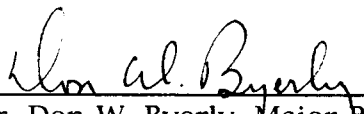
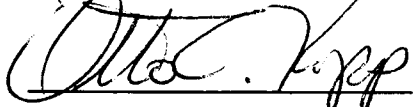
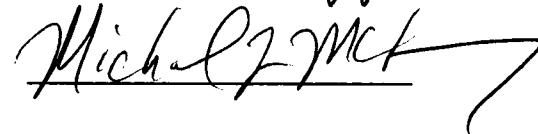


To the Graduate Council:

I am submitting herewith a thesis written by Anthony Robinson Tingle entitled "A Geochemical Assessment of Highway Construction Through Sulfidic Rock." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.


Dr. Don W. Byerly, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:


Associate Vice Chancellor
and Dean of The Graduate School

A GEOCHEMICAL ASSESSMENT OF HIGHWAY CONSTRUCTION
THROUGH SULFIDIC ROCKS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Anthony Robinson Tingle

May, 1995

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ABSTRACT

This research attempted to evaluate the impact of highway construction through sulfidic rock on the water chemistry of streams draining the construction site. The Tellico Plains to Robbinsville Scenic Highway crosses the mountains between Tellico Plains, Tennessee and Robbinsville, North Carolina encountering the sulfide mineral bearing rocks of the Late Precambrian Ocoee Supergroup. Portions of the highway were built prior to widespread knowledge of the adverse environmental impacts associated with road construction in sulfidic rocks. As a result, streams draining these sections of highway suffered the effects of Acid Drainage (AD). Since that time, road construction practices have improved and construction methods were developed to abate AD created by highway construction. This study evaluates the effectiveness of these construction methods at maintaining favorable water quality.

This investigation is divided into three parts: 1) Surface water chemistry was investigated in both streams draining watersheds containing the highway and streams with no possible influence from the road. 2) A geologic investigation was performed (mapping and collection and analysis of rock samples) to provide better understanding of the geologic contribution to water chemistry. and 3) Mineral coatings on outcrops and in streams, a possible indicator of AD conditions, were sampled and identified to provide information on possible AD sources and the chemical processes occurring near them.

Although the Tellico Plains to Robbinsville Scenic Highway is constructed through bedrock which exhibits locally abundant sulfide

mineralization, data collected during this study indicates that AD-abating methodology applied during road construction has been effective at minimizing adverse chemical alterations to the surface water in the study area. For most parameters measured statistical analysis of the water chemistry data indicates that there is no difference between streams draining watersheds containing the highway and streams not associated with the road. Widespread geologic influences on the water chemistry are not observed in the study area. Although mineral coatings characteristic of AD conditions are found, their extent is limited to sulfide mineral-bearing outcrops with abundant water. With the exception of one stream sample point, mineral coatings are absent from the stream sample points used in this study. In conclusion, data collected for this study indicates that the Tellico Plains to Robbinsville Scenic Highway does not adversely impact surface water draining the construction site.

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CHAPTER 1

INTRODUCTION

Background

This study compares the water quality between a watershed influenced by road construction and an undisturbed watershed. The comparison is intended to evaluate the effectiveness of measures taken in the construction of the Tellico Plains to Robbinsville Scenic Highway to abate the generation and release of Acid Drainage (AD). The water chemistry data combined with geologic mapping and petrographic and X-ray fluorescence analysis of lithologic samples are used to assess the relationship between the water quality and bedrock geology. Mineral coatings collected from outcrops and stream cobbles are also analyzed and discussed.

Statement of Problem

State Highway 165 transects rocks of the Late Precambrian Great Smoky Group of the Ocoee Supergroup as it crosses the mountains between Tellico Plains, Tennessee and Robbinsville, North Carolina (Figure 1-1). It was recognized early in the planning stages of the North Carolina segments of this highway, that road construction in this pristine setting could result in undesirable effects on the environment. The U.S. Forest Service (USFS) and Federal Highway Administration (FHWA) performed an evaluation of four possible routes for the highway, choosing the one with the lowest environmental impact (Hatcher, 1971). One unanticipated factor was the abundance of sulfide minerals found within some of the individual lithologies

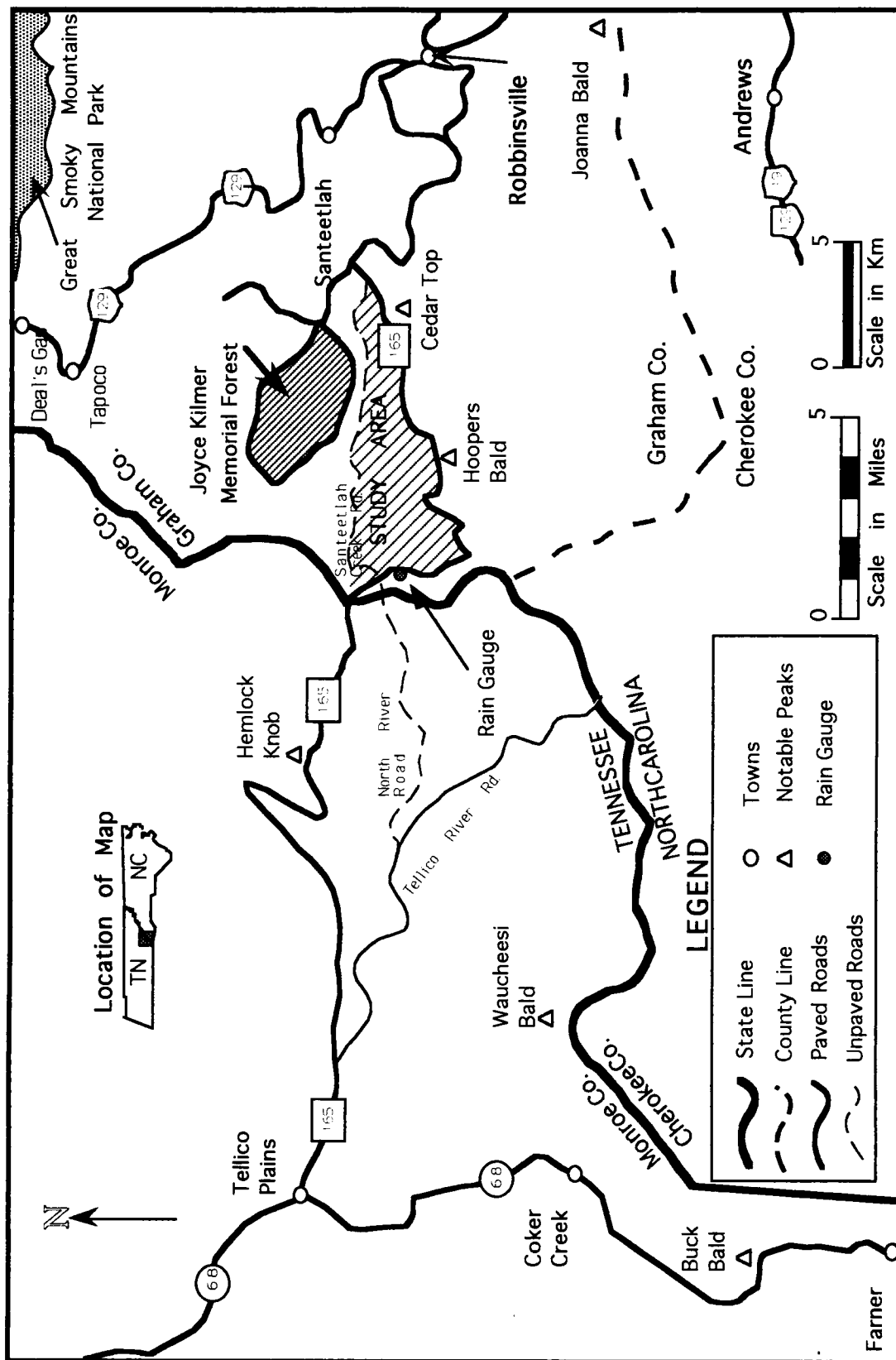


Figure 1-1. Location of Study Area.

of the Great Smoky Group, and the possible generation of AD. Exposure of these sulfide mineral-bearing rocks would create possible water quality problems regardless of which route was selected. Rocks of the Ocoee Supergroup, especially the Great Smoky Group, contain iron sulfide minerals in varying abundances with the most common species being pyrite and pyrrhotite (Carpenter, 1974).

Pyrite and pyrrhotite, among other sulfide minerals, are recognized as possible sources of AD when exposed to oxygenated water (Barton, 1978). Water flowing from man-made or natural sources of acidity and having pH values of 4.5 or lower is considered to be AD (Byerly, 1990). Acid drainage produced by the oxidation of sulfide minerals is characterized by high sulfate concentrations, low pH values, increased specific conductivity values, and elevated concentrations of dissolved metals (Huckabee and others, 1975; Barton, 1978; Sullivan and others, 1988; Herlithy and others, 1991; Hem, 1992). Highway construction through Great Smoky Group rock units containing significant quantities of pyrite and pyrrhotite or other sulfide minerals poses a potential problem. The exposure of rocks during construction facilitates the weathering process which can produce AD affecting water quality in streams draining the construction site. Acid drainage was generated by weathering and leaching of fills and cut slopes on certain segments of this highway in Tennessee, adversely impacting water quality of streams. (Morgan and others, 1978; Byerly, 1980). As a result, the FHWA has taken steps to ensure that current construction practices incorporate methods to avoid the generation of AD.

Byerly (1990) outlined steps for planning and construction of road projects in areas of sulfide mineralization. According to Byerly (1990), prior

to construction, the route of the road is evaluated with respect to the acid-producing nature of the rock units and this information is used in the planning and design of the roadway. If it is decided that acid-producing rock cannot be avoided and must be used in construction, the road fills are constructed in a manner to abate AD. A fill has been designed that incorporates a limestone blanket below the sulfidic rocks and agricultural lime mixed within the layers of fill material to provide alkalinity neutralizing acidity produced within the fills (Byerly, 1990). Underdrains and a tightly packed soil layer are used to facilitate drainage around the encapsulated sulfidic material and limit water and oxygen infiltration. A conceptual model of the fill design is shown in Figure 1-2.

Location and Study Area Description

Highway 165 will connect Tellico Plains, Tennessee to Robbinsville, North Carolina (Figure 1-1). The highway traverses mountains in the Blue Ridge Physiographic province in Monroe County, Tennessee and Graham County, North Carolina. Locally, the road is known as the Tellico Plains to Robbinsville Scenic Highway and is currently under construction in various stages of completeness ranging from finished highway to areas which are unconstructed with fully vegetated slopes. The route of the road within North Carolina follows a corridor along the ridgelines of several mountains. This route places road construction at or above the headwaters of several streams in the area.

The study area is bounded to the south by Highway 165 (both constructed and unconstructed segments) and Santeetlah Creek and the Santeetlah Creek Road to the north. The eastern and western boundaries are Santeetlah Gap and

Beech Gap, respectively (Figure 1-3). This study area, in general, is mountainous and is diversely forested. It is approximately 31 square kilometers (12 square miles) in area and exhibits greater than 900 meters (3000 feet) of relief. Commercial development within the study area includes Mud Gap Quarry, which provides road aggregate for construction and logging roads constructed for access to timber stands. The primary land uses for this area are recreation and logging. Sections of the study area are currently being harvested or have been harvested for timber.

Vegetation and Climate

Vegetation in the area is similar to that in the nearby Great Smoky Mountains National Park, an International Biospheric Reserve, which was characterized by Whittaker (1956) as a mix of deciduous and evergreen trees with an understory of shrubs and plants. Rhododendron and mountain laurel engulf many stream courses and some of the high points in the area are vegetated as grassy balds. A study of climate within the Great Smoky Mountains National Park showed increases in precipitation and decreases in temperature with elevation (Shanks, 1954). Shanks (1954), notes that the high elevation parts of the national park average 10-15° C. cooler than the low elevation valleys. Similar trends can be seen within this study area. For the period of July 1, 1989 to June 31, 1990, 170.40 centimeters (67.09 inches) of precipitation were recorded in the study area, at the Tennessee Valley Authority rain gauge located at Stratton Meadows (see Figure 1-1). The heaviest precipitation was recorded in February and March of 1990, when more than 25 centimeters (10 inches) of precipitation were recorded for each month.

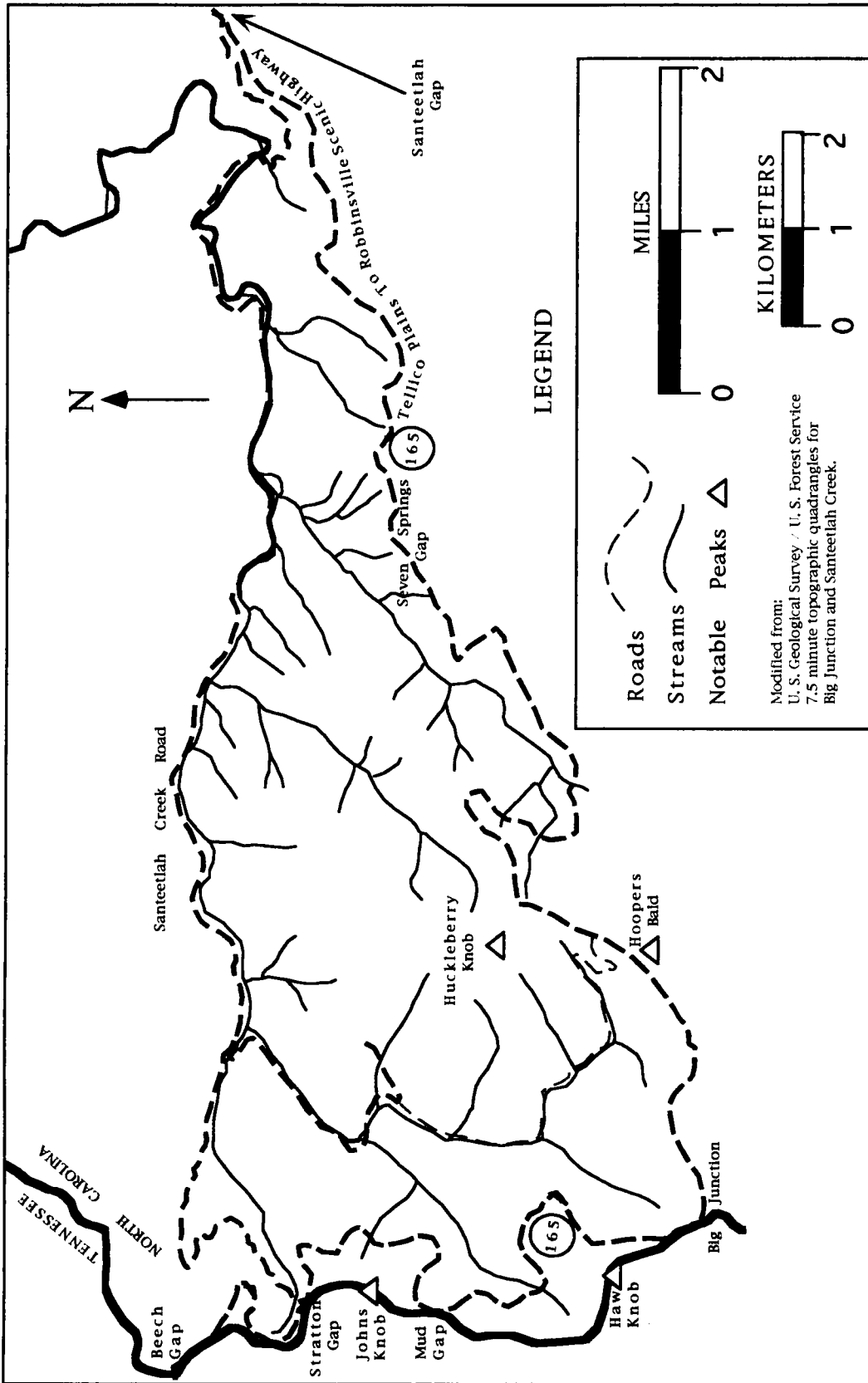


Figure 1-3. Detailed map of the study area.

General Geologic Setting

The Great Smoky Group, part of the Ocoee Supergroup, consists of a thick package of regionally metamorphosed terrigenous clastic rocks containing argillite, coarse-to fine-grained sandstone, graywacke, and conglomerate (Hadley and Goldsmith, 1963; King, 1964; Rast and Kohles, 1986) (Figure 1-4). As the Tellico Plains-Robbinsville road winds eastward toward North Carolina from Tennessee, it passes from lower grade metamorphic rocks to higher grade metamorphic rocks as is indicated by the appearance of metamorphic minerals (Carpenter, 1974) (Figure 1-4). The highest metamorphic grade (Barrovian Facies) observed in the field area is garnet grade. The first occurrence of pyrrhotite along the highway coincides with the pyrite/pyrrhotite metamorphic isograd as defined in the area by Carpenter (1974) (Figure 1-4).

Economic mineral deposits have been found within Great Smoky Group rocks close to the study area. To the north and east of the study area, along the boundary of the Great Smoky Mountains National Park, the inactive workings of the Hazel Creek and Fontana copper mines are found (Espenshade, 1963). To the south and west of the study area are the massive sulfide mines of the Ducktown district (Feiss and Slack, 1989). Although chalcopyrite is the dominant ore mineral in all three deposits, pyrrhotite and pyrite are the most abundant metallic sulfide minerals. Other deposits in the area include the gold deposits of the Coker Creek district located south and west of the study area (Hale, 1974).

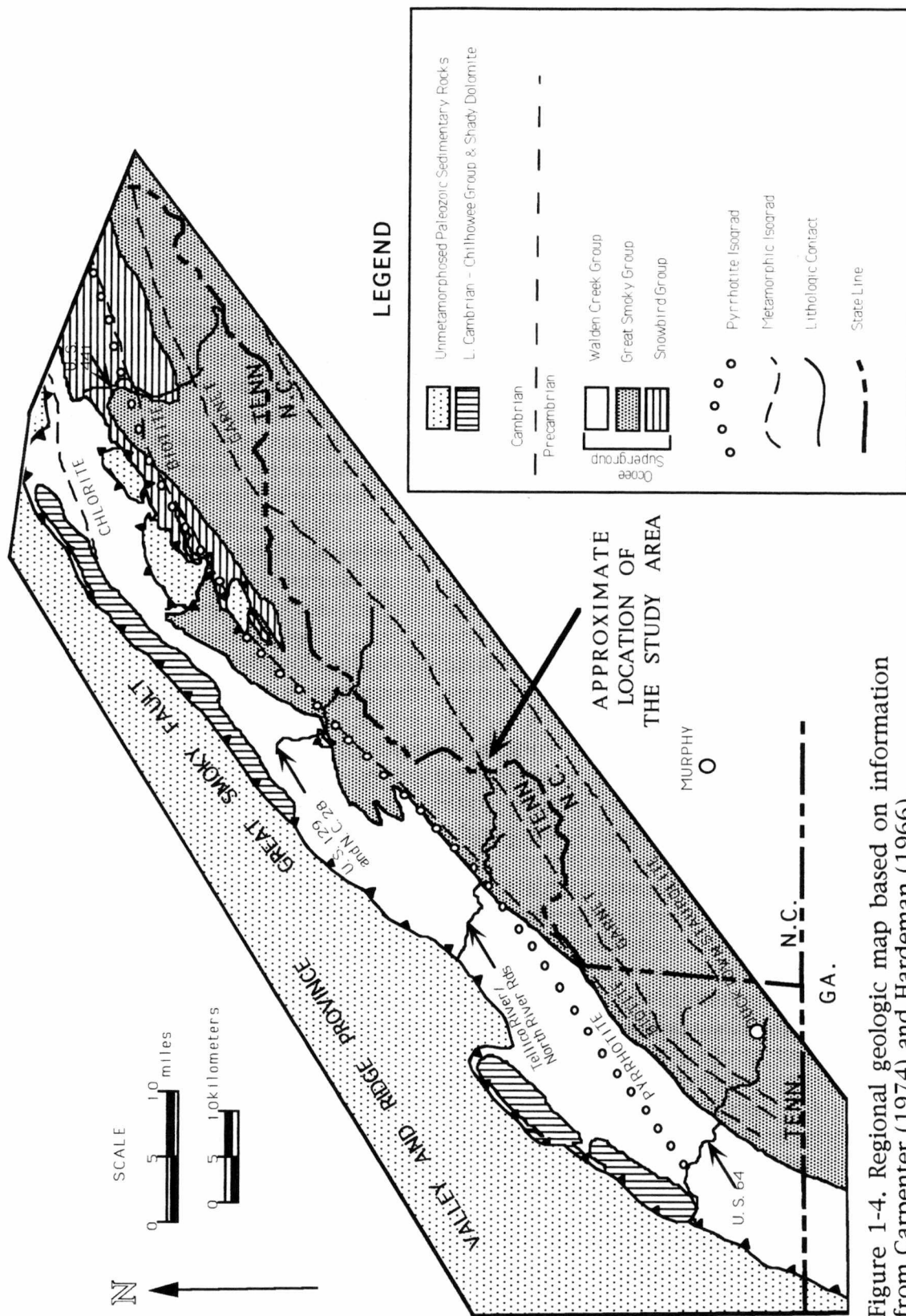


Figure 1-4. Regional geologic map based on information from Carpenter (1974) and Hardeman (1966).

Purpose of the Study

The purpose of this study is to determine and quantify the influence of construction of a segment of the Tellico Plains to Robbinsville Scenic Highway on the chemistry of streams near the construction site. This will be done by:

- Comparing water quality between streams draining the construction area and streams, within similar rock types, draining unaffected pristine watersheds.
- Visual and X-ray diffraction identification of mineral coatings found on outcrops and upon substrates in the ten streams selected for study.
- Geologic mapping to determine the spatial distribution of lithologic units.
- Visual (thin-section) and chemical (X-ray Fluorescence) study of the exposed lithologies to confirm the minerals responsible for acid production and identify the minerals which provide a naturally occurring source for alkalinity and contribute to the neutralization potential in the rock.

The study is intended to provide information on the sources of acidity, possible sources of alkalinity, secondary minerals formed, and distribution of rock types responsible for potential acid production. This information and the water chemistry data will be used to evaluate the effectiveness of measures taken to abate acid drainage from the highway construction site.

CHAPTER 2

GEOLOGY

Introduction

Geologic mapping was performed in the study area to determine the spatial distribution of rock types as they relate to their effects on the water chemistry. The distribution and composition of rocks underlying a watershed is a contributing factor on the chemistry of streams draining the watershed (Sillsbee and Larson, 1982; Winger and others, 1987; Herlithy and others, 1991; Kaufmann and others, 1991). Knowledge of the distribution and general mineralogy of rock types is necessary in determining any geologic influence on the chemistry of surface and groundwater. For this reason, this portion of the study will examine the mineralogy and distribution of the rock types found in the study area. The product of this examination is a geologic map (Plate 2-1), located in the pocket at the back of this thesis, and associated descriptions of the lithologic units.

Geologic Setting

The study area lies in the Blue Ridge province of western North Carolina adjacent to the Joyce Kilmer-Slickrock Wilderness Area in the Nantahala National Forest. Late Precambrian metasedimentary rocks of the Great Smoky Group of the Ocoee Supergroup underlie the region. Rocks of the Ocoee Supergroup have been studied by many workers. Among the earliest was Safford (1856, 1869) who noted and described the abundant slate and conglomeratic clastic rocks exposed along the gorge of the Ocoee and Tellico

ivers. In the Great Smoky Mountains National Park, King and others (1958) also described the stratigraphy of the Ocoee rocks and proposed that the Great Smoky Formations be raised to group status. Stratigraphically from lowest to highest the Great Smoky Group, as it is defined within the National Park, is comprised of the Elkmont Sandstone, Thunderhead Sandstone, and the Anakeesta Formation (King, 1964). A fourth unnamed unit is noted to exist in the Great Smoky Group, and lies stratigraphically above the Anakeesta Formation (King, 1964). The Elkmont and Thunderhead, which have thicknesses of approximately 2,750 and 3,050 meters (9,000 and 10,000 feet) respectively, are typically gray metamorphosed terrigenous clastic rocks. These units are composed of sandstone and graywacke containing varying amounts of quartz, feldspar, biotite, chlorite, sericite, garnet, and accessory minerals (King and others, 1958; King, 1964). The Thunderhead and Elkmont are similar at the contact between the units, but abundant blue quartz clasts in the Thunderhead, coarser texture, and thick bedded nature distinguish the Thunderhead from the Elkmont (King, 1964). The Anakeesta Formation overlies the Thunderhead Sandstone, is approximately 1,370 meters (4,500 feet) thick, and differs noticeably from both the Thunderhead and Elkmont Sandstones (King, 1964). According to King (1964) the intertonguing stratigraphic relationship between the Anakeesta Formation and the underlying Thunderhead Sandstone is complex. The Anakeesta Formation is dominated by metamorphosed silty and argillaceous rocks but contains minor amounts of graywacke and sandstone (King and others, 1958; King, 1964). Although present in all of the Great Smoky Group rocks, sulfide minerals (pyrite, pyrrhotite, chalcopyrite, and sphalerite) are locally abundant in the

Anakeesta Formation and provide the potential for environmental problems (King, 1964; Huckabee and others, 1975).

Sulfide mineralization of economic significance is present within Great Smoky Group rocks. Espenshade (1963) stated that chalcopyrite is the main ore mineral in the Hazel Creek and Fontana Copper mines, but hypogene pyrrhotite and sphalerite are also abundant. Similar mineral assemblages are found in the Ducktown mining district (Feiss and Slack, 1989).

Geological investigations located closer to the current study area and south of the national park include work by Lesure and others (1977) and Slack and others (1979). Lesure and others (1977) provided a mineralogical assessment with geologic map for the Joyce Kilmer-Slickrock Wilderness Area, which is located along strike immediately adjacent to the current study area. Although Lesure and others (1977) suggest that the rocks underlying the Joyce Kilmer-Slick Rock Wilderness Area are a continuation of the Great Smoky Group rocks exposed in the Great Smoky Mountains National Park, rocks within their study area are divided into 15 locally mappable units and are not directly correlated with the rocks described by King and others (1958) in the National Park. Similarly, Slack and others (1979) divided rocks exposed in the Citico Creek Wilderness Area into locally mappable units, but only suggest that these rocks are correlated with Great Smoky Group rock units in the vicinity of Ducktown, Tennessee as described by Hernon (1968). Although Lesure and others (1977) and Slack and others (1979) differ on the nomenclature for correlating rock units from previously mapped areas (units defined within the Great Smoky Mountains National Park versus units defined in the vicinity of Ducktown Tennessee) to rock units mapped in their respective study areas, both recognize the underlying lithologies in their studies as metamorphosed

sandstone, graywacke, and argillite of the Great Smoky Group. Wiener and Merschat (1992) present a geologic map on a regional scale which places rocks in the study area within the Copperhill Formation of Hurst (1955) and Hurst and Schlee (1962). In this map, Wiener and Merschat (1992) attempted a regional correlation of Great Smoky Group rocks. This correlation is provided in Figure 2-1. Although differences exist in the assignment of individual formation names, all workers agree that rocks underlying the current study area are part of the Great Smoky Group.

