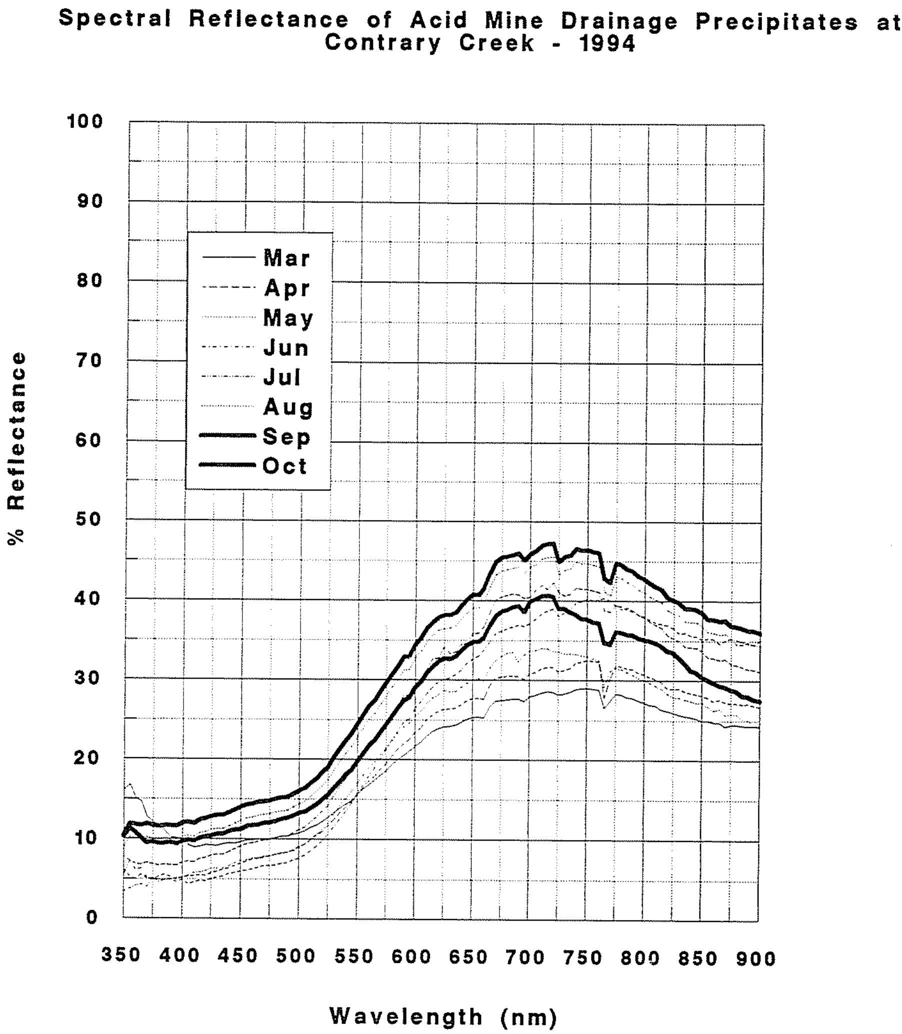

FIGURE 6. Spectral reflectance of acid mine drainage precipitates from March to October 1994.

widely, but wide variations in dissolved oxygen were recorded from winter to summer. This is probably due to this tributary emerging from an anoxic seep zone.

Following techniques described by Sokal and Rohlf (1981), linear regression equations (Figures 8 & 9) were used to investigate the possible relationships between acid and neutral reflectances and the measured water quality parameters. For both the acid and neutral precipitates a strong relationship between reflectance levels and specific conductivity emerges with an r^2 of 0.808 and 0.728, respectively. Relationships between reflectance, pH, dissolved oxygen, and temperature are not