Topographic Relief

The study area ranges in elevation from approximately 670 meters (2,200 feet) to greater than 1,670 meters (5,500 feet). North facing slopes are often quite steep and covered in large blocks of metasandstone. Across the study area quaternary colluvium consisting of metasandstone and metagraywacke blocks obscures the upper reaches of many of the drainages. These concentrations of blocks combined with heavy vegetation obscure the bedrock and render sections of the field area inaccessible.

Lithologic Units Defined in this Study

Three lithologic units are defined in the study area. These will be referred to as Units I, II, and III respectively with Unit III being the youngest (stratigraphically highest) (Figure 2-2). No estimated thickness is proposed for units I and III because the complete sections of the units were not exposed in the study area. Although a complete section of unit II was not measured, it is bounded by Units I and III and is estimated to be 30 to 100 meters thick based on mapped exposures. Each of the units will be described below.

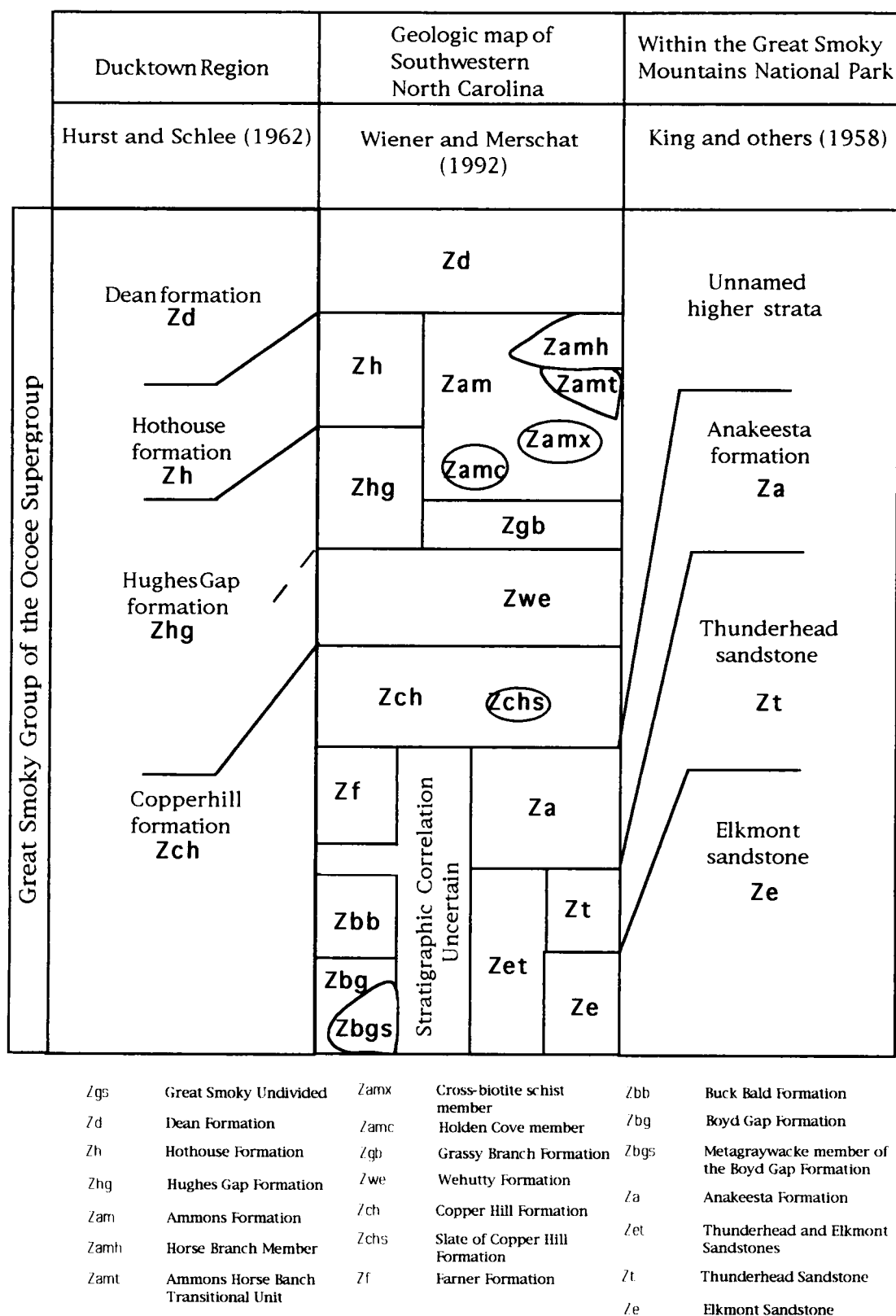


Figure 2-1. Stratigraphic correlations for the Great Smoky Group.

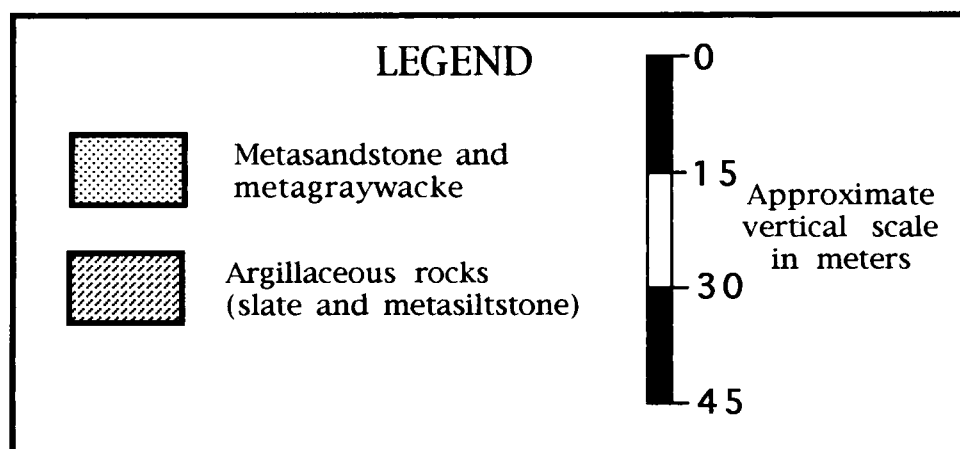
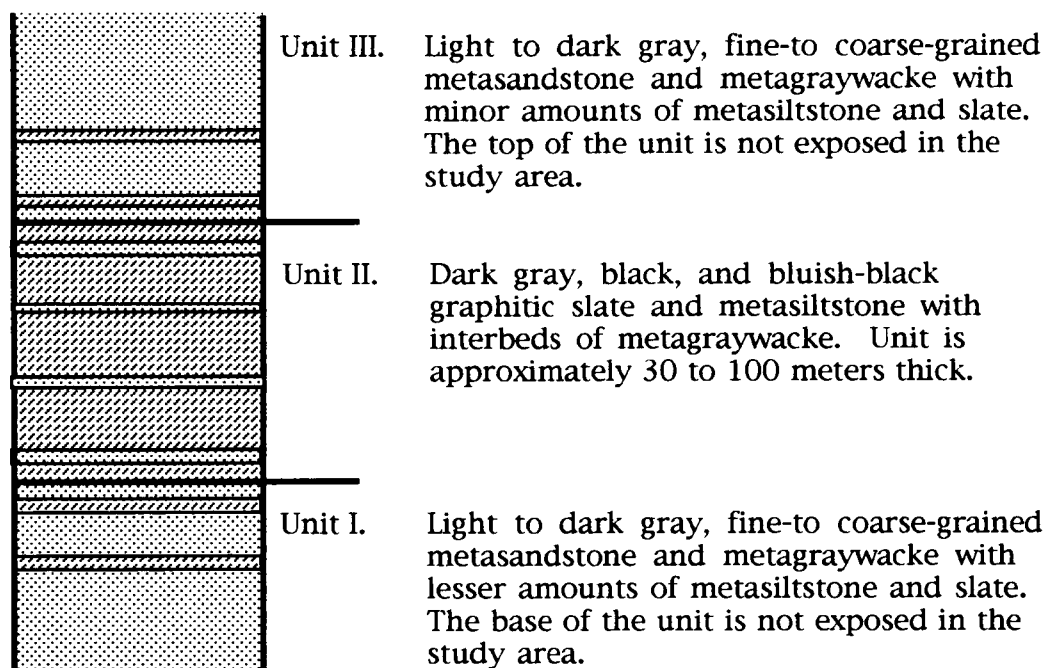
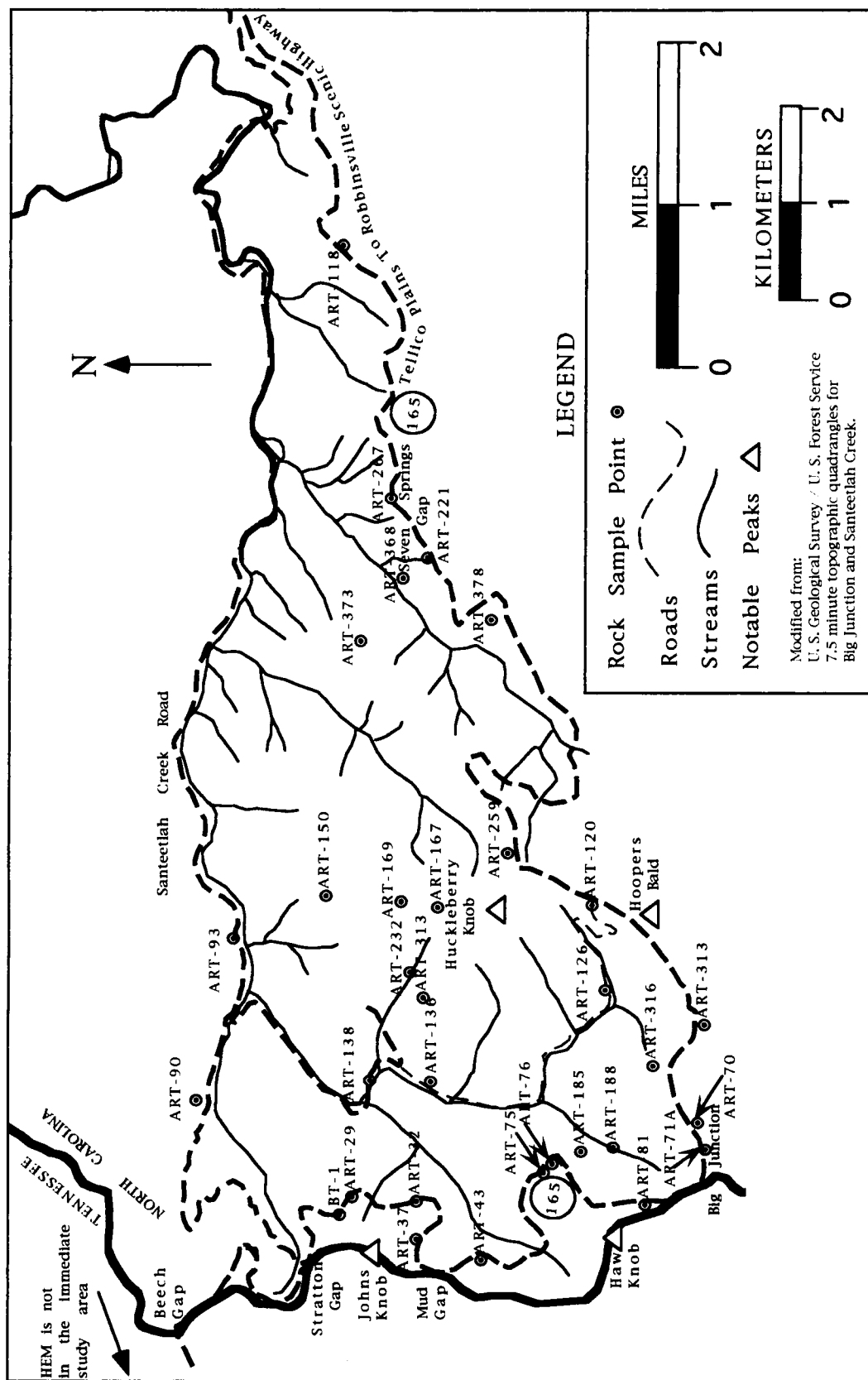


Figure 2-2. Generalized stratigraphic section for the lithologies exposed in the study area.

Rock samples were analyzed by X-ray fluorescence to determine the elemental composition of rocks in the study area. Figure 2-3 shows the locations from which these samples were collected. The data from the analyses is included in the appendix (Table A-1). This information is discussed in more detail the next chapter.

Unit I, the stratigraphically lowest unit exposed in the field area, is dominated by fine-to coarse-grained metamorphosed graywacke and sandstone with lesser amounts of argillite. The graywacke is metamorphosed to biotite and garnet grade as indicated by the assemblage of biotite, chlorite, and garnet. Feldspar, both alkali and plagioclase, is a common detrital constituent in these rocks. Plate 2-2 illustrates the mineral assemblage and textures of a typical metagraywacke from unit I. Although not common, interbeds of coarse-grained, blue and white quartz pebble conglomerate are found in this unit. Bedding (compositional banding) varies from less than one meter to greater than ten meters in thickness, but where outcrops are massive, bedding is indistinguishable. Some outcrops exhibit spherical concretions which appear darker in color and weather differentially with respect to the encompassing graywacke or sandstone. Differential weathering results from higher amounts of carbonate cement in these concretions (King, 1964). Some concretions reveal argillite chips at their centers that may have served as nuclei during the formation of the concretions (Plate 2-3). King (1965) notes similar concretions within the Thunderhead Sandstone of the Great Smoky Mountains National Park. Unit I also contains pods, lenses, and beds of a lithotype referred to as pseudodiorite (Emmons and Laney, 1926). Pseudodiorite is a light-colored rock exhibiting a granoblastic texture that is composed of quartz, plagioclase feldspar and porphyroblasts of poikilitic



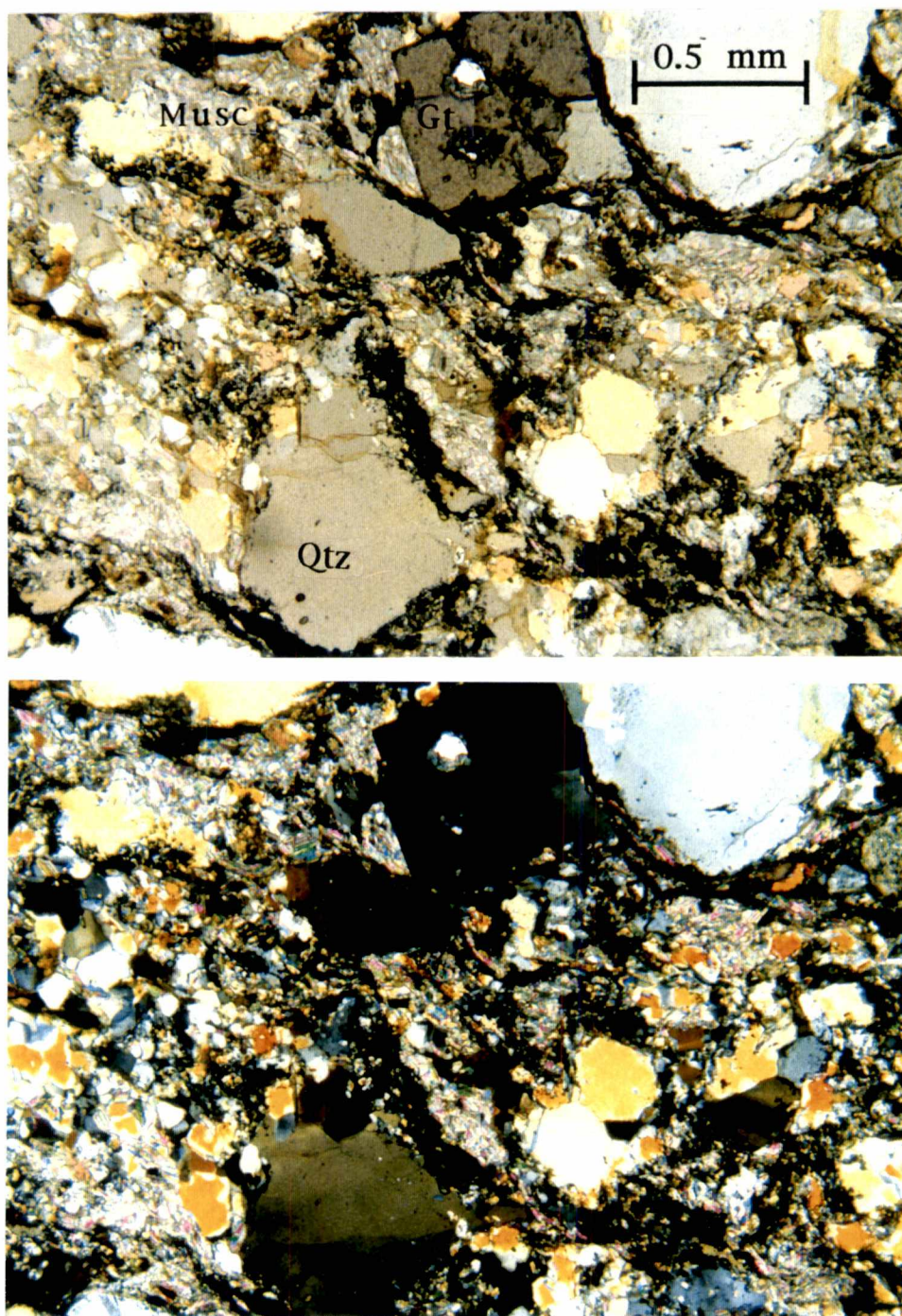


Plate 2-2. Photomicrographs of a typical Unit I metagraywacke. Upper view in plane polarized light and lower view with crossed nichols. Musc = muscovite, Gt = garnet, and Qtz = quartz.



Plate 2-3. Photograph of a spherical concretion within a Unit I metasandstone. Note the metashale chip at the center of the concretion and the hammer for scale.

garnet and amphibole (Plate 2-4). Minor constituents of the pseudodiorite include biotite, muscovite, and epidote. The presence of detrital quartz grains within the garnets and hornblende suggest a sedimentary protolith for the pseudodiorite. Hadley and Goldsmith (1963) note the occurrence of pseudodiorite in both the Anakeesta Formation and the Thunderhead Sandstone in the Great Smoky Mountains National Park. Hernon (1968) documents the occurrence of pseudodiorite in the Copperhill, Hughes Gap, Hothouse, and Dean formations near Ducktown Tennessee. The lower extent of Unit I is not exposed within the study area and the contact between Unit I and Unit II is gradational and sometimes obscure. The contact between the units is drawn at the base of the occurrence of abundant argillaceous rocks. In the field the contact between Unit I and Unit II was marked at the first occurrence of common argillaceous lithologies.

Unit II is dominated by argillaceous rocks. This unit is composed of dark gray, black, and bluish black argillite (metashale) and metasiltstone with lesser amounts of interbedded metagraywacke and metasandstone. Pods of amphibolite, generally less than 2 meters in length, are located within Unit II, but are discontinuous and poorly exposed. The poikilitic texture in these amphibolites, which is accentuated by calcite crystals, suggests a sedimentary origin for these rocks, similar to the pseudodiorite (Plate 2-5). The argillaceous rocks are primarily composed of chlorite, muscovite, biotite, garnet, and quartz (Plate 2-6). Pyrite and pyrrhotite are locally common sulfide minerals, which, upon weathering, color outcrops in shades of red, orange, or yellow. Pyrite and pyrrhotite coexist in these rocks, which have been subjected to metamorphism above the pyrrhotite isograd defined by Carpenter (1974). Merschat and Hale (1983) suggest that pyrite not consumed

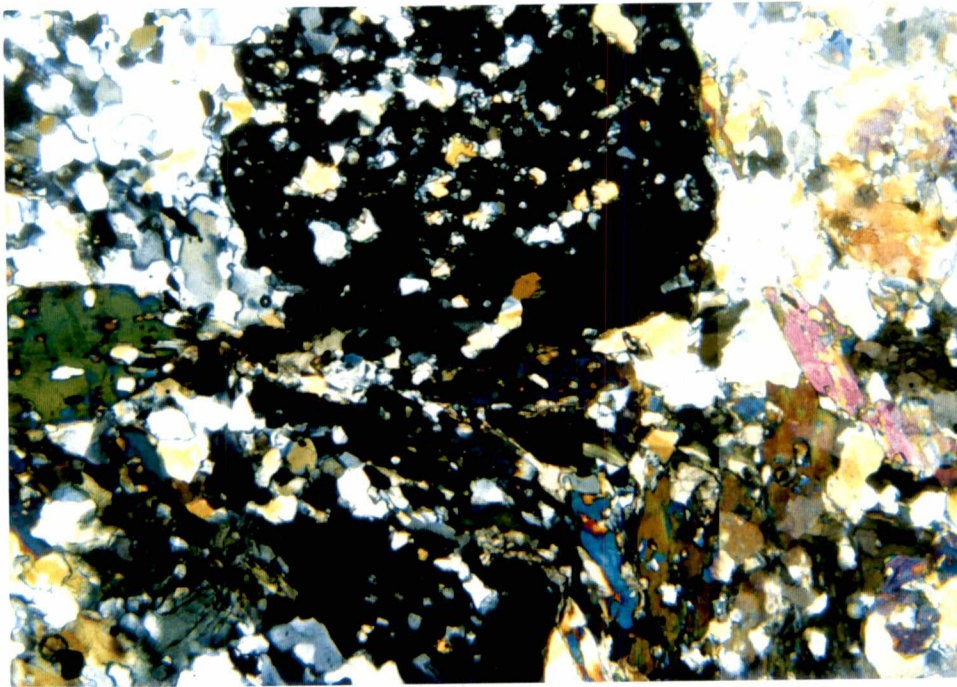
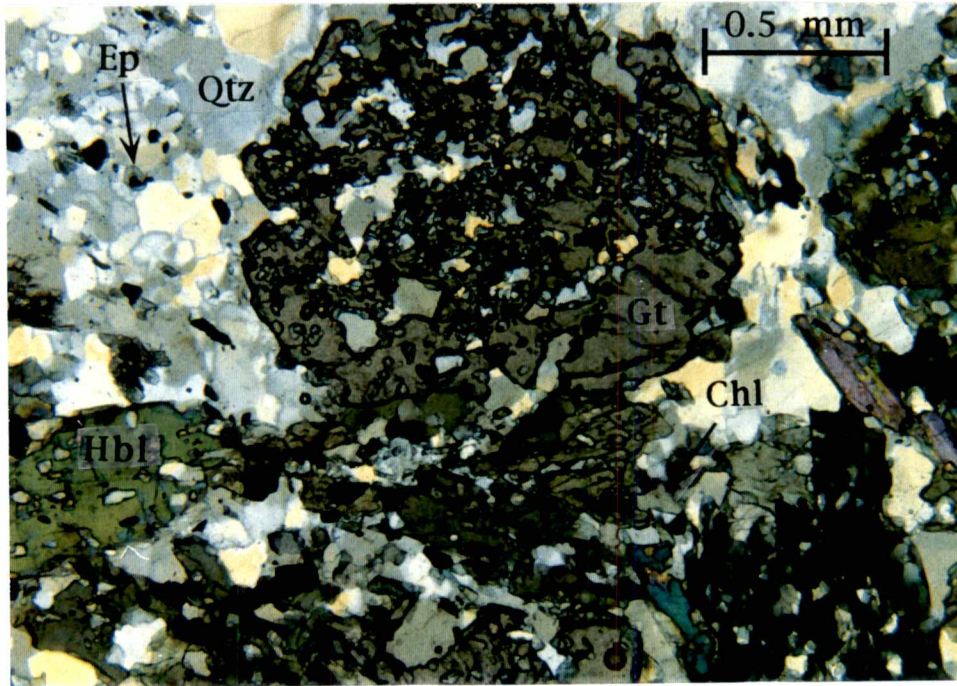


Plate 2-4. Photomicrographs of pseudodiorite from Unit I. Upper view in plane polarized light and lower view with crossed nichols. Ep = epidote, Gt = garnet, Qtz = quartz, Hbl = hornblende, and Chl = chlorite.

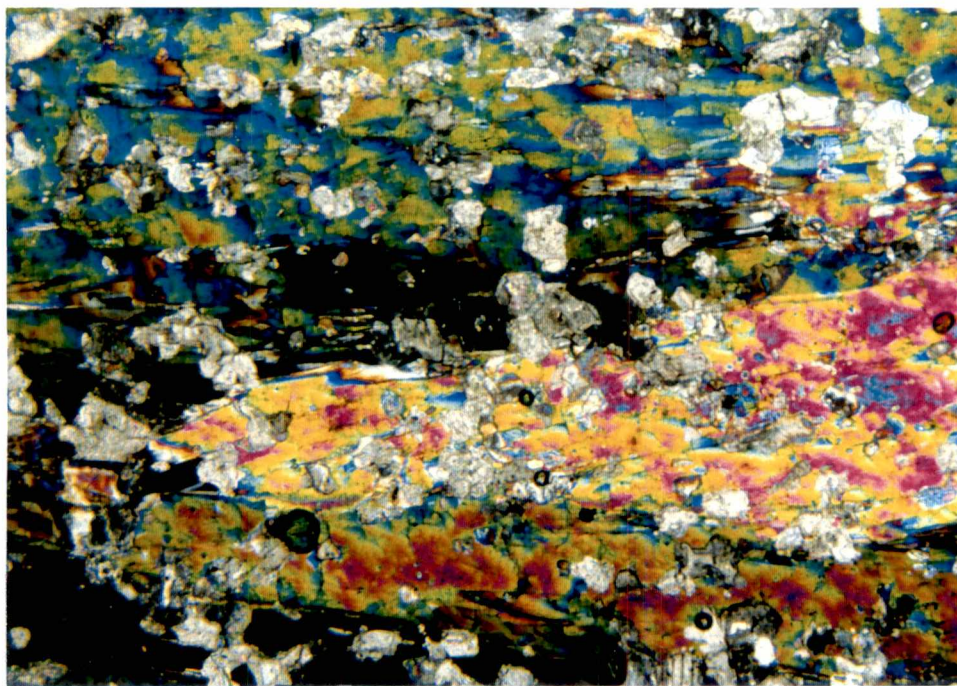
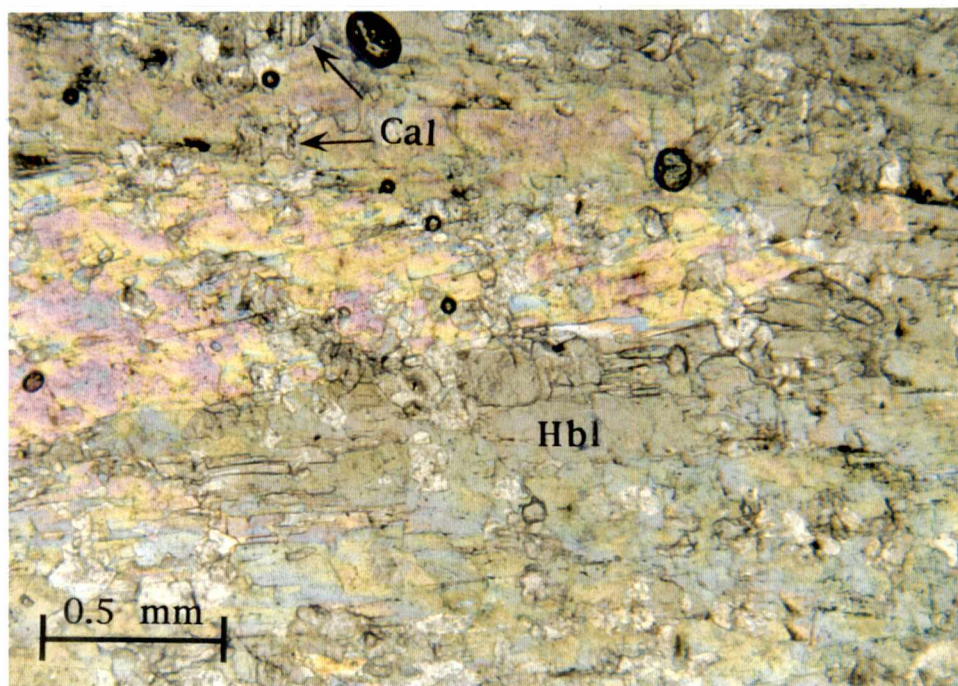


Plate 2-5. Photomicrographs of amphibolite from Unit II. Upper view in plane polarized light and lower view with crossed nichols. Cal = calcite and Hbl = hornblende.

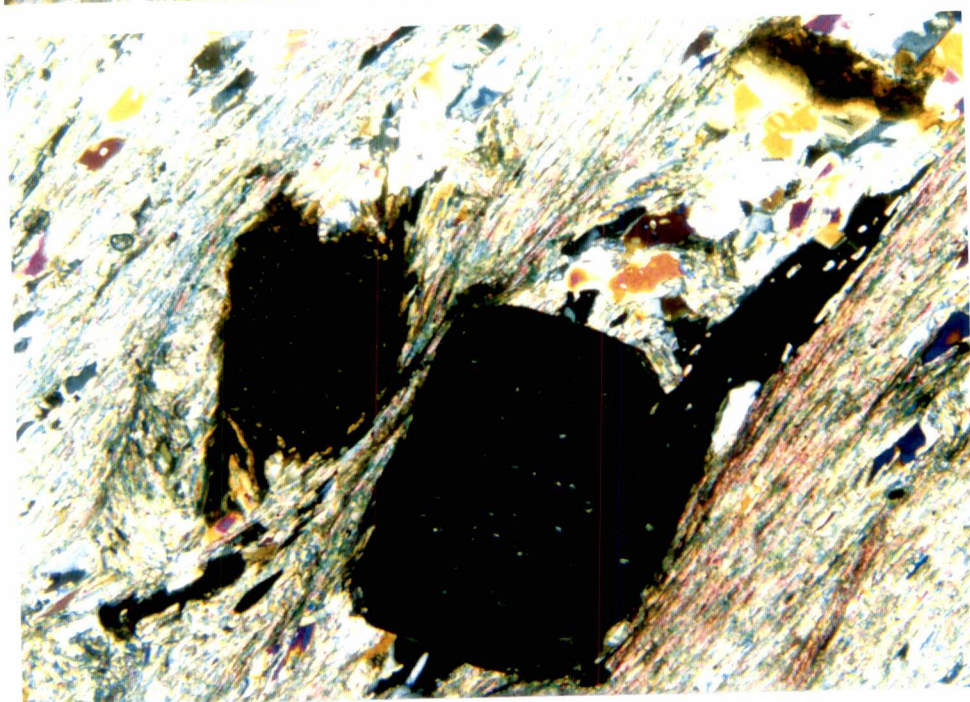
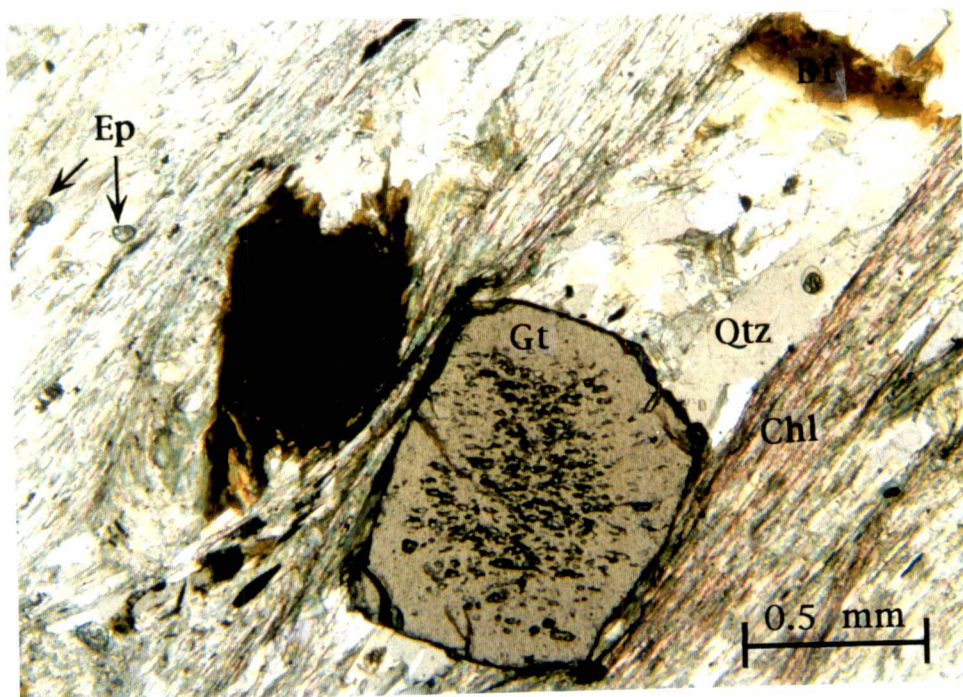


Plate 2-6. Photomicrographs of a Unit II argillaceous rock. Upper view in plane polarized light and lower view with crossed nichols. Bt = biotite, Gt = garnet, Qtz = quartz, Ep = epidote, and Chl = chlorite.

in the pyrite to pyrrhotite transition persists due to lithologic controls. They suggest that pyrite in the more impermeable slate was preserved while pyrite in neighboring porous metagraywacke was transformed to pyrrhotite. At some localities in the current study area similar observations are made. Plate 2-7 shows disseminated sulfide minerals within coarser-grained metagraywackes of Units I and III. In the lower photo, note the replacement of pyrite by pyrrhotite as is indicated by embayment features.

Bedding is well preserved at many localities within this unit and can be discerned at centimeter scale. Slaty cleavage is common in the finer-grained lithologies and in zones of more intense deformation a well-developed crenulation cleavage is present. The transition between Unit II and Unit III is gradational and geologic contacts were mapped based on the last occurrence of abundant argillaceous rocks.

Unit III is very similar to Unit I. Unit III is composed of fine- to coarse-grained metasandstone and metagraywacke with occasional slaty interbeds. The mineral assemblage for this unit is the same as for Unit I. Plate 2-8 shows a metagraywacke from Unit III. Note the presence of both plagioclase and alkali feldspar (microcline) in this thin section. The rocks of Unit III range from light to dark gray and at some localities appear to have a salt and pepper coloring resulting from abundant biotite. Like Unit I, Unit III exhibits bedding ranges from less than one meter to greater than ten meters thick, contains abundant blue quartz, and exhibits spherical concretions with elevated carbonate content. Unit III appears to have a greater occurrence of quartz pebble conglomerate, but this observation is based on only a few outcrops. The upper limit of Unit III is not exposed in the study area.

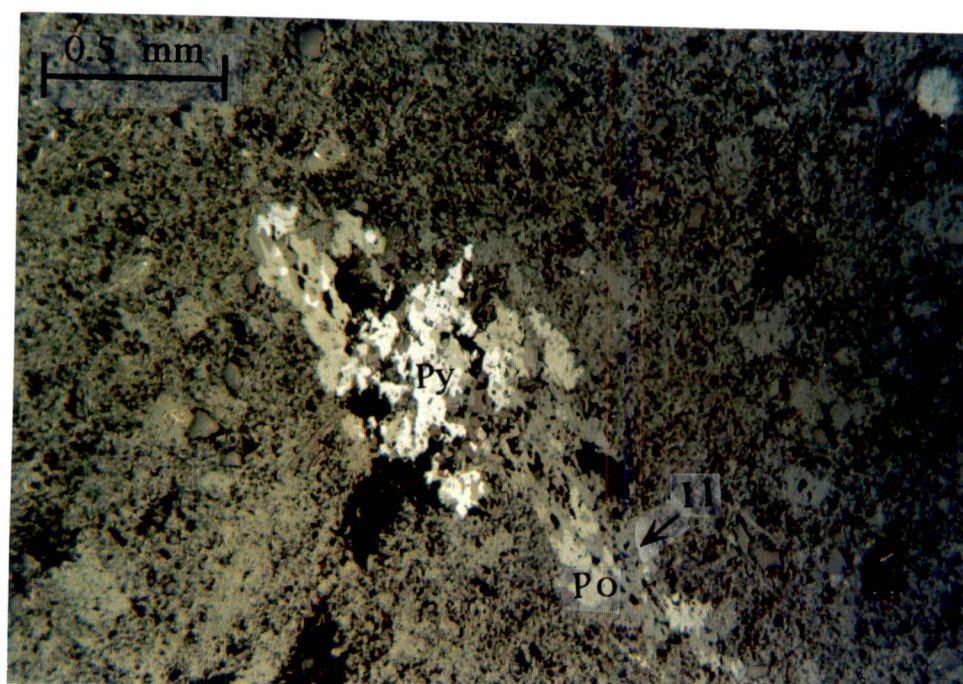
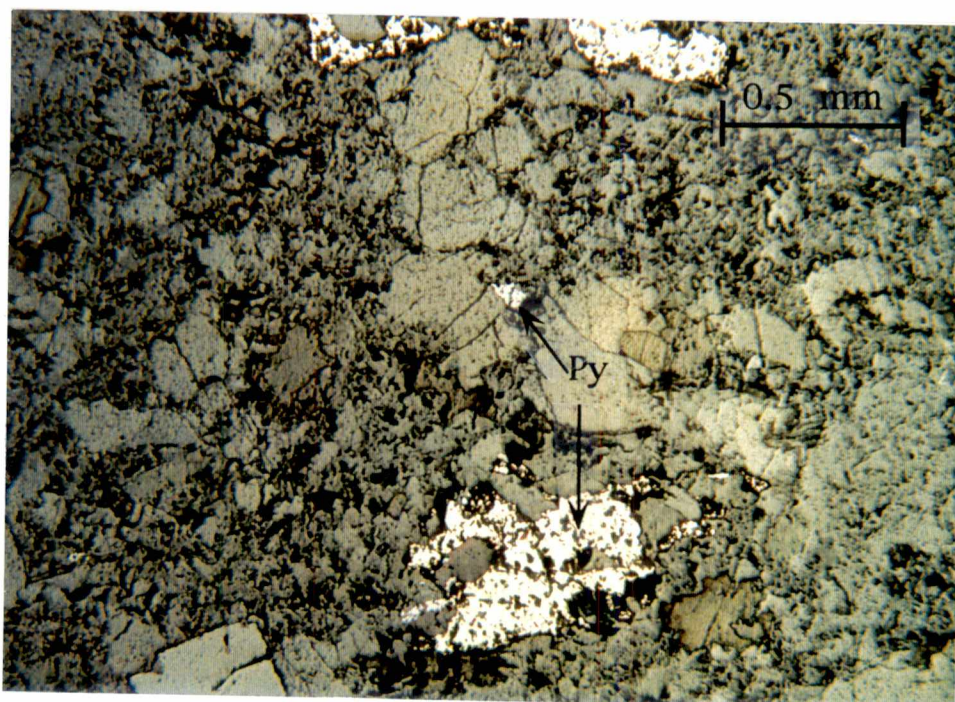


Plate 2-7. Photomicrographs of disseminated sulfides within Unit I (upper) and Unit III (lower) metagraywackes. Samples are shown in reflected plane polarized light. Py = pyrite, Po = pyrrhotite, and Il = Ilmenite.

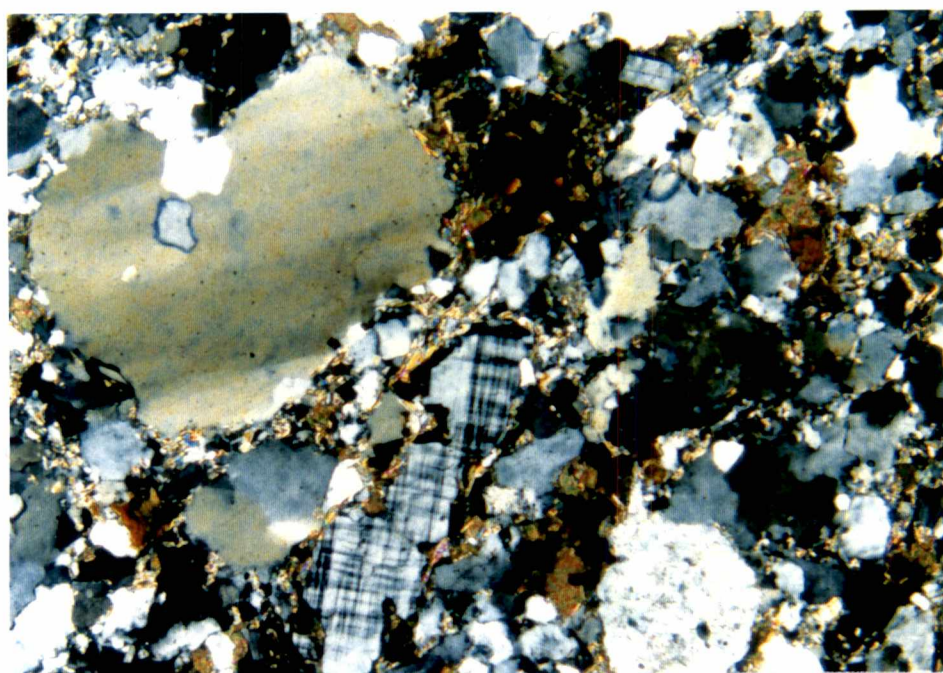
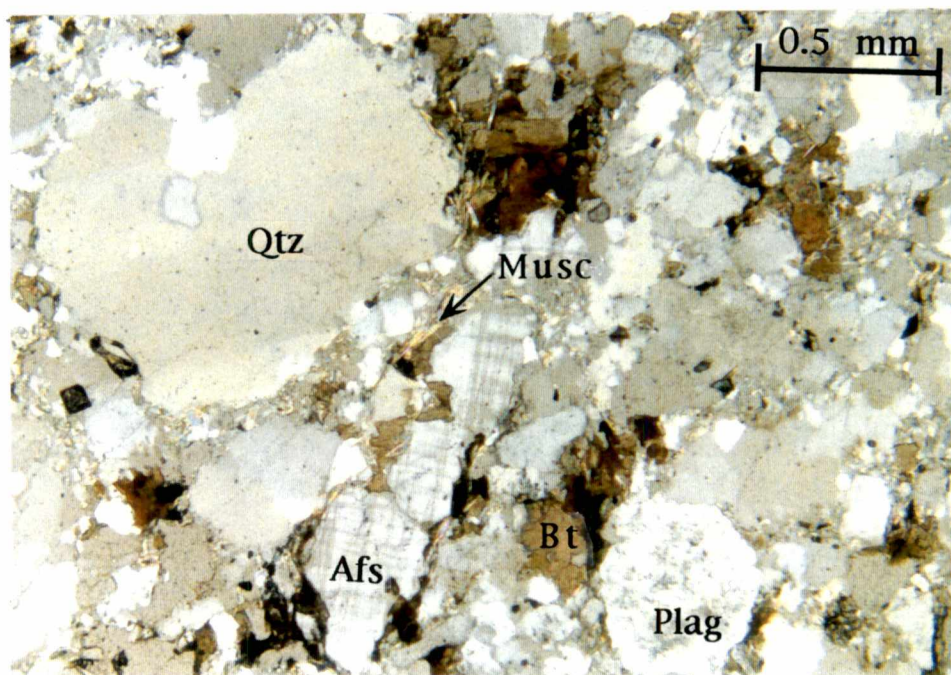


Plate 2-8. Photomicrographs of a Unit III metagraywacke. Upper view in plane polarized light and lower view with crossed nicols. Musc=muscovite, Bt=biotite, Afs=alkali feldspar (microcline), Plag=plagioclase, and Qtz=quartz.

Metamorphism

Rocks exposed in the field area have been subjected to at least three major compressional events (Bryant and Reed, 1970; Rast and Kohles, 1986). The isograd marking the transition from biotite to garnet metamorphic zones passes through the field area and is shown on Plate 2-1 (In pocket). Although the placement of the isograd was determined from only 4 thin sections, it agrees with the isograd location as determined by Lesure and others (1977) in the adjacent Joyce Kilmer-Slickrock Wilderness area and is similar to the isograd as determined by Carpenter (1970). The pyrrhotite isograd, defined in the area by Carpenter (1974) is located west of the boundary of the study area.

Structures

Sedimentary structures are abundant in the rocks exposed in the study area. Although the rocks have been metamorphosed from biotite to garnet grade, subtle sedimentary structures such as ripups, millimeter-scale cross-laminations, and graded bedding are preserved in many outcrops. These structures suggest the turbiditic nature of these rocks. (King, 1964 and Rast and Kohles, 1986).

Structures resulting from compressional deformation are present at all scales in this study. The most notable are the series of open folds which repeat the rock units across the map area. Smaller folds are observed within a single outcrops and even smaller folds can be seen only in thin-section (Plate 2-9). Slaty cleavage is well developed in the fine-grained lithologies and in zones of intense deformation (e. g. the areas around Big Junction and Seven Springs Gap) a well-developed crenulation cleavage is observed. No large scale faults were noted in the study area.

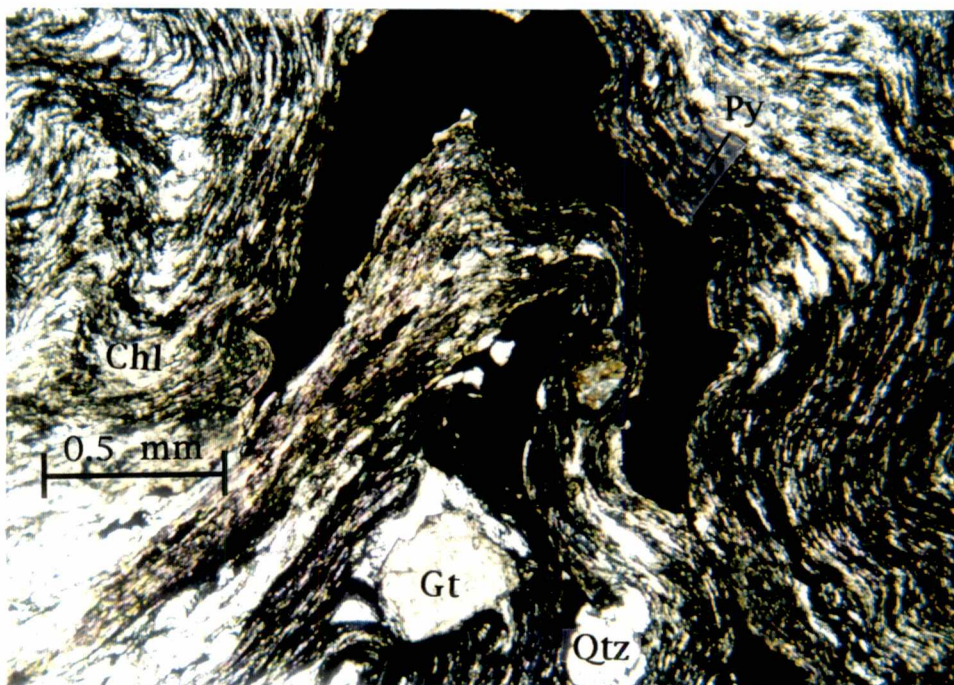
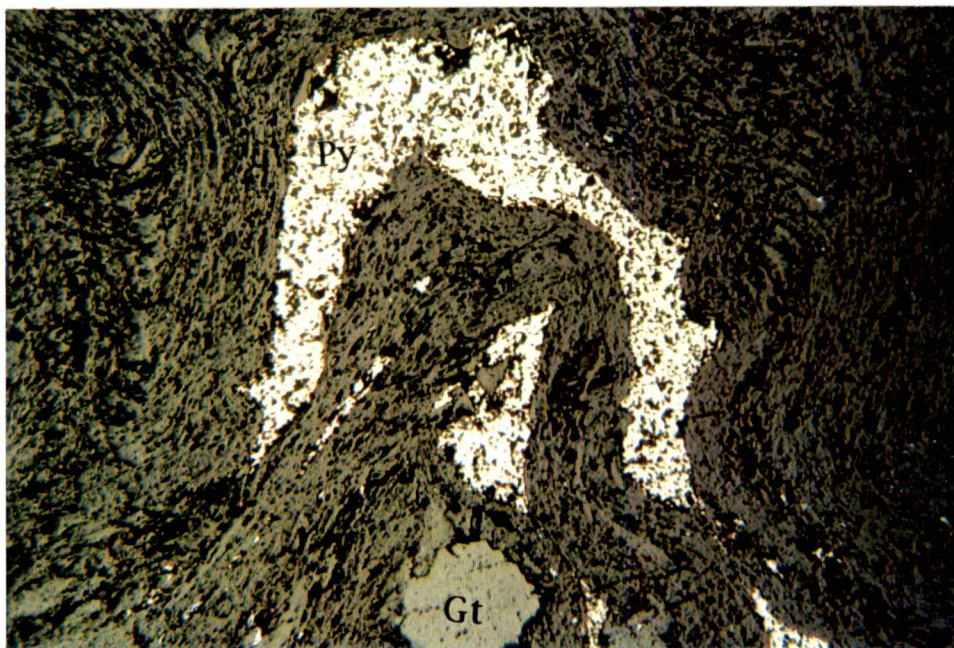


Plate 2-9. Reflected and transmitted light photomicrographs of pyrite in a Unit II argillaceous rock. Note the concentration of pyrite within the axis of the folds. Views in plane polarized light are provided. Py = pyrite, Chl = chlorite, Gt = garnet, and Qtz = quartz.

Conclusion

Rocks belonging to the Precambrian Great Smoky Group of the Ocoee Supergroup are exposed in the study area. The rocks form a package of terrigenous clastic lithologies, which have been regionally metamorphosed to biotite and garnet grade. The typical mineral assemblage for these rocks includes quartz, chlorite, plagioclase feldspar, alkali feldspar, garnet, amphibole (hornblende), biotite, muscovite, epidote, pyrrhotite, pyrite and lesser accessory minerals. Three mappable units are identified in this study and geologic mapping indicates that these units are repeated across the field area due to compressional deformation and folding (see Plate 2-1, in pocket). Although Unit II contains significant sulfide mineralization, the repetition of rock units and similarity between units I and III may decrease the obvious effects of geologic contributions on stream chemistry.

CHAPTER 3

WATER CHEMISTRY

Introduction

One purpose of this study was to monitor and evaluate the water chemistry of 10 streams. These streams drain watersheds underlain by rocks containing sulfide minerals which, upon exposure and weathering, have the potential to produce AD. The streams were monitored to determine if ongoing and past road construction along the Tellico Plains to Robbinsville Scenic Highway, Highway 165, produced conditions favorable for the generation of AD and have effected the quality of streams receiving drainage from the highway. Water quality monitoring for this project will determine if there is a measurable AD impact along one segment of the highway.

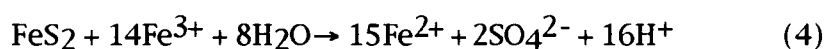
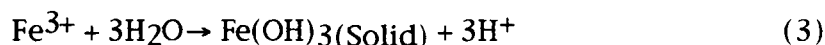
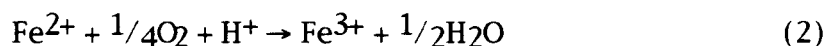
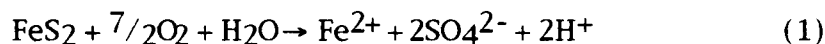
Background

Headwater streams in the southern Blue Ridge province are potentially sensitive to acidic inputs. Winger and others (1987) believed that these streams tend to lack acid-neutralizing capacity due to the low buffering contribution from geologic formations which underlie them. Although the study by Winger and others, (1987) was concerned with acidification of streams by atmospheric acid deposition, the sensitivity of the streams to acidification is pertinent regardless of the source. Water chemistry of streams draining heavily forested watersheds has been studied by many workers (Simmons and Heath, 1982; Herlithy and others, 1991; Kaufmann and others, 1991; Winger and others, 1987) among others. They indicate that in

undeveloped areas the primary influences on water chemistry are the quality of incident precipitation and the composition and weatherability of underlying geologic materials. These studies often are focused on the baseline water chemistry and the susceptibility of low-order streams to acidification by atmospheric inputs (Herlithy and others, 1991; Kaufmann and others, 1991; Winger and others, 1987; Elwood and others, 1991). Geologic influences on water chemistry are controlled by the composition of the geologic materials within the watershed. Several studies have shown that water with low acid-neutralization capacity coming into contact with rocks containing sulfide minerals may become acidified. This can result in water exhibiting low pH values and increased dissolved metals and sulfate concentrations (Barnes and Romberger, 1968; Huckabee and others, 1975; Barton, 1978; Nordstrom, 1982; Aanes, 1988; Sullivan and Yelton, 1988; Sullivan and others, 1988; Skousen and others, 1989; and Byerly, 1990). Conversely, water coming into contact with alkaline geologic materials (such as limestone or dolomite) has the potential to become more alkaline and exhibit high acid-neutralization potentials. Regardless of the source, streams of the southern Blue Ridge have been shown to be susceptible to acidification due to their low acid-neutralization capacities (Elwood and others, 1991; Kaufmann and others, 1991; Winger and others, 1987).