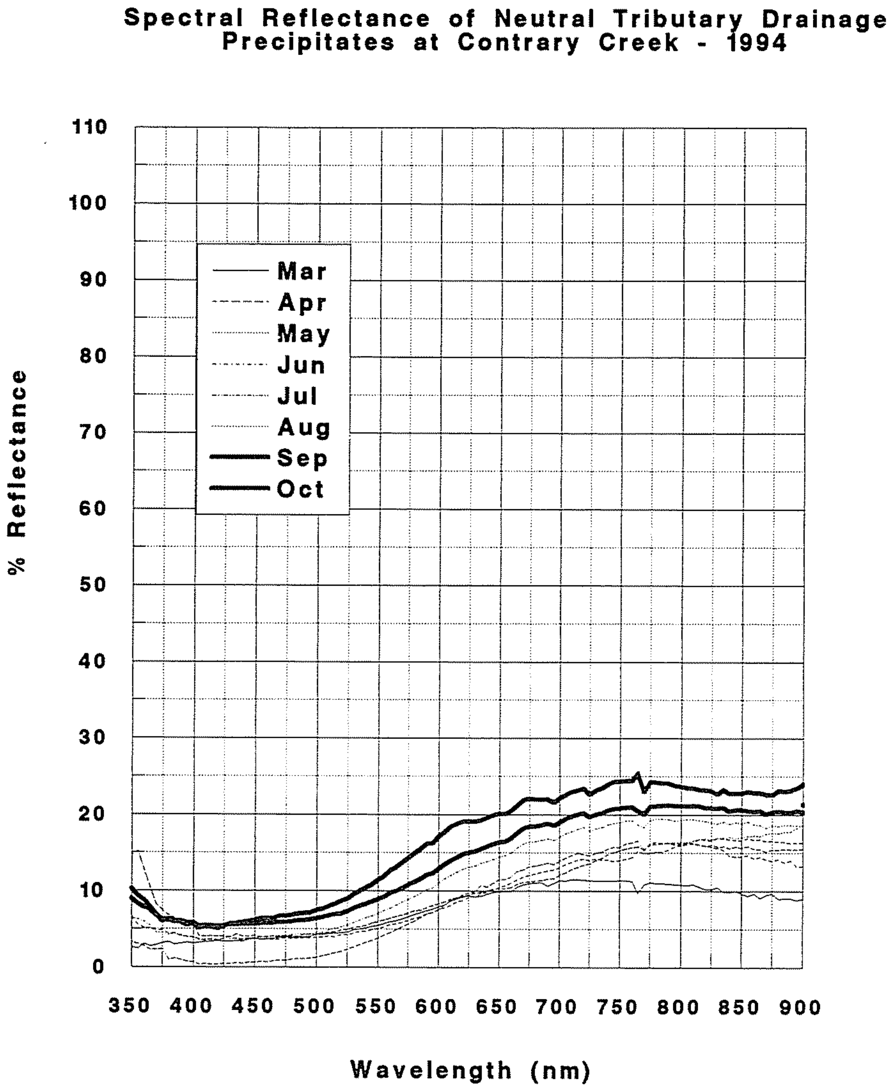

FIGURE 7. Spectral reflectance of neutral drainage precipitates from March to October 1994.

evident with r^2 values well under 0.40. The regression results suggest that specific conductivity levels may be predicted based upon reflectance values. Wetzel (1983) describes specific conductance as a parameter in determining water purity. Typically, as a function of ionic content, the lower the conductance, the purer the water.

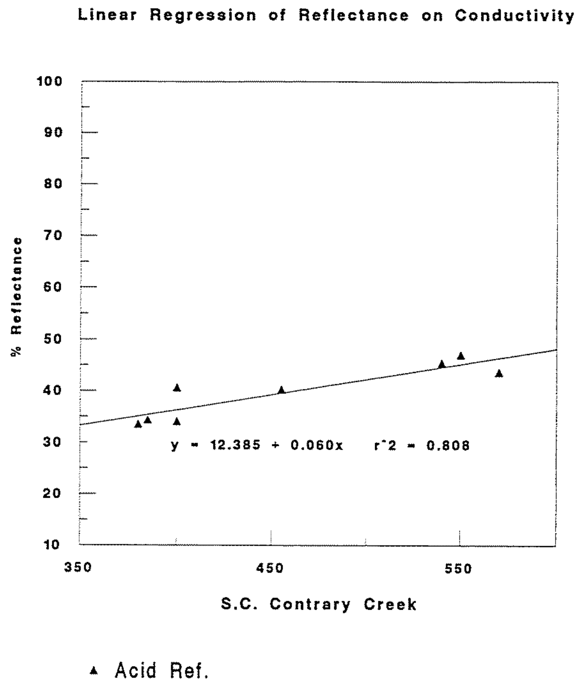

FIGURE 8. Linear regression of acid precipitate reflectance on specific conductivity.

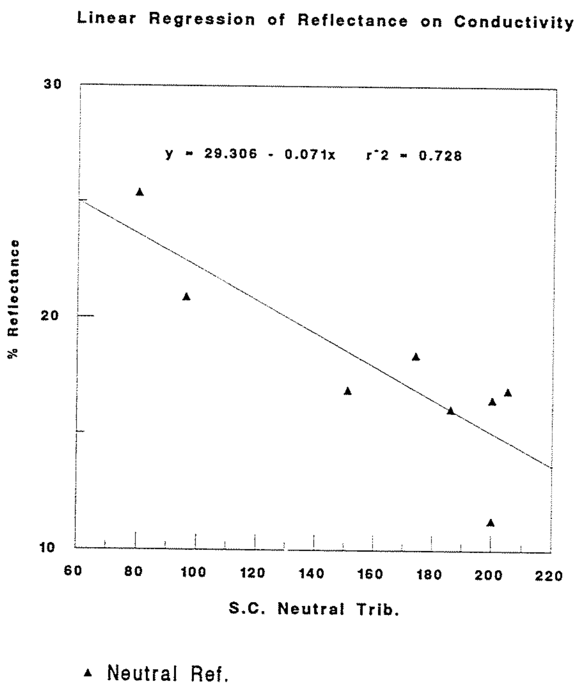

FIGURE 9. Linear regression of neutral precipitate reflectance on specific conductivity.