Although atmospheric acidification is notable in the Blue Ridge region, for this study, the potential source of AD being investigated is the oxidation of sulfide minerals. Weathering and oxidation of many sulfide minerals can produce AD, but pyrite is the most commonly studied mineral in this respect. When water and oxygen come into contact with pyrite (FeS_2), AD may

be generated by the following reactions:



(Stumm and Morgan, 1981)

This series of reactions illustrates the mechanisms responsible for producing the low pH, high sulfate concentrations, and high metals concentrations associated with AD. Pyrite reacts with water and oxygen to produce a solution with dissolved ferrous iron (Fe^{2+}) and sulfate (2SO_4^{2-}) and hydrogen ion (H^+). The presence of free H^+ is indicated by a decrease in the pH of the solution. The metals in solution may form solids, as in reaction 3. These solids form the efflorescent minerals often seen in areas associated with AD. The rate and efficiency of this series of reactions is described by Singer and Stumm (1970) who demonstrated that the initial oxidation of pyrite by oxygen (Reaction 1) is slow in contrast to the oxidation of pyrite by ferric iron (Reaction 4). It is reaction 2, the oxidation of ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}), that controls the rate of pyrite oxidation. (Singer and Stumm, 1970).

The overall reaction rate can be accelerated by the presence of indigenous, widely distributed bacteria which function as catalysts increasing the oxidation of ferrous iron to ferric iron (reaction 2), and thus, facilitating the generation of AD through reaction 4 (Silverman and Ehrlich, 1964). One such bacteria, *Thiobacillus ferrooxidans*, is particularly adept at accelerating the oxidation rate of pyrite. The introduction of *T. ferrooxidans* has been shown to increase the reaction rate of pyrite oxidation by a factor greater

than 10^6 (Singer and Stumm, 1970). Therefore, pyrite in the presence of water, oxygen, and bacteria provide conditions favorable for AD generation.

Previous Studies

Environmental studies focusing on acid drainage are wide and varied. Although many studies deal with mining operations, mining is not the only disturbance causing AD (Singer and Stumm, 1970; Kleinmann and others, 1981; Aanes, 1988; Mann and others, 1988). In any situation where sulfide mineral-bearing rocks are exposed to weathering, the potential for AD exists.

Construction of portions of Highway 165 in Monroe County, Tennessee and U. S. 441 in the Great Smoky Mountains National Park provides examples where road construction resulted in AD problems (Byerly, 1989; Byerly, 1990; Byerly, 1991). Portions of Highway 165 were constructed through sulfidic rocks prior to widespread knowledge of the environmental impacts associated with the use of sulfidic rocks as construction materials (Byerly, 1980). The water quality declined in streams receiving drainage from these early segments of construction (Morgan and others, 1978; Byerly, 1980). Morgan and others (1978) note that mortality rates of rainbow trout, *Salmo gairdneri*, were significantly higher in impacted streams, Hemlock and McNabb Creeks, when compared to control streams, Laurel and Sugar Creeks, which had no AD input. In a similar case, construction of a road fill over Beech Flats Prong along U. S. 441 resulted in a fish kill and significant AD generation (Huckabee and others, 1975; Bacon and Maas, 1979). At the affected site, Beech Flats Prong flows through and below road fill constructed of sulfide-bearing rocks of the Anakeesta Formation. Below the road fill water in the creek shows a decrease in pH, increased metals concentrations, and elevated sulfate

concentrations (Huckabee and others, 1975; Bacon and Maas, 1979). Trout mortality increased drastically below the road fill containing sulfidic rocks of the Anakeesta Formation (Huckabee and others, 1975).

Research, designed to avoid AD generation while allowing construction to proceed, has resulted in the development of innovative construction techniques (Byerly, 1990; Byerly, 1993; Schaeffer and Clawson, 1993). Schaeffer and Clawson (1993) discussed modifications in transmission line construction methods to avoid the generation of AD. Byerly (1990) described modified construction methods as they relate to road fill construction. In both cases, agricultural lime is mixed with the materials having a potential for AD production, and this mixture is isolated from atmospheric oxygen and water using a tight soil layer. The purpose of these methods is to abate the effects of AD before streams are impacted (Byerly, 1990). The specialized road fills described by Byerly (1990) are employed along recent segments of Highway 165. Previous work within the study area dealing with these road fills focuses on the processes within, and performance of these specialized fills. Jago (1989) using bench-scale and field-scale testing studied the effectiveness of several fill designs at abating AD and Gunderson (1991) monitored the oxygen, carbon dioxide and temperature profiles within selected fills as a measure of the *in situ* processes.

Stream Monitoring

Of the ten streams chosen for study, nine are part of the Santeetlah Creek, North Carolina drainage and lie in the immediate study area and one is located in the North River drainage in Tennessee. The distant stream, located beyond the boundaries of the immediate study area, was monitored because it

receives drainage from a segment of highway constructed prior to widespread knowledge of the possible impacts from construction in sulfide-bearing geologic materials. Historical data indicates that this stream was impacted by AD generated by the exposure and weathering of sulfidic rocks during road construction (Morgan and others, 1978; Byerly, 1980).

The locations of the ten sampling points are discussed below and are compiled in Table 3-1. Most of the sampling points are located along unnamed low-order tributaries which drain into larger streams in the area. The sampling points are organized into the following two groups: 1) streams within watersheds receiving drainage from completed segments of the highway as well as segments undergoing construction during this study and 2) streams overlying similar rock types, but receiving no construction. Spatial distribution of rock types was determined from geologic mapping performed in the area.

Sample nodes of group 1, located along receiving drainage from road construction, are designated HEM, SM, HOOP, HB, BJ, and WHIG. The first, designated HEM, lies beyond the boundary of the immediate study area. This site is located along a drainage previously impacted by AD generated from a segment of highway built before the implementation of AD abating road construction practices (Morgan and others, 1978). The sample site is located at the downstream end of Hemlock Creek, upstream of its confluence with the North River. The remaining sites are all located within the immediate study area and are shown in Figure 3-1.

Sampling point SM receives drainage from a completed section of highway and is located along the Santeetlah Creek Road approximately 150 meters north of the Stratton Meadows Bridge. HOOP is located in a drainage

Table 3-1. Sample site name, location of the sample site, and the influence of road construction.

Sample Site Name	Stream Location	Receives Drainage From Road?
HEM	Hemlock Creek (outside field area)	Yes
SM	Stratton Meadows	Yes
HOOP	Hoopers Bald/Huckleberry Knob	Yes
HB	Hoopers Bald	Yes
BJ	Big Junction Creek	Yes
WHIG	Whig Branch	Yes
JOHN	John Knob	No
HAW	Haw Knob	No
HUCK2	Huckleberry Knob	No
HUCK1	Huckleberry Knob	No

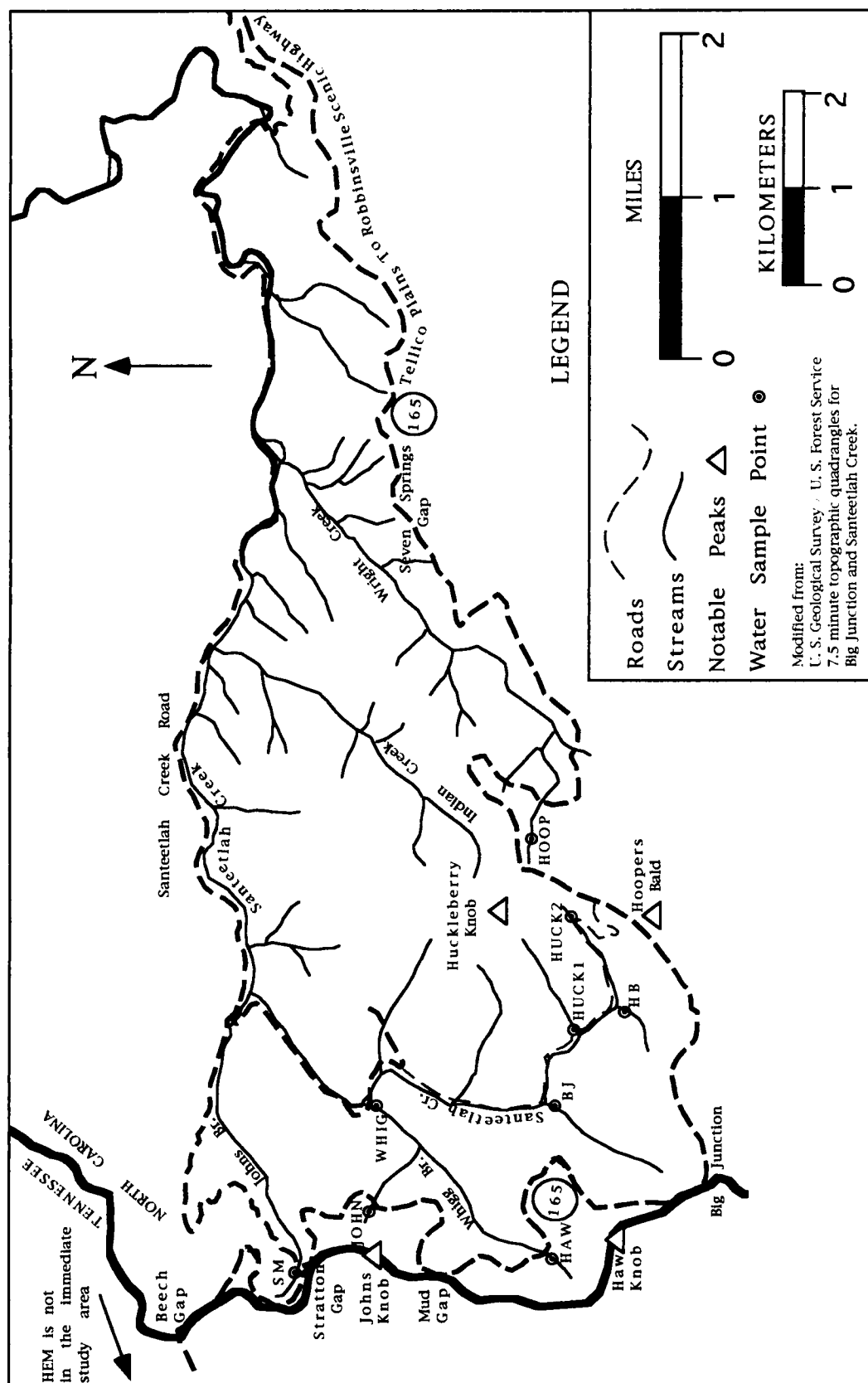


Figure 3-1. Locations of sampling points found in the immediate study area

near Hoopers Bald and Huckleberry Knob at a site underlain by rocks containing abundant sulfide minerals. HB is possibly influenced by the construction and is located on the north side of Hoopers Bald upstream from the confluence of this small drainage and Santeetlah Creek. The sample node, BJ, is located at the downstream end of the drainage flowing from Big Junction. WHIG lies at the end of Whig branch above its confluence with Santeetlah Creek. WHIG receives drainage from a completed section of highway and lies the farthest from the road construction of any of the sampling points in the immediate field area.

The remaining four sampling points are located upstream of road construction or in areas uninfluenced by the construction. The first and second of these streams, designated JOHN and HAW respectively, are located south of the Stratton Meadows Bridge upstream from a completed section of Highway 165. Sampling node WHIG receives drainage from both of these sampling points. The third node, HUCK2, is located along the western flank of Huckleberry Knob and receives no drainage from the construction site. HUCK1, the fourth site not impacted by the construction, lies along the western flank of Huckleberry Knob. At this point, the stream flows over rocks similar to those underlying BJ, but is uninfluenced by road construction.

Parameters Measured

Several parameters were measured to assess general stream quality. Specific conductance, pH, temperature, and dissolved oxygen were measured in the field. Discharge was estimated at each sampling location for each sampling event. Samples were collected and returned to the laboratory at the University of Tennessee Department of Geological Sciences for analysis of

sulfate, acidity, iron, manganese, magnesium, sodium, potassium, calcium, zinc, copper, and nickel. Aluminum was an analyte of interest but equipment problems prevented accurate analyses. Previous studies show that variations in some or all of the measured parameters may indicate the presence of AD (Barnes and Romberger, 1968; Huckabee and others, 1975; Barton, 1978; Nordstrom, 1982; Aanes, 1988; Sullivan and Yelton., 1988; Sullivan and others, 1988; Skousen and others, 1989; Byerly, 1990).

Field Measurements

Prior to sample collection for laboratory analysis, the following parameters were measured at each sample location and recorded for each sampling event: pH, specific conductance, temperature, and dissolved oxygen. Discharge was also estimated at this time.

Measurements of stream pH were made using an Orion model SA230 electronic pH meter/thermometer. The pH probe was immersed in the stream and the measurement was allowed to stabilize before recording the reading. Corrections for stream temperature were made either automatically or manually. The pH meter was calibrated twice a day using pH 4 and pH 7 buffer solutions. In cases where a pH was out of range or the reading seemed unusual, the pH meter was recalibrated and the readings taken again.

Specific conductance was measured using a YSI model 33 specific conductance/temperature/salinity meter. The temperature was measured prior to each specific conductance measurement and the meter adjusted to compensate for fluctuations in temperature. For these measurements, the specific conductance probe was immersed directly in the stream and the

reading was recorded after stabilization was achieved. The meter was calibrated monthly using a YSI standard solution.

The temperature of each stream was measured using both the temperature function of the specific conductance meter and the thermometer combined with the pH meter. Temperature measurements were obtained by immersing the thermometer probe directly in the stream. Once the reading stabilized, the reading was recorded. Concurrence between the two meters was within one degree Celsius.

Dissolved oxygen was measured using a HACH model 16046 dissolved oxygen meter. Prior to each measurement, a Ultimeter model 12 barometer was used to determine atmospheric pressure at each sampling location. The dissolved oxygen meter was calibrated to this reading and the dissolved oxygen probe was immersed directly in the stream. Upon stabilization of the reading, the measurement, in mg/L O₂, was recorded.

Discharge was estimated by measuring stream widths, depths, lengths and velocities at the time of sampling. This information was used to calculate an estimated volume for each sampling event. The stream velocity was measured by timing a buoyant object placed in the stream as it passed along the measured length. The discharge for streams passing through culverts near sampling nodes was estimated in a different way. The discharge of each culvert was estimated by measuring the culvert diameter, depth of water in each culvert, length of each culvert, and the time taken for an object to float from one end of the culvert to the other. The dimensional information for each culvert was used in formulas to compute discharge. Equations for the computation of discharge through a pipe are found in equations 1 and 2.

(1) $Q = LAT$

Where: Q = Discharge
 L = Length of the pipe
 A = Flow area of the pipe
 T = Time

(2) $A = (\pi\theta - 180 \sin \theta) (D^2/1440)$

Where: A = The flow area
 θ = The inner angle between the center of the pipe
 and the intersections between the water surface and
 the right and left sides of the pipe
 D = Diameter of the pipe

From Baumeister (1976)

In both methods, the time measurements were taken at least three times and averaged. Information gathered in the field was recorded on field log forms.

Sample Collection

Upon completion of the field measurements, water samples for laboratory analysis were collected at each site. All water samples collected for this study were grab samples collected by dipping the sample container into the stream with the container opening facing in the upstream direction. To avoid affecting the samples, collection occurred upstream of any disturbance caused by the sampler. Each sample container was filled to maximum capacity minimizing air space in the container. Prior to leaving the laboratory, sample containers were acid washed and rinsed with distilled deionized water. Before

sample collection, the container was rinsed three times with water from the stream being sampled. Three samples were collected at each site one; for dissolved metals, one for acidity, and one for sulfate. All samples collected for laboratory analysis were transported and stored at 4°C. Samples for dissolved metals analyses were collected in 250 ml Nalgene® poly bottles. The samples were field filtered using a manual vacuum pump and 0.45µm filter then acidified with 30% nitric acid to a pH of less than 2.0. The samples for sulfate analysis were collected in 250 ml Nalgene® poly bottles and those for acidity titrations were collected in 1 liter Nalgene® poly bottles.

Analytical Methods

Samples were analyzed in the laboratory for sulfate, acidity and dissolved metals. Analytical methods are discussed below. The precision and accuracy for dissolved metals and sulfate analyses is given in Table 3-2. No precision and accuracy data are presented for acidity analyses because variation in individual sample characteristics prevents an accurate determination of the precision of the analysis method (Standard Methods, 1985) For acidity analyses, the precision of the titration will most likely be more precise than uncertainties introduced by sample collection and handling (Standard Methods, 1985).

Sulfate

Sulfate analyses were performed using a turbidimetric, United States Environmental Protection Agency approved, technique described by HACH, (1975). This method is based on the formation of a barium sulfate precipitate created when barium reacts with sulfate in the sample. The concentration of

Table 3-2 Precision and accuracy for atomic absorption and sulfate analyses.

ANALYTE	STANDARD VALUE mg / L	MEAN OF MEASURED VALUES mg / L	STANDARD DEVIATION mg / L	AVERAGE RELATIVE ERROR %
Cu	0	0.02	0	NA
Cu	0.2	0.185	0.0051	7.5
Cu	0.5	0.5	0	0.0
Cu	1	0.999	0.0104	0.1
Fe	0	0.02	0	NA
Fe	0.3	0.258	0.0074	14.0
Fe	0.5	0.474	0.0221	5.2
Fe	2	1.994	0.0037	0.3
Zn	0	-0.01	0	NA
Zn	0.5	0.51	0.0126	2.0
Zn	0.7	0.712	0.0066	1.7
Zn	1	0.956	0.0151	4.4
Ni	0	-0.24	0	NA
Ni	0.3	0.18	0	40.0
Ni	0.7	0.92	0.0301	31.4
Ni	1	1.825	0.0565	82.5
Mn	0	0.02	0	NA
Mn	0.3	0.267	0.0298	11.0
Mn	0.5	0.497	0.0224	0.6
Mn	1	1.003	0.0553	0.3
Mg	0	0	0	NA
Mg	0.1	0.096	0.0037	4.0
Mg	0.2	0.193	0.0089	3.5
Mg	0.4	0.396	0.0169	1.0
K	0	0	0	NA
K	0.1	0.062	0.0045	38.0
K	0.5	0.515	0.0132	3.0
K	0.7	0.675	0.0182	3.6
K	1	0.938	0.0223	6.2
Ca	0	-0.03	0	NA
Ca	0.4	0.36	0.0135	10.0
Ca	1	0.956	0.006	4.4
Ca	2	2.03	0.0415	1.5
Ca	4	4.09	0.07	2.3
Na	0	-0.05	0	NA
Na	0.5	0.532	0.0164	6.4
Na	1	1.085	0.0366	8.5
Na	1.5	1.543	0.034	2.9
Na	2	1.97	0.0437	1.5
SO4	12.5	11.4	0.7683	8.8
SO4	25	24.2	0.5637	3.2

Notes: Statistics based on 10 measurements. NA = division by zero in the calculation.

sulfate in the sample is directly proportional to the amount of precipitate formed and indirectly proportional to the amount of light transmitted through the sample. The sample is placed in the HACH dr/2 spectrophotometer and the amount of light transmitted through the sample is measured. The spectrophotometer, barium chloride reagent pillows, and sulfate standard solutions were all manufactured by the Hach company. Standard solutions for sulfate were diluted to 25 and 12.5 ppm. Distilled deionized water was used as a 0 ppm solution. Prior to sample analysis the instrument was calibrated using the 12.5 ppm solution and zeroed using the 0 ppm solution. If the sample measured above the 12.5 ppm standard, the instrument was re-zeroed and re-calibrated using the 25 ppm standard. The sample was then re-analyzed. The standard solutions were analyzed before and after each 10 sample run.

Acidity

Acidity is described in the Standard Methods for the Examination of Water and Wastewater as the ability of water to react with a strong base to a desired pH (Standard Methods, 1985). The technique for acidity analysis is described in detail in Standard Methods for the Examination of Water and Wastewater. Using this method, the sample was titrated to a pH of 8.3 using NaOH. Although a microburet was used in the titrations, the minimal acidities found in the samples were neutralized by volumes of NaOH too small to be measured accurately. The standard method suggests the use of 0.02N NaOH solution but a 0.01N solution was substituted to increase the volume of titrant to a level sufficient for accurate measurement.

The tests for acidity included the pre-treatment for possible high metals concentrations (Standard Methods, 1985). This pre-treatment was performed

to avoid any interferences due to high metals associated with AD and involved boiling the sample in the presence of hydrogen peroxide to oxidize metals in the solution.

Dissolved metals

Dissolved metals concentrations were determined by atomic absorption (AA) spectrophotometry. A Varian® model AA-475 spectrophotometer was used for all analyses. Flame AA was used on all elements except aluminum. Recommended parameters for flame AA analyses are found in the Appendix (Table A-2). To achieve sufficiently low detection limits for aluminum analyses, graphite furnace AA spectrophotometry was attempted. Although the detection limits using this method were sufficiently low, instrument problems prevented reproducible readings. For this reason, analyses for aluminum are not included in this study. All elements analyzed were calibrated using standard solutions purchased from a commercial distributor. The standards were diluted in the lab to the working range for the samples (Varian, 1979; Standard Methods, 1985). A standardization curve was constructed for each run. Standards were re-aspirated during the sample runs to determine instrument drift. Standard solutions of concentrations not used in the calibration were analyzed as unknowns for the purpose of quality control. At regular intervals, the standards used to construct the standardization curve were re-analyzed to detect any instrument drift. If drift was noted, the instrument was recalibrated. Duplicate samples were run to assure reproducibility in the data. Although samples for dissolved metals were collected biweekly, lack of variation in the results, prompted analysis of every other sample (monthly data).

Chemical Data

Analytical results are arranged by parameter. Concentrations of copper, manganese, iron, nickel, and zinc were below the detection limit for the AA analysis method. For this reason, these data are not presented. Of the metals detected, all were not detected in each stream. In this case, data are presented, but ND is assigned when the metal concentration is below the detection limit of the method.

Temperature

Prior to sample collection, water temperature at each stream node was measured and this data is presented in Table 3-3.

Dissolved Oxygen

Dissolved oxygen was measured at each stream sample point prior to sample collection. Dissolved oxygen values are presented in Table 3-4.

Field pH

The pH of stream water at each sample node was measured approximately biweekly for 11 months. These data are given in Table 3-5.

Specific conductance

Before sample collection, the specific conductance of each stream was measured. The results of specific conductance measurements for all streams are presented in Table 3-6.

Table 3-3. The temperatures measured at each sample node. Units are degrees Celsius.

DATE	HEM	SM	JOHN	HAW	HOOP	HUCK 2	HB 1	HUCK 1	BJ	WHIG
8/28/89	ND	15.5	14.0	15.0	20.9	15.1	15.0	15.0	17.0	17.0
9/9/89	21.0	15.0	15.0	14.5	20.0	14.1	15.0	15.5	15.0	16.0
9/23/89	14.5	12.0	11.5	12.0	13.0	12.8	12.5	12.5	12.5	13.0
10/9/89	12.0	10.5	9.0	10.0	13.6	10.0	9.8	8.5	10.0	10.0
10/23/89	14.0	10.9	9.0	10.0	15.0	11.0	10.0	11.0	10.0	12.0
11/8/89	14.9	12.8	11.5	11.8	11.1	10.5	10.5	12.0	14.1	13.2
11/17/89	6.0	4.0	3.5	3.0	6.0	5.5	3.0	3.0	1.9	3.0
12/1/89	6.5	5.5	7.9	6.0	9.0	6.5	5.0	4.9	4.5	5.0
12/14/89	4.5	3.8	2.1	4.0	1.0	ND	ND	ND	ND	ND
12/29/89	4.9	5.8	6.5	4.8	3.5	ND	ND	ND	ND	ND
1/12/90	7.0	6.0	4.0	2.0	0.0	1.0	1.0	1.0	1.0	1.0
1/26/90	6.0	4.8	4.0	1.0	ND	ND	ND	ND	ND	ND
2/9/90	7.0	6.0	7.8	5.0	5.5	5.0	5.0	1.0	8.0	8.0
2/26/90	6.0	6.0	8.0	3.0	6.0	3.5	4.0	3.0	3.5	4.0
3/12/90	13.0	9.5	12.0	10.0	14.3	12.0	13.0	10.5	11.3	10.2
3/23/90	10.1	8.8	8.7	6.9	5.5	10.0	7.5	9.1	10.1	8.9
4/9/90	6.8	5.7	6.5	4.8	9.9	7.0	9.9	8.8	5.0	7.7
4/20/90	11.3	8.6	8.2	7.2	9.8	9.0	7.2	9.3	10.0	10.0
5/7/90	14.2	10.2	10.2	9.5	11.3	12.5	11.8	12.5	10.0	10.3
6/2/90	15.3	11.3	11.0	10.2	13.9	11.0	10.4	11.8	11.7	12.0
6/16/90	16.9	12.3	11.7	11.9	ND	12.6	13.6	13.5	15.2	13.4
6/28/90	16.5	13.2	12.3	11.2	ND	13.0	13.4	13.6	12.5	14.0

NOTE: ND = No data collected or data unavailable.

Table 3-4. Dissolved oxygen results at each sample node. Units are in mg/L.

DATE	HEM	SM	JOHN	HAW	HOOP	HUCK 2	HB1	HUCK 1	BJ	WHIG
8/28/89	ND	9.2	8.9	8.2	4.40	ND	8.2	7.7	9.8	9.2
9/9/89	7.2	9.0	8.0	8.8	4.9	8.5	8.1	8.6	9.8	9.8
9/23/89	7.7	8.9	9.9	8.9	8.6	7.3	7.3	8.2	9.5	10.9
10/9/89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10/23/89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11/8/89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11/17/89	ND	22.00	ND	ND	ND	ND	ND	ND	ND	ND
12/1/89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12/14/89	8.8	12.8	9.7	9.9	12.0	ND	ND	ND	ND	ND
12/29/89	14.0	12.4	10.2	9.5	9.6	ND	ND	ND	ND	ND
1/12/90	14.7	11.8	10.5	12.5	10.9	11.6	11.0	12.0	11.4	12.8
1/26/90	15.4	13.0	14.0	12.4	ND	ND	ND	ND	ND	ND
2/9/90	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2/26/90	15.6	8.4	6.0	13.0	11.7	13.5	13.4	12.0	13.0	ND
3/12/90	13.8	9.3	8.6	10.4	9.4	9.2	8.1	8.1	9.0	10.2
3/23/90	19.0	9.2	9.8	8.0	7.8	9.6	9.2	8.6	10.0	10.0
4/9/90	11.6	10.2	9.5	10.0	10.0	10.0	9.6	8.4	10.2	7.3
4/20/90	9.6	9.1	9.4	10.3	8.3	10.2	9.9	10.8	10.4	9.3
5/7/90	9.6	9.5	9.7	10.0	9.2	8.8	9.9	10.2	10.7	8.0
6/2/90	10.0	8.8	8.8	9.3	ND	ND	ND	ND	ND	ND
6/16/90	8.8	9.2	8.4	8.8	ND	8.8	8.1	8.4	9.6	9.6
6/28/90	8.2	9.2	8.4	8.3	ND	9.3	8.1	8.9	9.1	9.5

NOTE: ND = No data collected or data unavailable.

Table 3-5. The pH values collected at each sample node. Units are standard pH units.

DATE	HEM	SM	JOHN	HAW	HOOP	HUCK 2	HB	HUCK 1	BJ	WHIG
8/28/89	6.58	8.70	7.80	6.35	6.40	6.15	5.60	6.30	6.40	6.90
9/9/89	6.65	6.52	6.95	5.25	7.30	6.45	5.50	6.50	6.80	6.25
9/23/89	5.29	6.60	6.25	5.60	5.64	4.90	5.70	4.98	6.35	6.40
10/9/89	ND	6.10	5.91	4.55	5.98	5.12	5.31	5.62	6.15	6.80
10/23/89	5.21	ND	ND	ND	5.91	5.15	5.18	4.90	ND	ND
11/8/89	4.55	6.32	4.81	4.71	4.81	5.12	4.68	4.80	5.40	5.15
11/17/89	5.42	ND	4.61	4.60	5.48	4.70	3.91	3.93	5.33	5.81
12/1/89	4.52	5.35	5.40	5.20	5.70	4.85	4.55	4.80	4.80	5.95
12/14/89	4.85	6.50	5.30	5.20	4.75	ND	ND	ND	ND	ND
12/29/89	4.75	5.65	4.43	5.29	5.00	ND	ND	ND	ND	ND
1/12/90	3.95	5.25	5.49	5.49	5.31	5.30	4.45	4.80	5.10	5.75
1/26/90	4.10	5.30	4.80	3.90	ND	ND	ND	ND	ND	ND
2/9/90	5.60	4.80	4.60	4.00	3.90	5.35	4.95	4.51	4.70	5.50
2/26/90	5.84	6.50	4.92	4.65	5.05	4.25	4.70	4.20	ND	ND
3/12/90	ND	6.60	6.26	5.45	5.36	5.79	5.22	5.45	5.74	6.36
3/23/90	6.12	6.30	6.08	5.41	5.38	5.75	5.15	5.45	5.10	6.30
4/9/90	6.15	6.55	6.35	5.60	5.28	5.82	5.26	5.53	5.66	6.33
4/20/90	6.00	6.56	6.14	5.48	5.25	5.94	5.47	5.55	5.82	6.39
5/7/90	ND	6.71	6.09	5.50	5.90	5.79	5.35	5.36	6.00	6.31
6/2/90	6.01	6.60	6.45	5.52	5.93	5.80	5.48	5.54	6.05	6.45
6/16/90	5.98	6.47	6.25	5.40	ND	6.00	5.39	5.37	5.98	6.27
6/28/90	6.11	6.47	6.23	5.25	ND	6.10	5.36	5.28	6.08	6.60

NOTE: ND = No data collected or data unavailable.

Table 3-6. Specific conductance values measured at each sample node. Units are $\mu\text{mho}/\text{cm}$.

DATE	HEM	SM 1	JOHN	HAW	HOOP	HUCK 2	HB1	HUCK 1	BJ	WHIG
8/28/89	ND	22	10	9	21	8	9	8	11	12
9/9/89	23	20	118	10	23	8	9	8	10	11
9/23/89	109	160	180	200	109	158	130	169	28	12
10/9/89	78	73	61	65	84	69	63	59	70	71
10/23/89	29	22	12	14	19	13	14	13	18	17
11/8/89	41	21	14	15	14	12	15	13	19	19
11/17/89	30	6.2	13	11	14	12	12	11	17	13
12/1/89	25	18	11	11	10	10	10	9	12	12
12/14/89	28	15	9	10	10	ND	ND	ND	ND	ND
12/29/89	19	12	10	9	9	ND	ND	ND	ND	ND
1/12/90	21	15	9	9	10	5	10	5	10	9
1/26/90	22	18	8	9	ND	ND	ND	ND	ND	ND
2/9/90	21	15	9	8	9	5	12	9	11	13
2/26/90	11	9	11	6	5	9	8	5	10	9
3/12/90	23	16	8	9	10	10	12	9	12	10
3/23/90	6.05	13	10	9	10	5	10	5	12	10
4/9/90	16	15	5	9	10	9	10	9	15	10
4/20/90	20	16	8	7	9	6	9	5	12	10
5/7/90	25	18	9	9	10	5	15	8	19	10
6/2/90	28	15	8	4	10	6	9	6	13	10
6/16/90	26	11	9	8	ND	6	10	8	15	11
6/28/90	11	19	8	7	ND	7	10	8	15	11

NOTE: ND = No data collected or data unavailable.

Sulfate

Samples for the analysis of sulfate were collected and analyzed approximately biweekly for 11 months. Results for all sulfate analyses are given in Table 3-7.

Acidity

Samples from each of the sample nodes were analyzed for acidity. Results for these analyses are presented in Table 3-8.

Dissolved Metals

Samples collected for dissolved metals were analyzed by atomic absorption spectrophotometry. Results of the analyses are presented in Tables 3-9 to 3-12.

Discharge

Discharge was estimated at the time of sample collection for each sampling event. These estimates given in Table 3-13.

Evaluation of Water Chemistry Data

The results of the water chemistry data will be discussed in this section. Each type of analysis or measurement will be discussed, in the order presented in the previous section. Stream chemistry data, collected at any one location over a period of time is influenced by precipitation or other random events, seasonal correlation, and serial correlation (Loftis and Ward, 1980). Loftis and Ward (1980) studied the frequency of sample collection and the effects of seasonal and serial correlation on the data. They determined that for data sets

Table 3-7 Sulfate concentrations for each sample node. Units are in mg/L.

DATE	HEM	SM	HAW	JOHN	HOOP	HUCK 2	HB	HUCK 1	BJ	WHIG
8/28/89	ND	1	5	6	2	0	2	1	1	0
9/9/89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9/23/89	18	1	1	0	0	0	ND	0	0	2
10/9/89	12	0	0	0	2	0	0	0	0	0
10/23/89	12	1	0	ND	1	0	0	0	0	0
11/8/89	9	0	1	0	0	0	0	3	0	0
11/17/89	13	ND	0	0	ND	0	1	0	4	2
12/1/89	13	3	0	0	4	6	0	3	6	5
12/14/89	ND	1	0	0	1	ND	ND	ND	ND	ND
12/29/89	13	5	0	0	2	ND	ND	ND	ND	ND
1/12/90	ND	1	ND	ND	0	0	5	0	ND	0
1/26/90	13	1	0	0	ND	ND	ND	ND	ND	ND
2/9/90	11	0	0	0	0	ND	ND	ND	ND	ND
2/26/90	9	1	0	2	2	1	1	0	2	0
3/12/90	11	0	0	0	0	0	0	0	4	1
3/23/90	8	0	0	0	2	0	0	0	1	0
4/9/90	9	0	1	0	0	0	0	0	0	2
4/20/90	9	0	0	1	0	2	0	0	0	1
5/7/90	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6/2/90	14	0	0	0	0	0	0	0	0	0
6/16/90	9	0	0	0	ND	0	0	1	0	0
6/28/90	8	0	0	0	ND	0	0	0	0	0

NOTE: ND = No data collected or data unavailable.

Table 3-8. Acidity values measured from each sample node. Units are mg/L asCaCO₃.

DATE	HEM	SM	JOHN	HAW	HOOP	HUCK 2	HB	HUCK 1	BJ	WHIG
8/28/89	ND	-1.2	1.4	2.0	1.4	1.2	2.2	2.4	1.2	0.0
9/9/89	1.2	-4.2	0.0	0.6	0.2	-0.6	1.8	ND	0.8	0.0
9/23/89	1.6	-1.8	1.4	1.4	ND	10.8	ND	4.4	ND	ND
10/9/89	ND	-2.8	0.2	6.8	7.2	4.0	1.6	1.8	1.8	ND
10/23/89	2.4	-2.0	0.6	1.2	1.6	1.8	0.8	2.0	1.6	0.8
11/8/89	4.0	0.4	4.0	4.8	ND	4.4	4.8	4.4	4.6	4.0
11/17/89	ND	ND	ND	ND	ND	1.3	4.8	2.4	1.2	ND
12/1/89	4.0	-1.2	3.2	3.6	6.0	3.6	4.0	4.4	4.0	7.2
12/14/89	ND	0.8	3.6	4.4	7.6	ND	ND	ND	ND	ND
12/29/89	4.2	1.2	3.2	4.8	5.6	ND	ND	ND	ND	ND
1/12/90	2.4	-2.2	-2.8	1.2	2.8	2.6	2.6	2.0	1.2	0.8
1/26/90	3.0	-0.8	1.0	2.0	ND	ND	ND	ND	ND	ND
2/9/90	2.0	-2.0	0.4	1.3	2.4	ND	ND	ND	ND	ND
2/26/90	1.6	-1.8	0.2	1.8	4.0	2.9	1.6	1.6	2.0	1.5
3/12/90	1.8	-1.6	0.4	1.8	1.6	2.1	2.0	2.1	1.9	1.8
3/23/90	ND	-1.0	0.0	4.0	1.2	0.5	1.5	0.8	-0.3	0.4
4/9/90	0.0	-3.0	-0.2	0.8	1.4	0.4	1.2	1.1	0.6	0.2
4/20/90	0.9	-0.9	0.8	1.7	2.0	1.2	1.8	1.6	1.6	1.1
5/7/90	1.0	-2.4	0.0	1.4	1.8	1.1	1.3	1.6	1.9	0.2
6/2/90	5.6	-2.5	0.6	1.8	2.4	1.4	1.6	2.2	1.6	0.8
6/16/90	0.1	-5.2	0.4	0.5	ND	-0.7	0.2	-0.0	-0.2	-0.9
6/28/90	1.0	-4.2	68.0	1.2	ND	0.9	1.6	1.6	1.2	ND

NOTE: ND = No data collected or data unavailable.

Table 3-9 . Calcium results from each sample node. Units are in mg/L.

DATE	HEM	SM	JOHN	HAW	HOOP	HUCK 2	HB	HUCK 1	BJ	WHIG
8/28/89	1.5	2.3	0.8	0.6	0.9	1.0	0.6	0.4	1.1	1.3
9/23/89	3.0	5.3	0.8	0.6	0.6	1.1	0.6	0.4	1.4	1.3
10/23/89	2.0	2.1	1.0	0.7	0.7	1.0	0.5	0.4	1.1	1.2
11/17/89	2.4	2.1	0.6	0.6	0.7	1.3	0.8	0.3	1.6	1.3
12/1/89	ND	ND	ND	ND	ND	1.0	0.7	0.4	1.3	1.1
12/14/89	2.1	2.1	0.7	0.7	0.6	ND	ND	ND	ND	ND
1/12/90	1.8	ND	0.7	0.7	0.8	1.4	0.8	0.4	1.3	1.2
1/26/90	ND	2.0	ND	ND	0.6	1.4	1.2	0.5	1.7	1.4
2/9/90	2.3	2.0	0.7	0.7	ND	ND	ND	ND	ND	ND
2/26/90	ND	ND	ND	ND	ND	ND	ND	0.4	ND	1.2
3/12/90	2.0	2.0	0.7	0.7	0.6	1.5	0.8	0.4	1.7	1.1
4/9/90	1.3	2.1	0.6	0.6	0.7	1.2	0.8	0.4	1.2	1.4
5/7/90	1.9	2.3	0.8	0.7	0.7	1.3	1.1	0.4	1.6	1.3
6/2/90	2.5	ND	ND	0.7	0.9	1.4	1.1	0.5	1.7	1.2
6/16/90	ND	2.7	0.9	ND	ND	ND	ND	ND	ND	ND
6/28/90	2.1	2.4	0.8	0.7	ND	1.3	0.8	0.5	1.3	ND

NOTE: ND = No data collected or data unavailable.

Table 3-10 Magnesium results from each sample node. Units are in mg/L.

DATE	HEM	SM	JOHN	HAW	HOOP	HUCK 2	HB	HUCK 1	BJ	WHIG
8/28/89	0.7	1.1	0.2	0.2	0.28	0.1	0.2	0.1	0.3	0.3
9/23/89	0.7	1.1	0.2	0.2	0.18	0.2	0.2	0.1	0.4	0.3
10/23/89	0.6	1.1	0.2	0.2	0.20	0.2	0.2	0.2	0.3	0.3
11/17/89	0.7	1.0	0.2	0.2	0.21	0.2	0.3	0.2	0.4	0.3
12/1/89	ND	ND	ND	ND	ND	0.2	0.2	0.2	0.4	0.3
12/14/89	0.8	1.0	0.2	0.2	0.22	ND	ND	ND	ND	ND
1/12/90	0.8	ND	0.2	0.2	0.26	0.2	0.3	0.2	0.4	0.3
1/26/90	ND	0.9	ND	ND	0.20	0.2	0.4	0.2	0.5	0.3
2/9/90	0.9	1.0	0.2	0.2	ND	ND	ND	ND	ND	ND
2/26/90	ND	ND	ND	ND	ND	ND	ND	0.2	ND	0.3
3/12/90	0.8	1.0	0.2	0.2	0.2	0.2	0.3	0.1	0.4	0.3
4/9/90	0.6	1.0	0.2	0.2	0.2	0.2	0.2	0.1	0.3	0.3
5/7/90	0.7	1.0	0.2	0.2	0.2	0.2	0.3	0.2	0.4	0.3
6/2/90	1.0	ND	ND	0.2	0.2	0.2	0.3	0.2	0.4	0.3
6/16/90	ND	1.1	0.2	ND	ND	ND	ND	ND	ND	ND
6/28/90	0.7	1.2	0.2	0.2	ND	0.1	0.2	0.2	0.3	ND

NOTE: ND = No data collected or data unavailable.

Table 3-11. Potassium results from each sample node. Units are in mg/L.

DATE	HEM	SM	JOHN	HAW	HOOP	HUCK 2	HB	HUCK 1	BJ	WHIG
8/28/89	0.5	0.8	0.4	0.2	0.5	0.2	2.9	0.1	0.2	0.4
9/23/89	0.4	0.8	0.5	0.3	0.3	0.3	2.7	0.2	0.3	0.4
10/23/89	0.4	0.7	0.5	0.5	0.4	0.3	2.9	0.2	0.3	0.5
11/17/89	0.5	0.7	0.5	0.3	0.4	0.3	2.8	0.2	0.3	0.5
12/1/89	ND	ND	ND	ND	ND	0.2	2.8	0.2	0.3	0.4
12/14/89	0.4	0.6	0.4	0.3	0.3	ND	ND	ND	ND	ND
1/12/90	0.4	ND	0.4	0.3	0.3	0.2	2.8	0.2	0.3	0.4
1/26/90	ND	0.8	ND	ND	0.3	0.3	2.9	0.2	0.4	0.5
2/9/90	0.5	0.7	0.5	0.3	ND	ND	ND	ND	ND	ND
2/26/90	ND	ND	ND	ND	ND	ND	ND	0.3	ND	0.4
3/12/90	0.4	0.6	0.5	0.3	0.4	0.2	2.8	0.2	0.3	0.5
4/9/90	0.4	0.6	0.4	0.3	0.3	0.2	2.8	0.2	0.3	0.6
5/7/90	0.4	0.7	0.5	0.3	0.3	0.2	2.7	0.2	0.3	0.4
6/2/90	0.6	ND	ND	0.2	0.4	0.2	2.7	0.2	0.2	0.4
6/16/90	ND	0.7	0.4	ND	ND	ND	ND	ND	ND	ND
6/28/90	0.4	0.7	0.4	0.2	ND	0.2	2.7	0.1	0.3	ND

NOTE: ND = No data collected or data unavailable.

Table 3-12. Sodium results from each sample node. Units are in mg/L.

DATE	HEM	SM	JOHN	HAW	HOOP	HUCK 2	HB	HUCK 1	BJ	WHIG
8/28/89	1.0	0.7	0.7	0.4	0.4	0.5	0.6	0.6	0.5	0.7
9/23/89	1.0	1.3	0.5	0.5	0.4	0.4	0.5	0.5	0.5	0.7
10/23/89	1.0	0.7	0.7	0.7	0.4	0.6	0.5	0.5	0.5	0.6
11/17/89	1.0	0.7	0.5	0.4	0.3	0.4	0.4	0.5	0.5	0.6
12/1/89	ND	ND	ND	ND	ND	0.5	0.5	0.5	0.5	0.6
12/14/89	0.9	0.7	0.6	0.4	0.3	ND	ND	ND	ND	ND
1/12/90	0.9	ND	0.5	0.4	0.3	0.5	0.4	0.5	0.6	0.5
1/26/90	ND	0.7	ND	ND	0.3	0.4	0.4	0.4	0.5	0.6
2/9/90	1.0	0.7	0.5	0.4	ND	ND	ND	ND	ND	ND
2/26/90	ND	ND	ND	ND	ND	ND	ND	0.6	ND	0.5
3/12/90	0.9	0.7	0.5	0.4	0.4	0.4	0.4	0.5	0.5	0.6
4/9/90	0.9	0.7	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.8
5/7/90	1.0	0.7	0.6	0.5	0.4	0.5	0.5	0.5	0.6	0.6
6/2/90	1.2	ND	ND	0.5	0.4	0.5	0.5	0.6	0.5	0.6
6/16/90	ND	0.7	0.6	ND	ND	ND	ND	ND	ND	ND
6/28/90	1.1	0.8	0.5	0.4	ND	0.5	0.5	0.6	0.6	ND

NOTE: ND = No data collected or data unavailable.

Table 3-13 Discharge estimates for each sample node at each sampling event.

Units are in cubic meters per second.

DATE	HEM	SM	JOHN	HAW	HOOP	HUCK 2	HB	HUCK 1	BJ	WHIG
8/28/89	ND	>0.5	>0.5	>0.5	>0.01	>0.5	>0.5	>0.5	>0.5	>0.5
9/9/89	>0.5	>0.5	>0.5	>0.5	>0.01	>0.5	>0.5	>0.5	>0.5	>0.5
9/23/89	ND	>0.5	>0.5	>0.5	>0.01	>0.5	>0.5	>0.5	ND	>0.5
10/9/89	>0.5	>0.5	>0.5	>0.5	>0.01	>0.5	ND	>0.5	>0.5	>0.5
10/23/89	>0.5	>0.5	>0.5	>0.5	>0.01	ND	>0.5	>0.5	>0.5	ND
11/8/89	ND	ND	ND	ND	>0.01	>0.5	>0.5	>0.5	0.6	0.5
11/17/89	ND	>0.5	>0.5	>0.5	>0.01	>0.5	>0.5	>0.5	1.2	ND
12/1/89	>0.5	>0.5	>0.5	>0.5	>0.01	>0.5	>0.5	>0.5	>0.5	>0.5
12/14/89	0.5	>0.5	>0.5	>0.5	>0.01	ND	ND	ND	ND	ND
12/29/89	>0.5	ND	>0.5	>0.5	ND	ND	ND	ND	ND	ND
1/12/90	>0.5	>0.5	>0.5	>0.5	>0.01	>0.5	ND	ND	>0.5	>0.5
1/26/90	1.1	>0.5	>0.5	>0.5	>0.01	ND	ND	ND	ND	ND
2/9/90	1.0	>0.5	>0.5	>0.5	>0.01	>0.5	>0.5	>0.5	>0.5	1.1
2/26/90	0.7	>0.5	>0.5	>0.5	>0.01	>0.5	>0.5	>0.5	>0.5	ND
3/12/90	0.6	>0.5	>0.5	>0.5	>0.01	>0.5	>0.5	>0.5	>0.5	>0.5
3/23/90	>0.5	>0.5	>0.5	>0.5	ND	>0.5	>0.5	>0.5	>0.5	ND
4/9/90	>0.5	>0.5	>0.5	>0.5	>0.01	>0.5	>0.5	>0.5	>0.5	>0.5
4/20/90	>0.5	>0.5	>0.5	>0.5	>0.01	>0.5	>0.5	>0.5	>0.5	>0.5
5/7/90	0.9	>0.5	>0.5	>0.5	>0.01	>0.5	>0.5	>0.5	>0.5	>0.5
6/2/90	>0.5	>0.5	>0.5	>0.5	>0.01	>0.5	>0.5	>0.5	>0.5	>0.5
6/16/90	>0.5	>0.5	>0.5	>0.5	ND	ND	>0.5	>0.5	>0.5	>0.5
6/28/90	>0.5	>0.5	>0.5	>0.5	ND	>0.5	>0.5	>0.5	>0.5	>0.5

NOTES: ND = No data collected or data unavailable.

There are two significant figures for the data collected at HOOP because discharge was sufficiently low enough to allow direct measurement using a graduated cylinder.

with greater than 10 samples and less than 30 samples per year corrections for seasonal and serial correlation are not advisable. The basis for their conclusion was that errors introduced by correcting for serial and seasonal correlation in data sets containing 10-30 samples per year may be larger than the errors introduced by the correlations themselves (Loftis and Ward, 1980). The data collected for this study fall within this range, thus will be presented without corrections for seasonal or serial correlation.

Statistical methods

Most statistical methods require an approximation of a normal distribution and do not allow missing data points and/or non-detect values (Gilbert, 1987). The data collected for this study contains missing values due to inaccessibility to some stream sites (weather related) or equipment problems and, therefore, may not approximate a normal distribution. For this reason a nonparametric statistical test, the Kruskal-Wallis test, was selected to be applied to the data collected for this study. The Kruskal-Wallis test requires that the data sets be independent, but does not require that the individual data sets approximate a known distribution or be of identical size (Gilbert, 1987;). This test also allows for missing and non-detect values (Gilbert, 1987). The null hypothesis for the Kruskal-Wallis test is that the data sets share a common population mean. The alternate hypothesis is that at least one data set differs significantly from the population mean at the confidence level specified. If the null hypothesis is true, the data sets can be described as being similar.

Computation of the Kruskal-Wallis statistic requires that the data be ranked from smallest to largest. Ties in the data set are given a midrank. The

number of ties, and the number of sets of ties is computed. This information is used in the equation:

$$K'_W = \frac{\left[\frac{12}{m(m+1)} \sum_{j=1}^k \frac{R_j^2}{n_j} \right] - 3(m+1)}{1 - \frac{1}{m(m^2 - 1)} \sum_{j=1}^g t_j(t_j^2 - 1)}$$

Where: n= The number of data points in each independent data set

m = The total number of data (n₁ + n₂ + n₃ + ... + n_k)

g = Number of tied data groups

t = Number of tied data in each tied data group

k = Number of data sets

The Kruskal-Wallis statistic was computed for all of the parameters measured at the streams sampled in this study. The value generated using the equation above is compared to Chi Square values at 95% level for 9 degrees of freedom. The cut-off value for the Chi Square tables is 16.92. If the Kruskal-Wallis statistic is greater than 16.92 then the null hypothesis is rejected indicating that at least one stream differs from the population mean at the 95% level. If the Kruskal-Wallis statistic for all of the streams in the study, K'_{w10}, rejected the null hypothesis the test was performed again, using only data from the nine streams in the immediate study area, K'_{w9}. This second computation was performed to avoid any skew in the data due to the location of sample site HEM along a stream known to have been impacted by AD. The Kruskal-Wallis statistic was also used to more closely examine three parameters; temperature, dissolved oxygen, and pH. Data from each these parameters was divided into two data sets based on the visual identification of seasonality determined from

the graphs of the data. Data associated with the summer data set was collected from 8/28/89 to 11/8/89 and 4/20/90 to 6/28/90. The winter data set includes data collected from 11/17/89 to 4/9/90. Division of the data sets in this manner yields summer and winter data sets of equal size.

Summary statistics (mean, median, mode, standard deviation, range, minimum value, maximum value, sum, and the number of observations) were computed for both the entire data set (all ten sample nodes) and for the data collected at each individual sample node.

Interpretation of Analyses

The general water quality for the entire study area is summarized in Table 3-14 which contains a statistical summary, by parameter, for all water chemistry data collected in this study. Detailed discussions of each of the measured parameters follow in the sections below.

Temperature

Temperature measurements for all streams in the study show the effects of seasonal variation. This is seen in Figure 3-2, as a decrease in temperature during the winter months. Individual graphs of temperature measurements from each sample node are located in the Appendix (Figures A-1 to A-10). Table 3-3 contains the raw temperature data and Table 3-15 contains a statistical summary for the data. The Kruskal-Wallis statistics, $K'_{w10} = -64.11$ and $K'_{w9} = -37.61$ indicate that the mean of the data from at least one sample node in both data sets differs significantly from the population mean at a 95% confidence level. When the temperature data is divided into summer and winter data sets and the Kruskal-Wallis statistic is re-computed for each season

Table 3-14. Statistical summary for all of the data for each parameter.

Statistic	T	DO	pH	SC	SO ₄	Acid	Ca	Mg	K	Na
Mean	9.5	9.9	6.6	21.	1.8	1.8	1.2	0.4	0.6	0.6
Median	10	9.5	5.5	11	0	1.4	1.0	0.2	0.4	0.5
Mode	10	8.8	4.8	10	0	1.6	0.71	0.2	0.2	0.5
Std. Dev.	4.40	2.28	7.6	31.4	3.62	5.41	0.72	0.3	0.7	0.2
Range	21.5	17.6	8.7	196	18	73.2	5.3	1.2	2.9	1.3
Minimum	0	4.4	3.9	4	0	-5.2	0.0	0.0	0.0	0.0
Maximum	21.5	22	8.7	200	18	68.0	5.3	1.2	2.9	1.3
Count	202	134	202	202	168	180	121	121	121	121

Notes:

T = Temperature in °C.