DISCUSSION

The microbial communities and their associated precipitates in the acid stream and neutral tributary were spectrally distinct and different. The orange-yellow precipitates, which had high reflectance values, were dominated by colorless rods typical of the acid-producing thiobacilli. The stream reach in which these measurements were collected was void of invertebrates and fish due to the consistently high acid conditions of the water. The reddish precipitates in the neutral tributary were characterized by very low reflectance values and had the usual consortium of iron depositing bacteria . This neutral tributary also was colonized by fly larva (Dixidae) and aquatic worms (Oligochaeta).

The disparity of acid- and neutral-precipitate seasonal spectral reflectance and its association with specific conductivity suggests that passive spectroradiometry has the capacity for evaluating acid and neutral drainages where the colors of these precipitates become confusing. Furthermore, it should be possible to predict both bacterial communities and conductivity levels based upon the spectral reflectance response of the precipitates.

Although more research and analysis is required to evaluate longer spatial and temporal influences on the spectral reflectance signatures of acid mine and neutral drainage precipitates, this investigation demonstrates that certain properties do exist and are associated with different water qualities. In watersheds where acid mine drainage is a problem, the spectral characteristics of these precipitates may be used to evaluate water quality using remote sensing.

LITERATURE CITED

Alexander, S.S., J. Dein, D.P. Gold. 1973. The Use of ERTs-1 MSS Data for Mapping Strip Mines and Acid Mine Drainage in Pennsylvania. Symposium on Significant Results Obtained from the Earth Resources Technology Satelite 1, Vol. 1 Technical Presentations, Section A. S.C. Freden and E.P. Mercanti (Eds.) NASA, Washington, D.C. pp. 569-575.

Carboni, S. and A. Moreau. 1990. Valuation of Landsat-TM Data in the Identification of Mine Tailings Zones: A Case Study Taken From the Rouyin-Noranda Area, Quebec, Canada. In Proceedings of the Twenty-third International Symposium on Remote Sensing of Environment, Vol. II. pp. 739-746.

Chapelle, F.H. 1993. Ground-water Microbiology and Geochemistry: New York, Wiley, 424p.

Chukhrov, F.V., B.B. Zvyagin, A.I. Gorshkov, L.P. Yermilova, and V.V. Balashova. 1973. Ferrihydrite: International Geology Reviews, Vol. 16, pp. 1131-1143.

Dierberg, F.E. and N.E. Carriker. 1994. Field testing two instruments for remotely sensing water quality in the Tennessee Valley: Environmental Science and Technology, 28:1, pp. 16-24.

Ehrlich, H.L. 1990. Geomicrobiology, 2nd Ed.: New York, Marcel Dekker, 646 p.

Ferris, F.G., K. Tazaki, and W.S. Fyfe. 1989. Iron oxides in acid mine drainage environments and their association with bacteria: Chemical Geology, Vol. 74, pp. 321-330.

Ghiorse, W.C. 1984. Bacterial transformations of manganese in wetland environments, in M.J. Klug and C.A. Reddy (Eds.) Current Perspectives in Microbial Ecology. American Society of Microbiology, Washington, D.C., pp. 625-632.

Lackey, J.B. 1938. The Flora and Fauna of Surface Waters Polluted by Acid Mine Drainage. United States Public Health Reports, Vol.53 No. 34, pp.1499-1506.

Poole, J.L. 1973. Iron sulfide mines in Virginia: Virginia Minerals, v. 19, no. 3, pp. 29-33.

Robbins, E.I. 1994. U.S. Geological Survey Personal Communication.

Satterwhite, M.B. and J.P. Henley. 1990. Hyperspectral Signatures (400 to 2500 nm) of Vegetation, Minerals, Soils, Rocks, and Cultural Features: Laboratory and Field Measurements. U.S. Army Corps of Engineers Engineer Topographic Laboratories Report ETL-0573, pp. 21-24.

Singer, R.C., and W. Stumm. 1970. Acid mine drainage: The rate-determining step: Science, Vol. 167, pp. 1121-1123.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry. Second Edition. W.H. Freeman and Company, New York. 859p.

U.S. Bureau of Mines, Proceedings of the International Land Reclamation and Mine Drainage Conference and 3rd International Conference on the Abatement of Acidic Drainage:U.S. Bur. Mines Spec. Pub. SP 06D-94, (1994), Vol. 1, 440 p.; Vol. 2, 433 p.; Vol. 3, 353 p.; Vol. 4, 422 p.

Wetzel, R.G. 1983. Lymnology. Second Edition. Saunders College Publishing, New York. 767p.

Wilkes, G.P. 1988. Mining history of the Richmond coalfield of Virginia: Virginia Division of Mineral Resources, Publication 85, p. 51.