DO = Dissolved Oxygen in mg/L

pH = pH in standard units

SC = Specific conductance in $\mu\text{mho}/\text{cm}$

SO₄ = Sulfate in mg/L

Acid = Acidity in mg/L as CaCO₃

Ca = Calcium in mg/L

Mg = Magnesium in mg/L

K = Potassium in mg/L

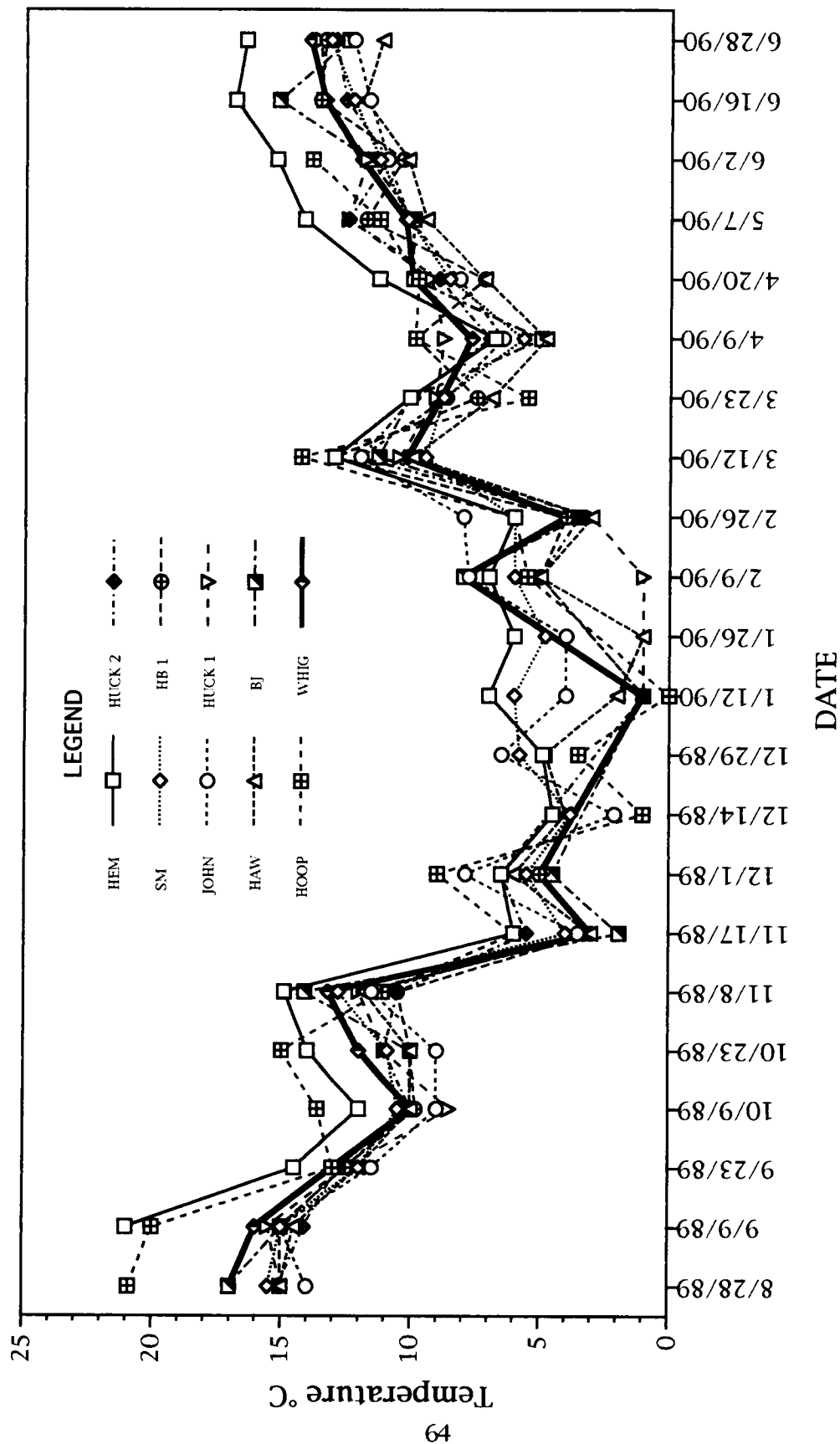


Figure 3-2. Temperature measurements for all streams over the duration of the study.

Table 3-15. General statistics for temperature data collected for each sample node in the study.

Units are Degrees Celsius.

STATISTIC	HEM	SM	JOHN	HAW	HOOP	HUCK 2	HB 1	HUCK 1	BJ	WHIG
Mean	10.9	9.0	8.8	7.9	10.0	9.6	9.4	9.3	9.7	9.9
Median	11.3	9.2	8.9	8.4	9.9	10.5	10.0	10.5	10.0	10.2
Mode	6.0	6.0	12.0	10.0	6.0	10.0	15.0	12.5	10.0	10.0
Std. Deviation	4.8	3.6	3.5	4.1	5.8	3.9	4.2	4.6	4.6	4.4
Range	16.5	11.7	13.0	14.0	20.9	14.1	14.0	14.5	16.0	16.0
Minimum	4.5	3.8	2.1	1.0	0.0	1.0	1.0	1.0	1.0	1.0
Maximum	21.0	15.5	15.0	15.0	20.9	15.1	15.0	15.5	17.0	17.0
Sum	228.4	198.2	194.4	173.8	189.3	182.1	177.6	176.5	183.3	188.7
Count	21	22	22	22	19	19	19	19	19	19

the results are $K'_{w10}(\text{summer})=19.85$ and $K'_{w10}(\text{winter})=6.00$. This suggests that in the smaller data sets at the 95% confidence level at least one node differs from the population mean during the summer but during the winter the streams share a population mean.

The differences between the sample nodes may result from several factors including, among others, differences in stream lengths above each collection point, water volumes in each stream, amount of exposure to the sun, and the elevation of the collection points. For example, HOOP a collection point which is at high elevation (>1500 m), has low flow volumes, and lacks vegetative cover due to the road construction has the highest range in temperature of any of the streams in the study (Table 3-15). Sillsbee and Larson (1982) noted that stream temperature decreases by approximately $7^{\circ}\text{C}/305$ meters of elevation in the Great Smoky Mountains National Park. They also stated that, during the winter season, daily fluctuations in stream water temperature are greater than daily temperature fluctuations observed during the summer. Sillsbee and Larson (1982) indicated that these daily temperature fluctuations may be the result of increases in radiative heating and cooling caused by a winter-time lack of leafy cover. Although the fluctuation in temperature over the course of a day may explain some of the variation seen in the data for this study, factors causing variations within the temperature data set are too complex to be totally explained with the information gathered in this study. In addition no obvious pattern is observed between streams draining the highway and streams draining areas uninfluenced by the highway. It is possible that other influences on temperature overprint any patterns associated with the highway construction.

Dissolved oxygen

The concentration of dissolved oxygen is a function of an equilibrium reaction which is mainly controlled by temperature and atmospheric pressure (Hem and others, 1990). Dissolved oxygen plays an important role in the ability of a stream to support aquatic life (Hem and others, 1990). Depletion of dissolved oxygen in surface waters may be the result of the presence of oxidizable metal ions or organic compounds (Hem and others, 1990).

Dissolved oxygen measurements are presented in Table 3-4 and Table 3-16 statistically summarizes the dissolved oxygen data collected in this study. Figure 3-3, the distribution of dissolved oxygen over time, shows no obvious seasonal variation. Individual graphs for each stream illustrating the dissolved oxygen concentration over time can be found in the Appendix (Figures A-11 to A-20). The mean dissolved oxygen concentration for all streams in the study is 9.9 mg/L (Table 3-14). This value is near the saturation concentration for dissolved oxygen at the temperature and pressure ranges present during the study. Dissolved oxygen values near the equilibrium saturation concentration are a favorable indicator of stream health and suggest that the streams are well aerated. The minimum and maximum dissolved oxygen values, 4.40 and 22.00 mg/L respectively, may be outliers resulting from natural processes which consume organic matter in the water, processes related to photosynthesis, or instrument problems (Hem, 1992). The dissolved oxygen meter was the least reliable instrument used in this study especially when exposed to harsh weather conditions.

The Kruskal-Wallis statistic computed on the dissolved oxygen data for all the streams in the study, $K'_{w10} = 10.54$, indicates that dissolved oxygen values for each stream share a common population mean at the 95% confidence

Table 3-16. General statistics for dissolved oxygen data for each sample node in the study.

STATISTIC	HEM	SM	JOHN	HAW	HOOP	HUCK	HB1	HUCK	BJ	WHIG
						2		1		
Mean	11.4	10.7	9.4	9.9	8.9	9.7	9.2	9.3	10.2	9.7
Median	9.8	9.2	9.5	9.7	9.3	9.3	8.7	8.6	9.9	9.6
Mode	8.8	9.2	9.7	8.8	N/A	8.8	8.1	8.6	9.8	N/A
Std. Deviation	3.6	3.3	1.6	1.6	2.4	1.7	1.7	1.5	1.1	1.4
Range	11.8	13.6	8.0	5.0	7.6	6.3	6.1	4.3	4.0	5.5
Minimum	7.2	8.4	6.0	8.0	4.4	7.3	7.3	7.7	9.0	7.3
Maximum	19.0	22.0	14.0	13.0	12.0	13.5	13.4	12.0	13.0	12.8
Sum	181.8	182	149.8	158.3	106.7	106.75	110.9	111.91	122.5	106.6
Count	16	17	16	16	12	11	12	12	12	11

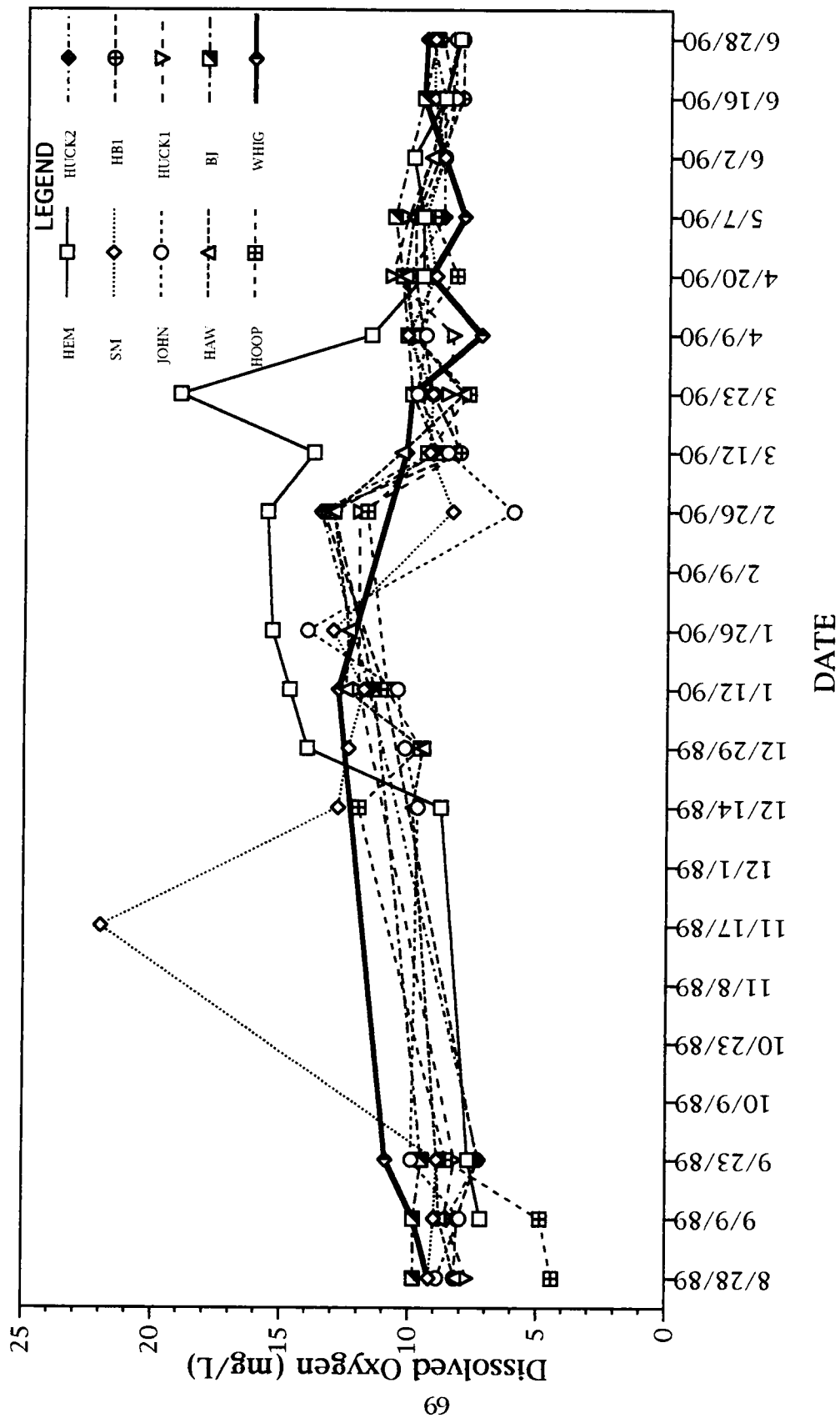


Figure 3-3. Dissolved oxygen measurements for all sample nodes over the duration of the study.

are $K'_{w10}(\text{summer})=12.61$ and $K'_{w10}(\text{winter})=15.66$. Suggesting that in each of the smaller data sets the data share a common population mean. This suggests that streams draining the construction areas do not significantly differ, with respect to dissolved oxygen, from streams draining unconstructed areas.

pH

The measure of hydrogen ion, H^+ , activity (concentration) expressed in logarithmic units is defined as pH (Hem, 1992). Values range from 1 to 14 with 7 being neutral and at 25 C° pure water has a pH of 7.00 (Hem, 1992). Water at equilibrium with carbon dioxide in the atmosphere ranges in pH from about 5.6 to 5.7 (Snoeyink and Jenkins, 1980; Hem and others, 1990). In addition to H^+ several species can lower the pH of surface water. The presence of organic acids, NO_3^- , SO_4^{2-} , and soluble aluminum can lower the pH of streams (Joslin and others, 1987). In a similar fashion, streams receiving AD often display low pH values. One example of a stream with low pH values resulting from AD inputs is found in the Great Smoky Mountains National Park, where the pH of Beech Flats Prong decreases noticeably as the stream passes under an AD producing road fill (Huckabee and others, 1975; Bacon and Maas, 1979; Sillsbee and Larson, 1981).

Measured pH values collected in this study are compiled in Table 3-5 and are statistically summarized in Table 3-17. General trends in measured pH values over the duration of the study are illustrated in Figure 3-4. In this figure obvious seasonal variations in pH readings are evident, as seasonal effects lower pH values during the winter months. Individual graphs for each stream are found in the Appendix (Figures A-21 to A-30).

Table 3-17. Summary statistics for pH at each sample node in the study.

STATISTICS	HEM	SM	JOHN	HAW	HOOP	HUCK	HB	HUCK	BJ	WHIG
						2		1		
Mean	6.0	7.4	6.6	5.5	6.2	5.8	5.3	5.6	6.1	6.4
Median	5.6	6.5	6.1	5.3	5.4	5.8	5.3	5.4	5.8	6.3
Mode	N/A	6.6	6.3	5.3	N/A	5.1	N/A	4.8	5.1	N/A
Std. Deviation	6.1	81	7.1	5.7	6.7	5.8	5.1	5.9	6.2	6.3
Range	6.7	8.7	7.8	6.4	7.3	6.5	5.7	6.5	6.8	6.9
Minimum	4.0	4.8	4.4	3.9	3.9	4.3	3.9	3.9	4.7	5.2
Maximum	6.7	8.7	7.8	6.4	7.3	6.5	5.7	6.5	6.8	6.9

Notes: N/A indicates that the no mode was computed because each value was only found once in the data set.

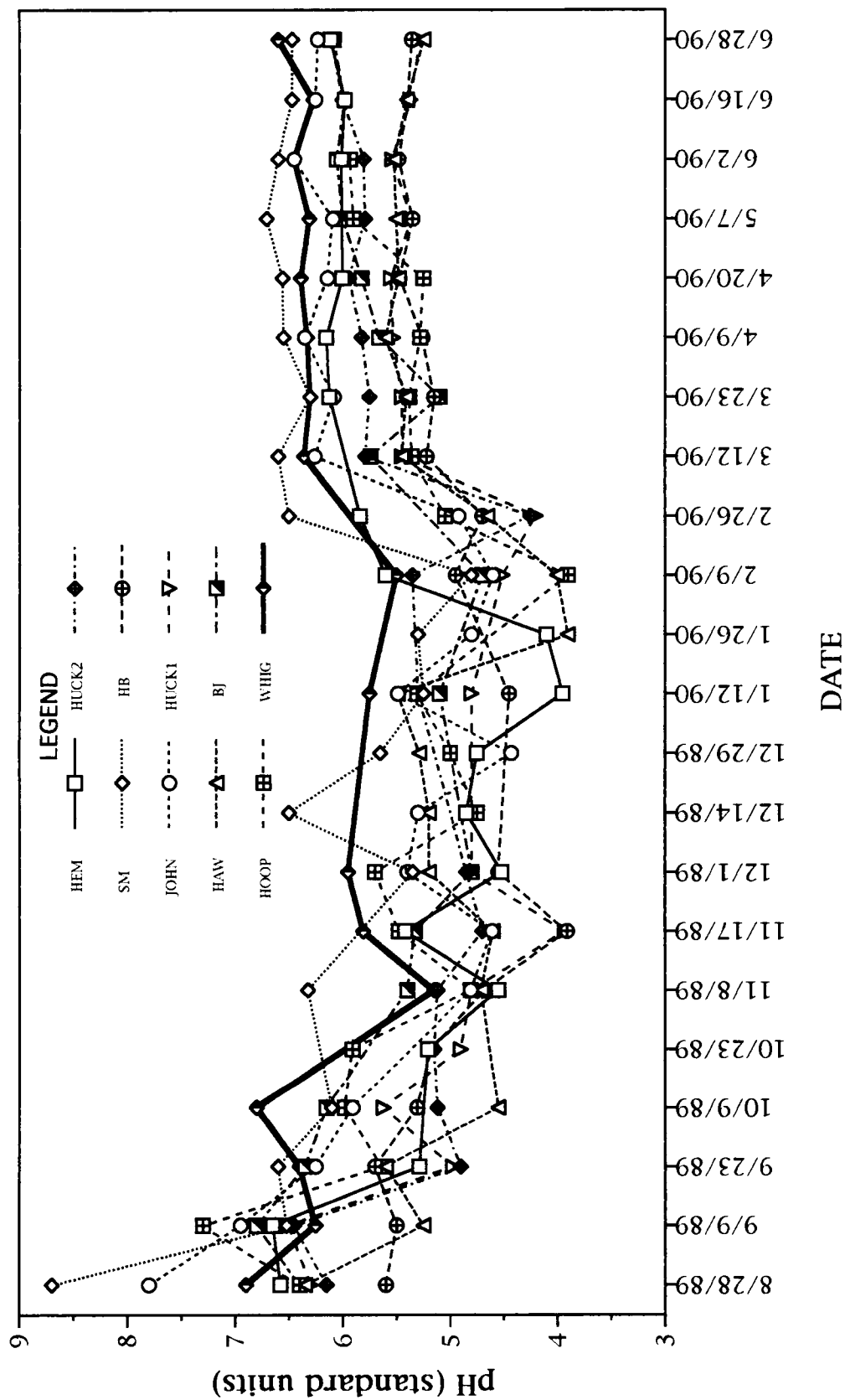


Figure 3-4. pH values through time for all sample nodes over the duration of the study.

The range of pH values for all streams in the study is 3.7 to 8.7 (Table 3-14). Minimum values range from 3.90 to 5.15 and maximum values range from 5.7 to 8.7 (Table 3-17). Figure 3-4 illustrates that the low pH values are not sustained for long periods of time. The Kruskal-Wallis statistic, $K'_{w10} = -10.81$, indicates that all of the streams in the study share a common population mean at the 95% confidence level. When the pH data is divided into summer and winter data sets and the Kruskal-Wallis statistic is re-computed for each season the results are $K'_{w10}(\text{summer}) = 43.77$ and $K'_{w10}(\text{winter}) = 25.45$. This suggests that in both of the smaller data sets at the 95% confidence level the data from at least one sample node differs from the population mean. This difference between the Kruskal-Wallis statistic determined for the entire data set and the Kruskal-Wallis statistic determined for the smaller data sets may result from the small number of points in the seasonal data sets, from the somewhat arbitrary choice of the dates to be included in each seasonal data set, or from some unknown factor.

Variation in the pH values may be influenced by many factors. Winger and others (1987) indicated that small high altitude streams generally have lower pH values and in general pH increases longitudinally downstream. Sillsbee and Larson (1982) also noted the trend of decreasing pH with altitude. Storm events can decrease the pH of streams due to rapid subsurface flow mobilizing soluble forms of sulfate (Joslin and others, 1987). Bedrock geology can also influence pH. A lack of minerals capable of providing buffering capacity combined with the presence of sulfide minerals in rocks underlying a watershed can contribute to low pH values in streams draining the watershed. An example of this can be seen in streams in the Great Smoky Mountains National Park where streams draining sulfide-bearing lithologies

exhibit low pH values (Huckabee and others, 1975; Bacon and Maas, 1979; Sillsbee and Larson, 1982).

The similarity of pH values between streams (as indicated by the Kruskal-Wallis statistic), and mean pH values near or above the equilibrium pH for water in contact with CO₂, suggests that the highway construction has no noticeable effect on the pH of streams in this study. Although low pH values were recorded during the study, depressed values were not sustained over long periods of time.

Specific conductance

Specific conductance, the ability of a substance to conduct an electrical current over a unit length and unit cross section at a given temperature, is influenced by many factors including the ionic concentration, dissolved solids concentration, and the ionic mobility of the solution (Hem, 1992). Specific conductance values for water cover a wide range. Typical values have been shown to range from 1 $\mu\text{mho}/\text{cm}$ to 50,000 $\mu\text{mho}/\text{cm}$ (Hem, 1992). Sillsbee and Larson (1982) found that specific conductance values in streams of the Great Smoky Mountains National Park are significantly influenced by underlying geology. Herlithy and others (1991) noted that high specific conductance values are often associated with streams receiving AD, thus, specific conductance measurements may be a possible indicator of AD problems.

Specific conductance values measured for this study are given in Table 3-6. Table 3-18 contains a statistical summary of the specific conductance data and general trends in measured specific conductance values are illustrated in Figure 3-5. Although Figure 3-5 shows no obvious seasonal influence on specific conductance values, a slight seasonal variation is noted in the

Table 3-18. Summary statistics for specific conductivity for each sample node in the study

STATISTIC	HEM	SM	1	JOHN	HAW	HOOP	HUCK	HB1	HUCK	BJ	WHIG
							2		1		
Mean	29.2	25.0	24.6	20.4	20.8	19.1	19.1	19.8	19.3	17.3	14.7
Median	23	16	9.5	9	10	8	8	10	8	13	11
Mode	23	15	9	9	10	5	5	10	8	12	10
Standard Deviation	23.2	32.8	42.9	41.9	27.4	36.5	36.5	29.3	38.2	13.5	13.9
Range	103	154	175	196	104	153	153	122	164	60	62
Minimum	6	6	5	4	5	5	5	8	5	10	9
Maximum	109	160	180	200	109	158	158	130	169	70	71
Sum	612.05	549.2	540	448	396	363	363	377	367	329	280
Count	21	22	22	22	19	19	19	19	19	19	19

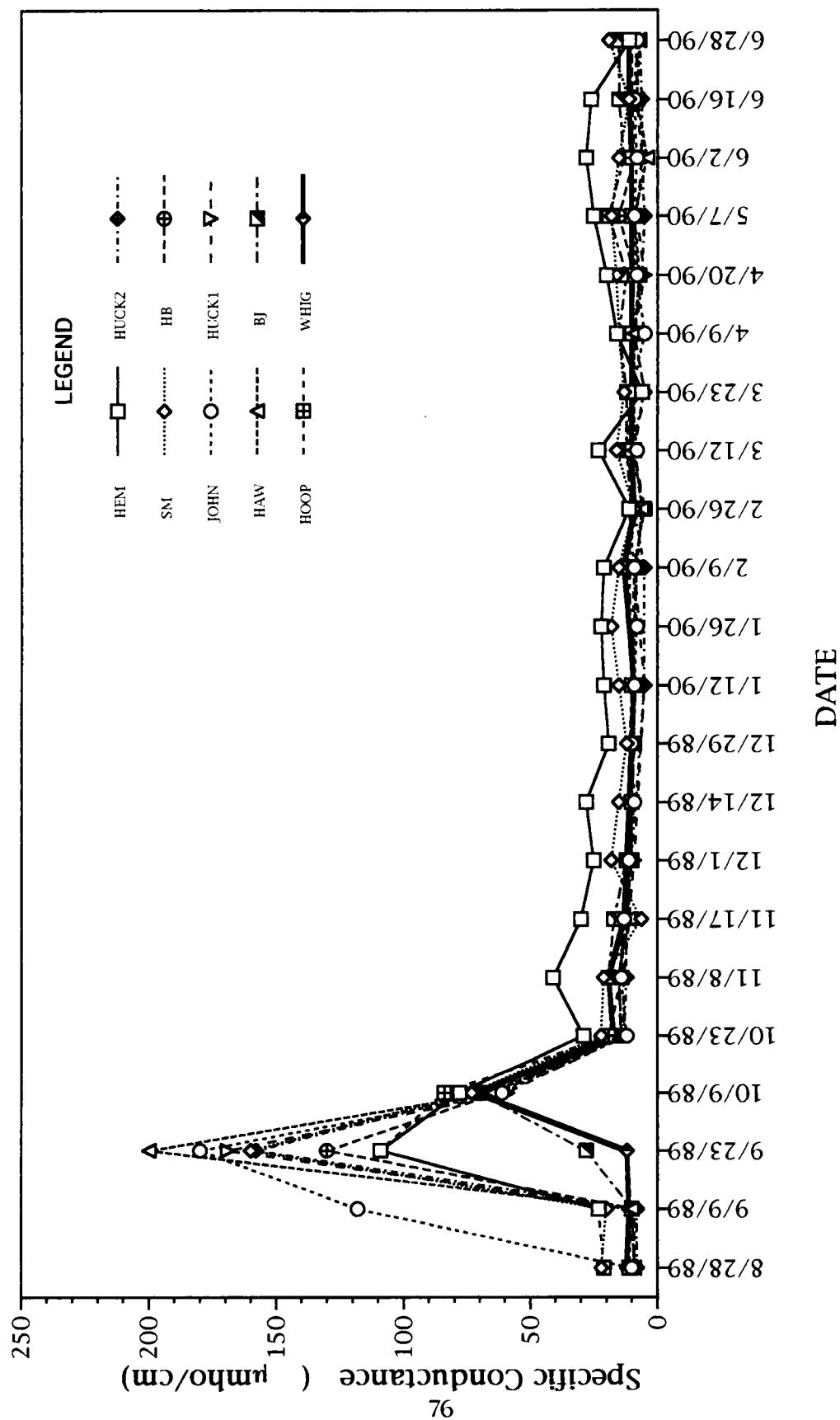


Figure 3-5. Specific Conductance values through time for all sample nodes over the duration of the study.

individual graphs for each stream found in the Appendix (Figures A-31 to A-40). Over the course of the study, the specific conductance values for each stream generally fluctuated over a narrow range. Exceptions to this are found in the data for two sampling events 9/23/89 and 10/9/89. During these events all streams nodes exhibit elevated specific conductance readings. The exact reasons for these increases in specific conductance cannot be determined from the available data. Two possible reasons, precipitation and leaf drop, may be related to these increases in specific conductance. Precipitation occurred on the day of sampling for the 9/23/89 event. The highest specific conductance values were measured on this date. This sample event occurred during a rainfall event as is illustrated in Figure 3-6. Precipitation data from the Tennessee Valley Authority Stratton Meadows rain gauge is given in Table A-3 which is located in the Appendix. Although the possibility exists that rainfall may dilute streams and decrease the specific conductance, studies have shown that rainfall can flush soluble components from the soils and forest litter and in fact raise the specific conductance of stream water (Sillsbee and Larson, 1982). The other possibility proposed is that the increase in specific conductance is related to the change of the seasons and the fall leaf-drop in the study area. More data is required to confirm either of these theories.

The Kruskal-Wallis statistic, $K'_w 10 = 10.37$, suggests that all of the streams in the study share a common population mean at the 95% confidence level. The median value for specific conductance is $11 \mu\text{mho}/\text{cm}$ (Table 3-14).

Although variation exists in the data set, no continuously high specific conductance readings are evident in the study area. Short term elevations in specific conductance may result from precipitation events or other random

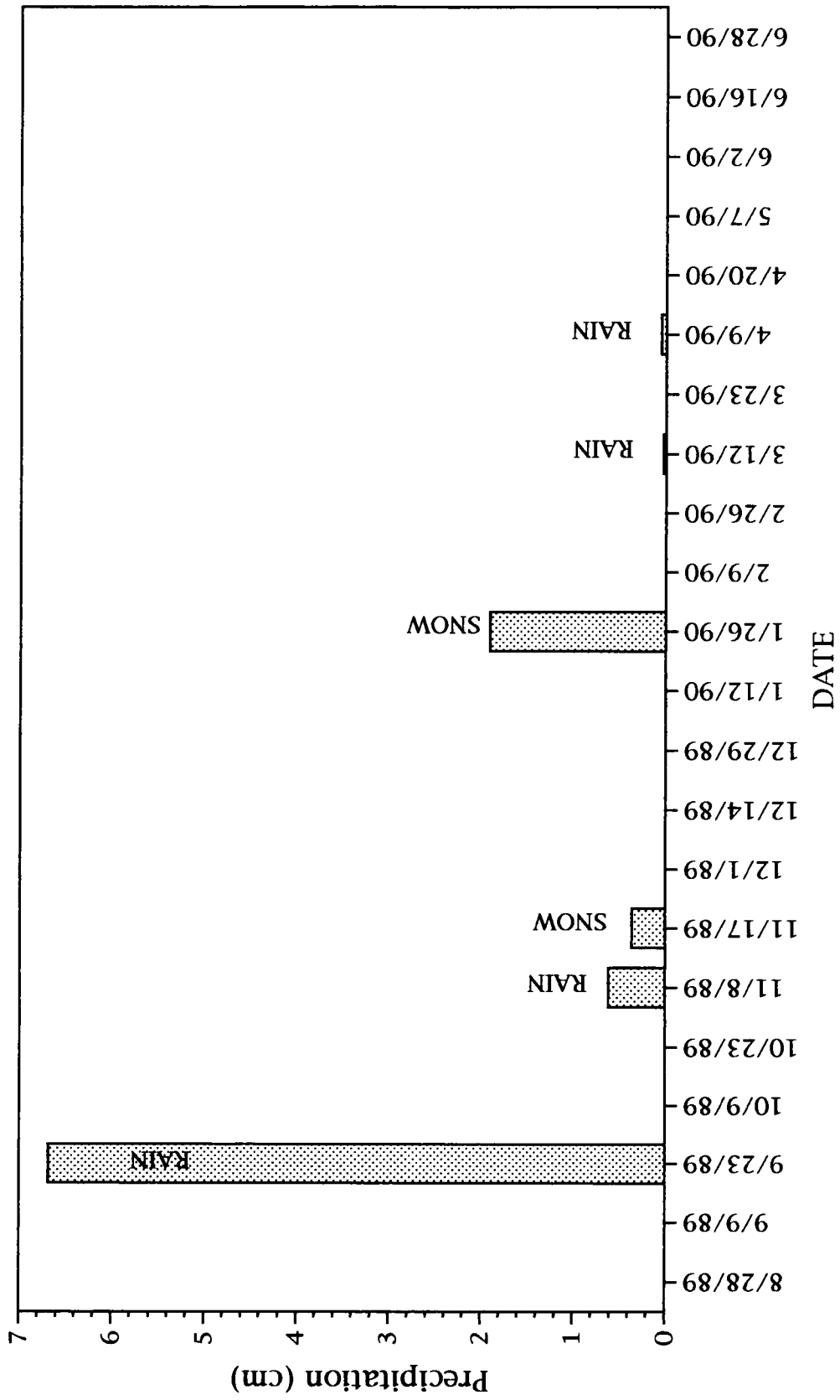


Figure 3-6 . Precipitation occurring on the day of sample collection.

forces. A natural or manmade geologic source of high specific conductance would be a continuous problem noticeable for the duration of the study. The relatively low values of specific conductance, as well as similarity in the data sets (as indicated by the Kruskal-Wallis statistic), suggests little difference between highway-influenced and nonhighway-influenced streams in this study.

Sulfate

The concentration of sulfate in streams is governed by many factors. Sulfate can originate from the weathering of sulfide minerals and increased concentrations of sulfate from this type of source were noted to occur in the Great Smoky Mountains National Park (Huckabee and others, 1975). Forest soils can act as a sink for atmospherically deposited sulfate, releasing sulfate when the soils are flushed during storm events (Johnson and Henderson, 1979). This release of sulfate may account for episodic rises in sulfate concentrations in headwater streams in the Walker Branch watershed in east Tennessee near Oak Ridge National Laboratory (Johnson and Henderson, 1979). Since sulfide minerals are common in the study area, the obvious suspected source of any increase in sulfate concentration is geologic in nature. Historical data shows that previous highway construction within rocks associated with the study area increased sulfate concentration in some streams (Morgan and others, 1978).

Sulfate measurements are given in Table 3-7 and a statistical summary is presented in Table 3-19. Figure 3-7 shows general trends in the sulfate measurements collected over the course of this study. Graphs of sulfate concentration over time for each individual stream in the study are located in

Table 3-19. Summary statistics for sulfate data. Data represents each sample node sampled in this study.

STATISTIC	HEM	SM	HAW	JOHN	HOOP	HUCK	HB	HUCK	BJ	WHIG
						2		1		
Mean	11.2	0.8	0.4	0.5	1	0.6	0.6	0.5	1.2	0.8
Median	11.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Mode	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Std. Deviation	2.7	1.3	1.2	1.5	1.2	1.6	1.4	1.0	1.9	1.4
Range	10.0	5.0	5.0	6.0	4.0	6.0	5.0	3.0	6.0	5.0
Minimum	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	18.0	5.0	5.0	6.0	4.0	6.0	5.0	3.0	6.0	5.0
Sum	191	15	8	9	16	9	9	8	18	13
Count	17	19	19	18	16	16	15	16	15	16

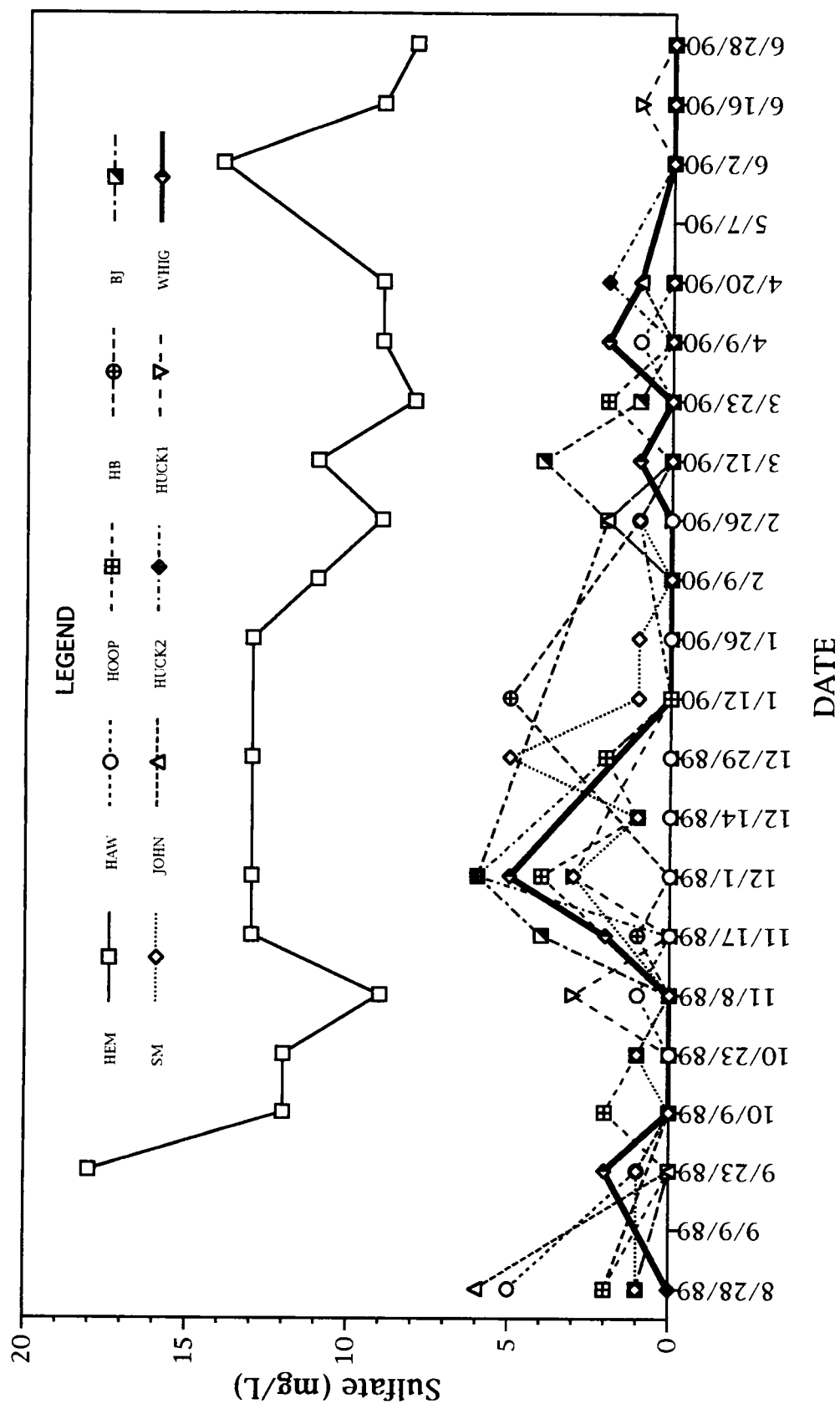


Figure 3-7. Sulfate concentrations through time for all sample nodes in the study.

the Appendix (Figures A-41 to A-50). Since no obvious seasonal variation is seen in Figure 3-7, the most notable trend with respect to sulfate data is the relatively high values for HEM. The highest sulfate value measured in this study was recorded at this sample node during the 9/23/89 rainfall event. The elevated values measured at HEM are likely to be the result of untreated sulfidic material from road fills constructed in the past. The Kruskal-Wallis statistic computed for all streams in the study is $K'_{w10} = 55.09$ indicating that at least one stream in the data set has a mean significantly different than the population mean at the 95% confidence interval. By omitting HEM from the data set and re-computing the Kruskal-Wallis statistic $K'_{w9} = -10.21$. This suggests that all streams in the immediate study area share a common population mean with respect to sulfate concentration. Therefore, sulfate values collected within the immediate study area for streams draining construction and streams draining undisturbed portions of the watershed are not significantly different at the 95% confidence level. Values for sulfate for streams in the immediate study area are low (6 mg/L or less). Values of 0 mg/L in the data set represent analyses where sulfate concentrations were below the detection limit of the method of analysis. The low sulfate concentrations coupled with statistical inferences that the streams draining disturbed and undisturbed portions of the watershed are similar, suggests that the highway construction has no notable impact on streams draining the construction area.

Acidity

Acidity measured in a water sample usually can not be attributed to any single species (Hem, 1992). Hem (1992) indicates that sources for acidity in surface waters may include acid rain, oxidation of sulfide minerals, and

dissolved CO₂. Table 3-8 contains acidity values measured during this study and Table 3-20 contains a statistical summary of the data. No apparent seasonal influence is evident in Figure 3-8 as values tend to fall within a narrow range. Individual graphs of acidity values measured at each sampling node can be found in the Appendix (Figures A-51 to A-60). The Kruskal-Wallis statistic for all streams in the study and for only the streams in the immediate study area, $K'_{w10} = 55.62$ and $K'_{w9} = 44.85$ respectively, indicate that at least one stream in each data set has a mean significantly different than the population mean at the 95% confidence level. A maximum acidity value, 68.0 mg/L as CaCO₃, was measured at JOHN. When this value is compared to the entire acidity data set it is apparent that this high value is an outlier caused by sample handling or error in the laboratory. Acidity values observed in all streams are generally low. Several values in the data are below zero. Negative acidity values are not unique to this study. Jago (1989) measured several negative acidity values during leaching experiments on rocks from the vicinity of the study area. During this study, acidity values for SM, with a few exceptions, were consistently negative. The lack of acidity at this site is unexplainable. Possible reasons for the negative acidity values include acidity consumption by the highway construction materials or by other geologic sources. Acidity values measured at sample nodes along streams draining the highway versus values measured at sample nodes along streams draining undisturbed watersheds show no significant difference.

Calcium

Hem (1992) reports that sources for calcium in surface waters can include many igneous and metamorphic rocks, especially rocks containing

Table 3-20. Summary statistics for acidity data at each sample node.

STATISTIC	HEM	SM	JOHN	HAW	HOOP	HUCK	HB	HUCK	BJ	WHIG
						2		1		
Mean	2.2	-1.8	4.1	2.3	3.1	2.2	2.1	2.1	1.6	1.2
Median	1.9	-1.8	0.6	1.8	2.2	1.4	1.6	2	1.6	0.8
Mode	1.6	-1.2	0	1.2	1.4	1.2	1.6	4.4	1.2	0
Std. Deviation	1.5	1.6	14.7	1.7	2.3	2.6	1.3	1.2	1.2	2
Range	5.6	6.4	70.8	6.3	7.4	11.5	4.6	4.4	4.9	8.1
Minimum	0	-5.2	-2.8	0.5	0.2	-0.7	0.2	0.0	-0.3	-0.9
Maximum	5.6	1.2	68	6.8	7.6	10.8	4.8	4.4	4.6	7.2
Sum	39.5	-38.3	86.4	49.1	49.2	38.9	35.4	36.4	26.7	17.9
Count	18	21	21	21	16	18	17	17	17	15

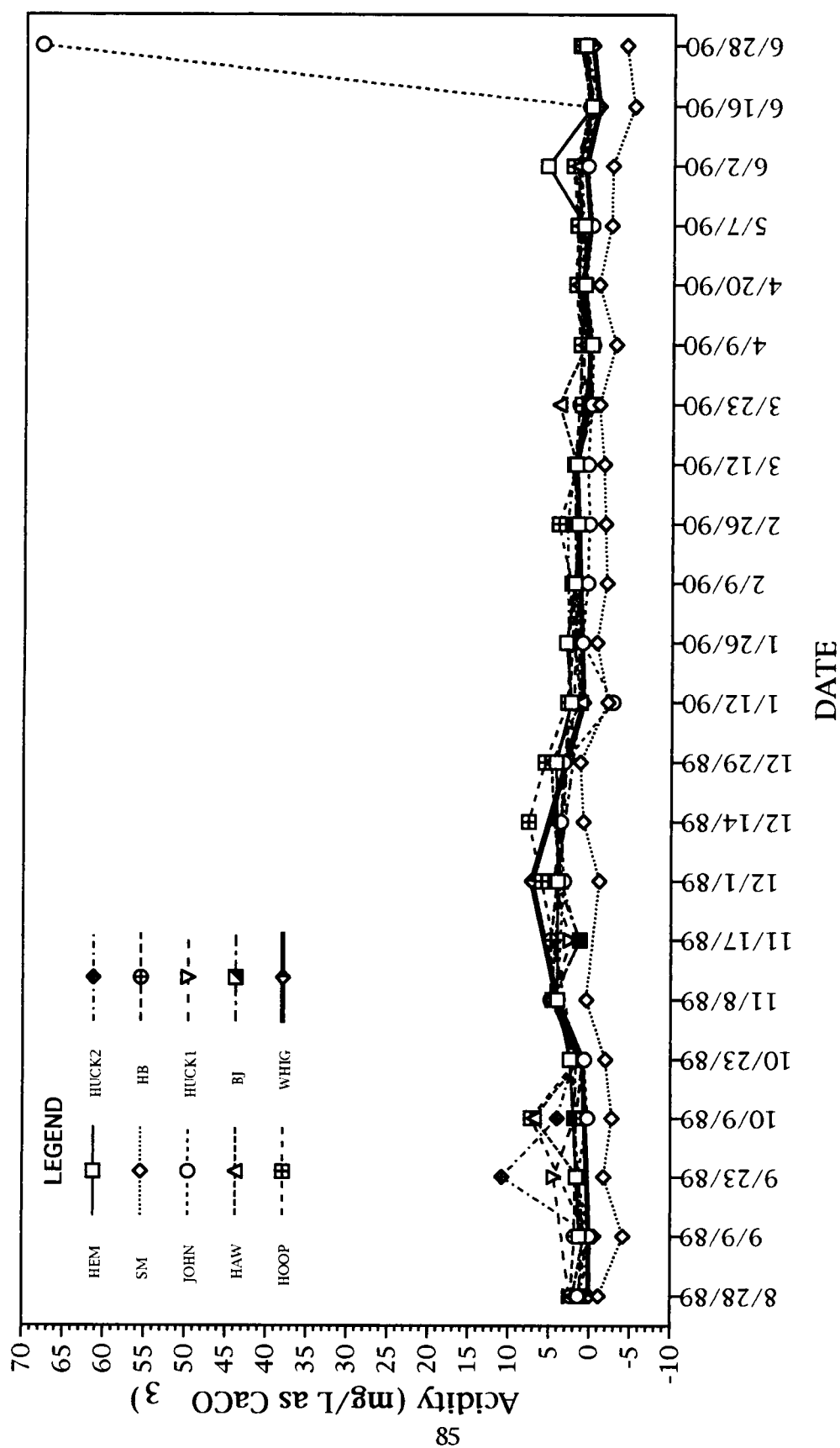


Figure 3-8. Acidity concentrations through time for all sample nodes over the duration of the study.

pyroxene, amphibole or feldspar. Carbonate rocks (limestone and dolomite) may also act as sources for calcium. Petrographic identification of potential mineralogical sources of calcium underlying watersheds in the study area include feldspar, amphibole, epidote, and calcite. In addition to calcium carbonate naturally occurring in the rocks, agricultural lime and limestone aggregate (CaCO_3) are used in the construction process to abate potential AD produced by the road fills and to fertilize newly planted grass. Thirty four rock samples were analyzed by X-ray fluorescence for calcium. The results show an average calcium concentration in the rocks of the field area, expressed as CaO, of 2.7%. Concentrations of CaO in rocks ranged from values below the detection limit to 28.9% (Table 3-21).

Results from the analysis of calcium in surface water are presented in Table 3-9 and are summarized in Table 3-22. The Kruskal-Wallis statistic computed for all streams in the study and for only streams in the immediate study area yields values of $K'_{w10} = 104.63$ and $K'_{w9} = -24.57$ respectively. In both cases, at least one stream in the data set differs from population mean significantly at the 95% level. Trends in the distribution of calcium concentration are illustrated in Figure 3-9. This figure shows no obvious influence due to seasonal influences. The elevated values recorded for SM and HEM on 9/23/89 may be related to the storm event which occurred during the sample collection (Figure 3-6). For streams unaffected by road construction, JOHN, HAW, and HUCK1, the data show fairly consistent readings; whereas, streams possibly influenced by construction, HEM, SM, HB, and BJ, show more variation within each of their respective datasets. Individual graphs for each stream are located in the Appendix (Figures A-61 to A-70). Three streams,

Table 3-21. Summary statistics for major elemental components found in rock samples from the study area.

STATISTIC	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	K ₂ O	CaO	Cu	TiO ₂	MnO	Fe ₂ O ₃	Ni	Zn	S
	%	%	%	%	%	%	%	ppm	%	%	%	ppm	ppm	%
Mean	2.4	3.1	15.3	65.0	0.3	2.9	2.7	27	0.7	0.1	5.6	88	74	0.4
Median	2.2	2.5	14.3	68.6	0.2	2.8	1.0	26	0.7	0.1	5.3	38	69	0.1
Std Deviation	0.8	3.5	4.9	12.5	0.2	2.0	5.4	9	0.3	0.1	2.3	254	31	0.6
Minimum	0.8	0.3	5.1	35.2	0.0	0.0	0.0	9	0.1	0.0	1.0	11	29	0.0
Maximum	4.4	21.0	25.9	95.2	0.8	7.3	28.9	52	1.3	0.8	10.6	1513	168	2.7
Count	34	34	34	34	34	34	34	34	34	34	34	34	34	33

Notes: Sulfur analyzed using a LECO sulfur furnace, % = percent.

Table 3-22. Summary statistics for calcium data collected at each sample node in the study area.

STATISTIC	HEM	SM	JOHN	HAW	HOOP	HUCK	HB	HUCK	BJ	WHIG
						2		1		
Mean	2.1	2.5	0.8	0.7	0.7	1.2	0.81	0.4	1.4	1.1
Median	2.1	2.1	0.7	0.7	0.7	1.3	0.8	0.4	1.4	1.2
Mode	N/A	N/A	0.6	0.7	0.7	N/A	0.8	0.4	N/A	1.2
Std. Deviation	0.4	0.9	0.1	0.0	0.1	0.2	0.22	0.1	0.2	0.4
Range	1.6	3.4	0.4	0.1	0.3	0.5	0.73	0.2	0.6	1.4
Minimum	1.3	2.0	0.6	0.6	0.6	1.0	0.5	0.3	1.1	0
Maximum	3.0	5.3	1.0	0.7	0.9	1.5	1.23	0.5	1.7	1.4
Sum	25	29.5	9.2	8.0	7.7	14.9	9.77	5.3	17.1	14.8
Count	12	12	12	12	11	12	12	13	12	13

NOTE: N/A indicates no duplicate values to determine the mode.

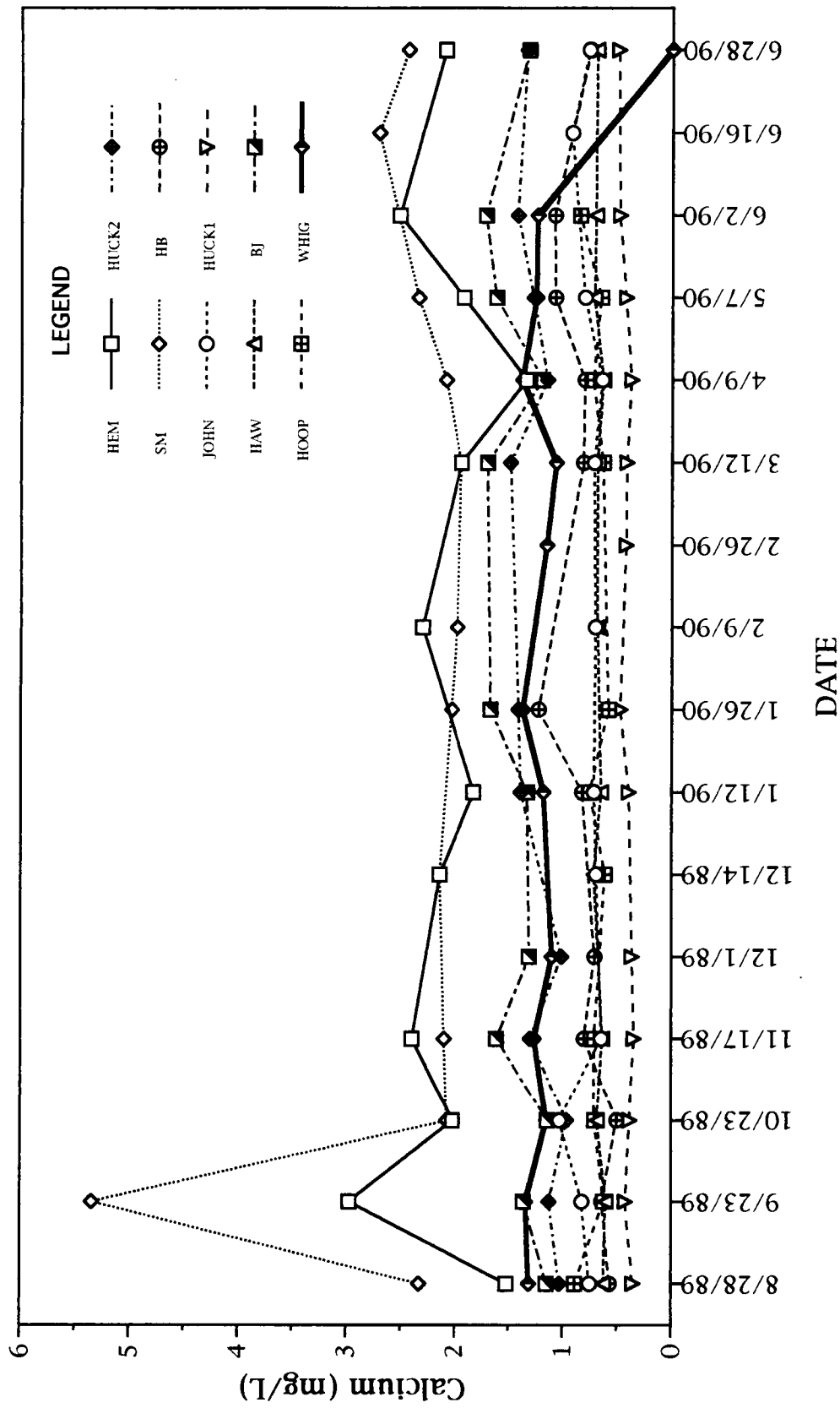


Figure 3-9. Calcium concentrations through time for all sample nodes in the study.

HUCK2, WHIG and HOOP, differ from this pattern. Variation seen within the data set for HUCK2, a stream uninfluenced by the highway construction, is indicated by a higher standard deviation (0.2 mg/L) when compared to data for JOHN, HAW, and HUCK1 (standard deviations of 0.1, 0.0, and 0.1 respectively). This variation may result from agricultural lime applied to an access road constructed upstream of the sample point. WHIG and HOOP, both streams receiving drainage from the road, show less variation in their data sets than other streams draining construction areas. WHIG receives drainage from the road via two first order streams and is located farthest from the road construction of any of the collection points. Calcium data collected at WHIG, because of the distance between the sampling location and the highway, may be influenced by dilution and a decrease of any effects related to the road construction. Although HOOP is located close to the road, it may lack variation due to its position along the segment of highway under construction. HOOP was located at the end of the construction project and water sample collection at this site was completed prior to the active construction of road fills in the area, thus application of agricultural lime occurred after the water monitoring was completed. The pattern that develops suggests that in areas unaffected by construction, the calcium input to streams is fairly constant representing weathering type reactions. Variation in calcium input to streams draining construction areas may result from the use of calcium carbonate as a road construction material. Calcium data yields the most noticeable differences between areas undergoing construction and areas not impacted by construction.

Magnesium

Possible mineralogical sources of magnesium are amphibole, dark-colored mica, dolomite, chlorite, pyroxene, olivine, and serpentine (Hem, 1992). Petrographic analysis of rock samples from the study area identifies the presence of biotite, chlorite, and amphibole. Biotite and chlorite are very common in the rocks underlying the study area. Thirty four rock samples analyzed by X-ray fluorescence show that the mean value of magnesium in rock samples, expressed as MgO, is 3.49%. Magnesium content of the rocks ranged from 0.3% to 21.06% thus, a source for Mg is present in the study area (Table 3-21).

No seasonal variation was noted in the trends in magnesium concentrations which are illustrated in Figure 3-10. Graphs for individual streams are located in the Appendix (Figures A-71 to A-80). Magnesium values tend to fluctuate within a limited range. Elevated magnesium concentrations, relative to other streams in the study, are found at HEM and SM (Figure 3-10). This trend is also seen in the summary statistics found in Table 3- 23. The Kruskal-Wallis statistic for all streams in the study and for only the streams in the immediate study area yields values of $K'_{w10} = 104.89$ and $K'_{w9} = 89.55$ respectively. In both cases, the values show that at least one stream in the study area differs from the population mean at the 95% confidence level. No obvious pattern was noted regarding differences with respect to magnesium concentration between streams influenced by the highway and streams beyond the influence of the highway. The narrow range of magnesium concentrations found within each stream suggests a constant source (weathering of geologic materials).

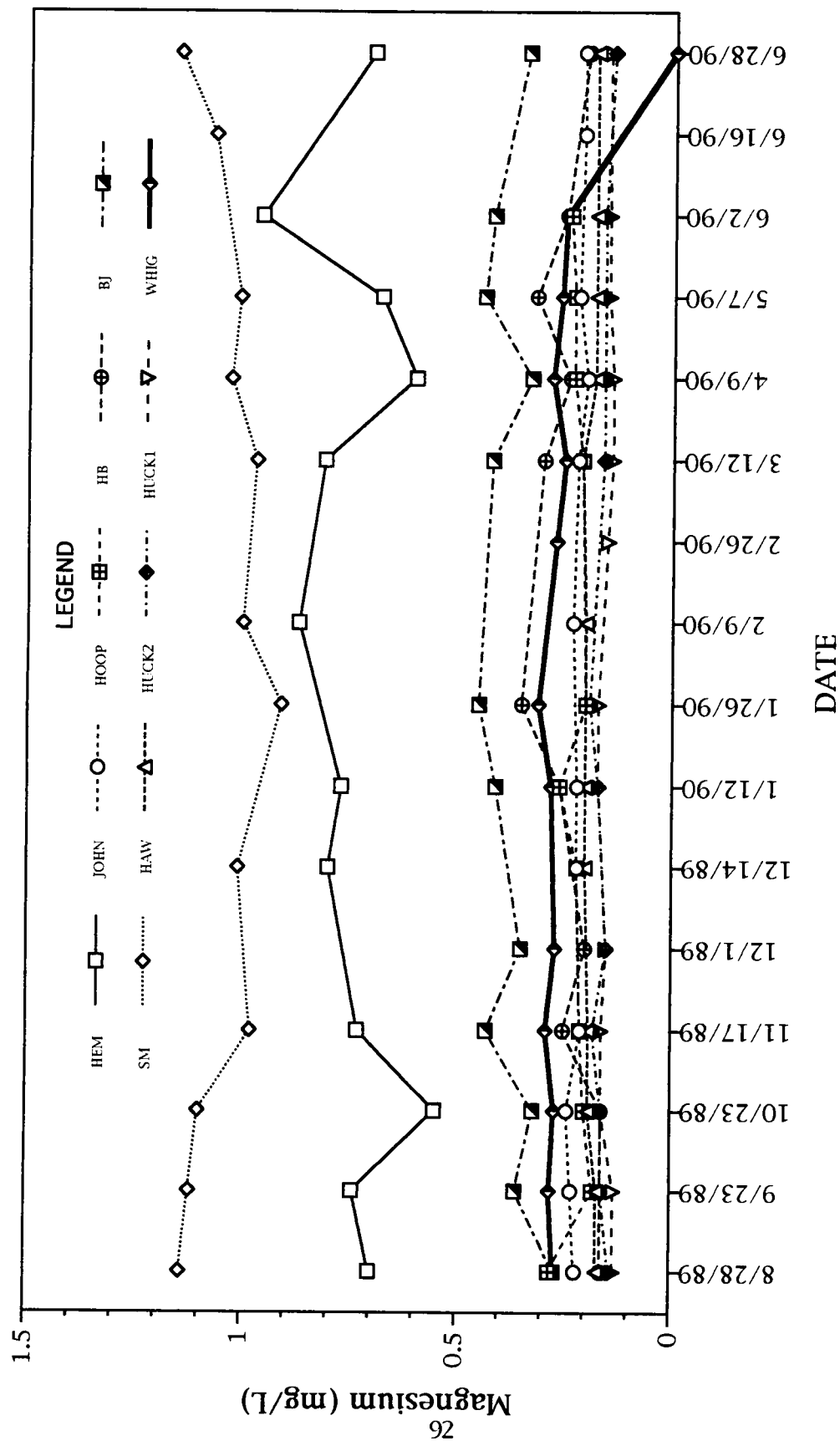


Figure 3-10. Magnesium concentrations through time for all sample nodes in the study.

Table 3-23. Summary statistics for magnesium data collected at each sample node in the study.

STATISTIC	HEM	SM	JOHN	HAW	HOOP	HUCK	HB	HUCK	HUCK	BJ	WHIG
						2		1			
Mean	0.7	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.3
Median	0.7	1.0	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.4	0.3
Mode	0.7	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.3
Std. Deviation	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1
Range	0.4	0.2	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.2	0.3
Minimum	0.6	0.9	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.3	0.0
Maximum	1.0	1.2	0.2	0.2	0.3	0.2	0.4	0.2	0.2	0.5	0.3
Sum	8.9	12.5	2.6	2.3	2.5	1.9	2.9	2.0	2.0	4.5	3.3
Count	12	12	12	12	11	12	12	13	12	12	13

Potassium

Hem (1992) indicates that potassium in surface water may be present due to weathering of alkali feldspar (orthoclase and microcline), mica, illite and other clay minerals. Petrographic analysis of rocks in the study area identifies alkali feldspar and white mica as the two most abundant minerals cited above. Illite has been identified by X-ray diffraction at some localities in the study area. Bulk rock analysis by X-ray fluorescence performed on 34 rock samples yields an average potassium content, expressed as K_2O , of 2.82% (Table 3-21). In the 34 rock samples, potassium concentrations ranged from values below the detection limit for the method of measurement to 7.3%. Given this source for potassium, it is possible that weathering of potassium-bearing minerals will result in the presence of potassium in water samples.

Table 3-11 contains the data from potassium analyses. A statistical summary of this data is found in Table 3-24 and Figure 3-11 shows the trend of potassium concentration for each stream for the duration of the study. Potassium concentrations for each sample site fluctuate within a narrow range (Figure 3-11 and Table 3-24). Individual graphs for each sample node are located in the Appendix (Figures A-81 to A-90). The Kruskal-Wallis statistic for all streams and only the streams in the immediate study areas gives values of $K'_{w10} = 100.48$ and $K'_{w9} = -88.79$ respectively. In both cases, the mean of at least one stream differs significantly from the population mean at the 95% confidence level. Figure 3-11 illustrates that the potassium data lack a pronounced seasonal variation. Most values, with the exception of HB, range between 0 and 1 mg/L. Elevated potassium values in HB may be the result of the sampling localities close proximity to the construction site and/or the weathering of potassium-bearing minerals in rock units underlying the area

Table 3-24. Summary statistics for potassium data. Data represents each sample node in the study.

STATISTIC	HEM	SM	JOHN	HAW	HOOP	HUCK	HB	HUCK	BJ	WHIG
						2		1		
Mean	0.4	0.7	0.4	0.3	0.3	0.2	2.8	0.2	0.3	0.4
Median	0.4	0.7	0.4	0.3	0.3	0.2	2.8	0.2	0.3	0.4
Mode	0.4	0.8	0.5	0.2	0.3	0.2	2.7	N/A	0.3	0.4
Std. Deviation	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1
Range	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.1	0.2	0.6
Minimum	0.4	0.6	0.4	0.2	0.3	0.2	2.8	0.1	0.2	0.0
Maximum	0.6	0.8	0.5	0.5	0.5	0.3	2.9	0.3	0.4	0.6
Sum	5.1	8.1	5.2	3.4	3.7	2.7	33.4	2.4	3.4	5.4
Count	12	12	12	12	11	12	12	13	12	13

NOTE: N/A indicates that no value was repeated for the computation of the mode.

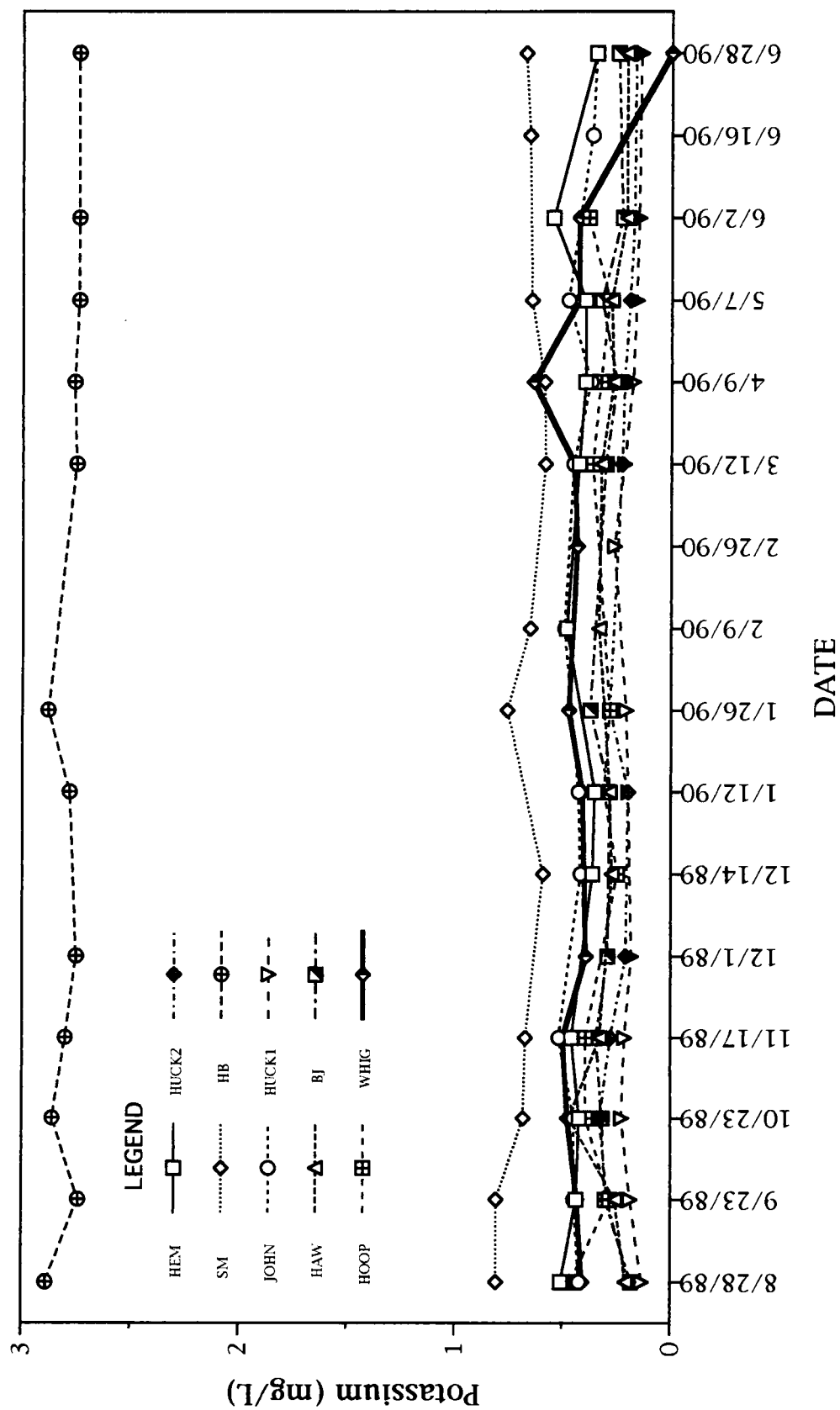


Figure 3-11. Potassium concentrations through time for all sample nodes in the study.

drained by HB. Two rock samples, ART-313 and ART-316, are from outcrops in drainage above HB (Figure 2-3) and range in potassium concentration from 0.81% to 7.29% expressed as K_2O . The 7.29 % value is the highest detected in any of the rock samples collected in this study. Otherwise, no obvious differences between streams draining the construction site and streams draining unconstructed areas is noted.

Sodium

Possible sources for sodium in the field area are the weathering of sodium-bearing minerals and road salt. Because of the unfinished nature of the highway, it is unlikely that road salt is used in the field area. Petrographic analysis indicates that plagioclase feldspar is the most common sodium-bearing mineral in rocks underlying the study area. Hem (1992) and Velbel (1985) both identify the weathering of plagioclase feldspar as a possible source for sodium in surface and groundwater. A geologic source for sodium is present in the field area and is indicated by analyses of 35 rock samples by X-ray fluorescence (Table 3-21). These analyses yield a mean concentration of sodium, expressed as Na_2O , of 2.4 %.

Sillsbee and Larson (1982) noticed a significant relationship ($p < 0.05$) between sodium concentration in surface water and elevation. They suggest that the lower concentrations of sodium at higher elevations may result from higher rainfall amounts and steeper slopes. The steep slopes and abundant water would decrease the retention time for water in contact with the bedrock and limit the ability of water to react with the sodium-bearing minerals. Low concentrations of sodium in streams draining high elevation watersheds underlain by rocks of the Anakeesta Formation, may reflect the dominance of

clay minerals over sodium-bearing feldspar in the bedrock (Sillsbee and Larson, 1982).

Data from all of the aqueous sodium analyses are compiled in Table 3-12 and Table 3-25 contains a statistical summary of the analytical data. The distribution of sodium for each stream for the duration of the study is illustrated in Figure 3-12 which shows that the concentration of sodium for each stream remains fairly constant. Graphs for each individual stream are located in the Appendix (Figures A-91 to A-100). The Kruskal-Wallis statistic computed for all streams in the study and for only the streams in the immediate study area yields values of $K'_{w10} = 86.91$ and $K'_{w9} = 67.81$ respectively. Both values suggest that at least one stream in the data set differs significantly from the population mean for all streams in the study. The elevated value recorded on 9/23/89 at sample node SM, may be the result of heavy rainfall during sample collection (Figure 3-6), the close proximity of the sampling node to the roadway (Figure 3-1), contamination of the sample in the laboratory or during collection, or some unknown factor. Obvious differences in sodium concentration between streams draining construction areas and non-construction were not observed. Variation between streams is unexplainable with the available data. Differences in elevation, stream length above the sample point, rock type, and the gradient of the stream may all contribute to the differences in sodium concentrations between streams.

Discharge

Discharge estimates are presented in Table 3-13. Because of these values are only estimates no summary statistics were computed for this parameter.

Figure 3-13 shows no notable seasonal variation in discharge but streams with

Table 3-25. Summary statistics for sodium data. Data for each sample node in this study.

STATISTIC	HEM	SM	JOHN	HAW	HOOP	HUCK	HB	HUCK	BJ	WHIG
						2		1		
Mean	1.0	0.8	0.6	0.5	0.4	0.5	0.5	0.5	0.5	0.6
Median	1.0	0.7	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.6
Mode	0.9	0.7	0.5	0.4	0.4	0.4	N/A	0.5	0.5	0.6
Std. Deviation	0.1	0.2	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.2
Range	0.3	0.7	0.2	0.3	0.1	0.2	0.2	0.2	0.2	0.9
Minimum	0.9	0.7	0.5	0.4	0.3	0.4	0.4	0.5	0.5	0.0
Maximum	1.2	1.3	0.7	0.7	0.4	0.6	0.6	0.6	0.6	0.8
Sum	11.8	9.0	6.7	5.5	4.1	5.8	5.5	6.9	6.3	7.5
Count	12	12	12	12	11	12	12	13	12	13

NOTE: N/A indicates no duplicate measurements were available for computation of the mode.

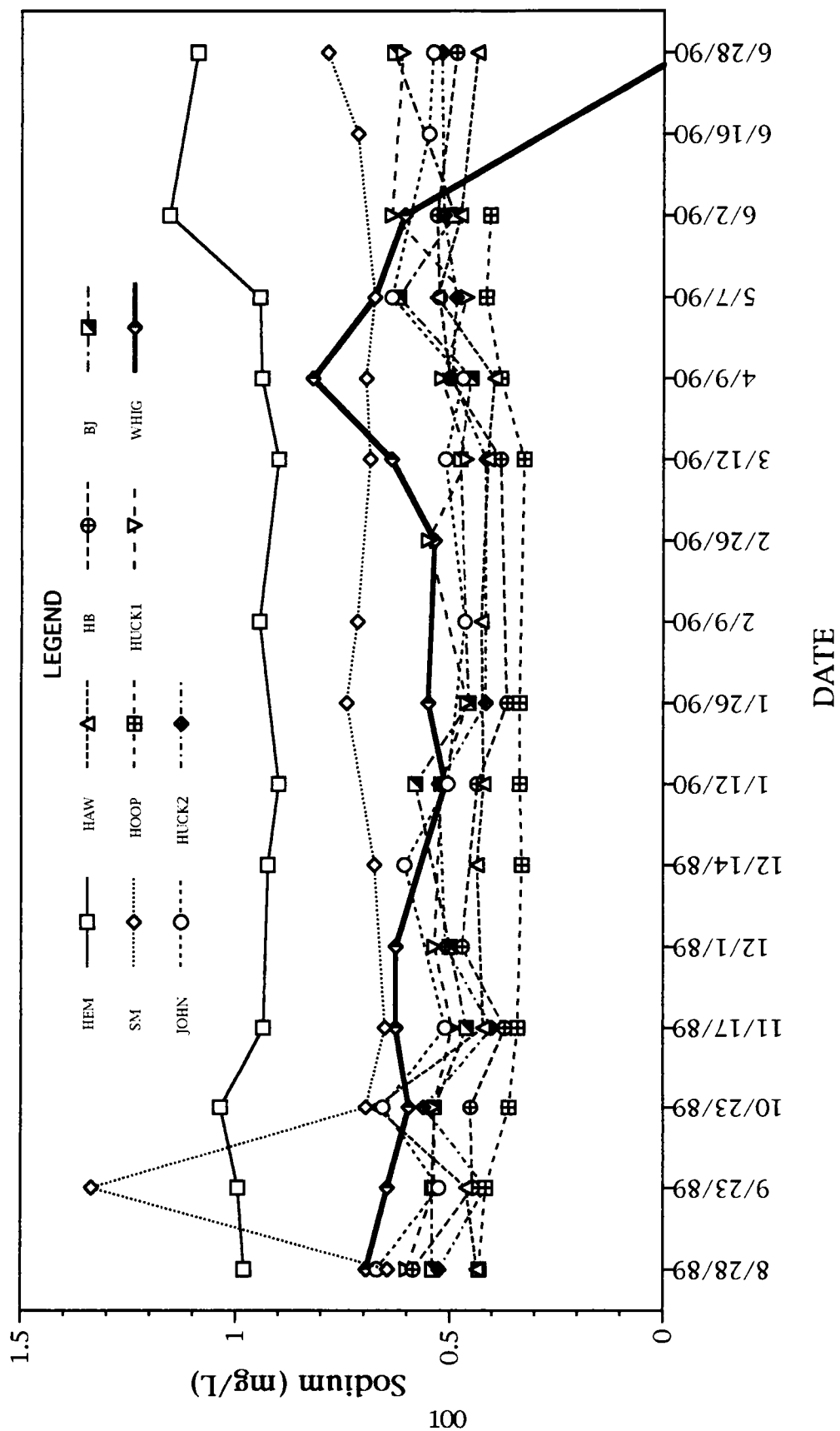


Figure 3-12. Sodium concentrations through time for all sample nodes in the study.

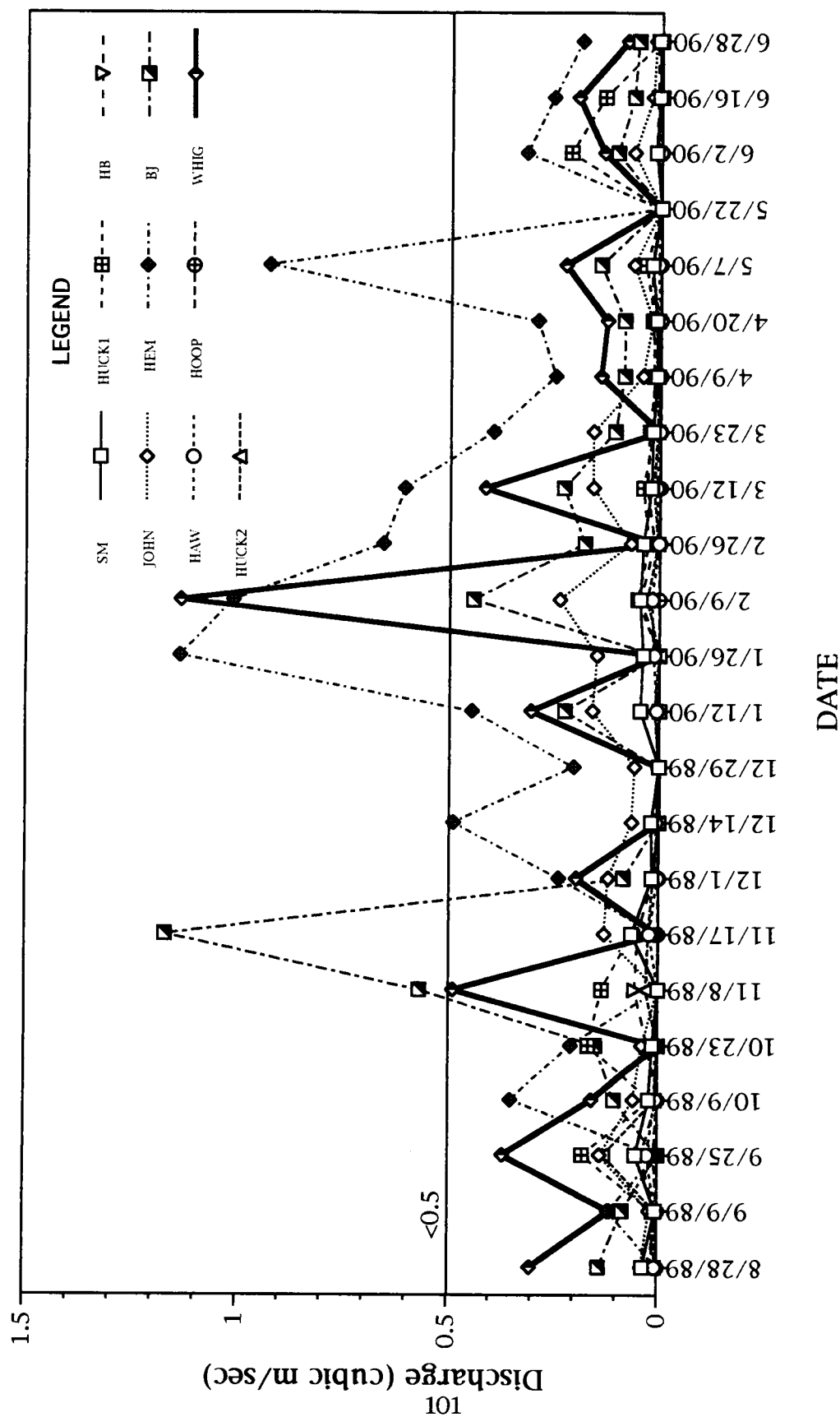


Figure 3-13. Discharge for all sample nodes in the study.

the highest flow (HEM, JOHN, BJ, and WHIG) demonstrate more variability in the discharge data set. This may be a result of errors in the measurement procedures. Individual graphs for each stream are located in the Appendix (Figures A-101 to A-110). Discharge often influences other parameters (Sillsbee and Larson, 1982). Sillsbee and Larson (1982) noted general decreases in temperature, hardness, alkalinity, and pH, and increases in nitrate, specific conductance, and turbidity in relation to increased discharge. In this study, no substantial differences were observed in relation to discharge for streams draining the highway area and streams draining areas uninfluenced by the highway.

Discussion

With the exception of calcium, the data presented above show no pattern to suggest that streams draining the highway construction area differ substantially from streams draining areas uninfluenced by construction. The most notable indication of influence from the highway is found in the sulfate data. Although streams draining the immediate field area show no substantial differences, the sulfate levels in HEM are notably higher indicating the probable effects of past road construction practices involving untreated sulfidic materials.

Current construction practices for dealing with potential AD producing materials give indications of being successful. One notable apparent effect on water quality due to construction through acid-producing materials is an increase in the variation for calcium. The most probable explanation for this variation in calcium concentrations is the application of agricultural lime and the use of limestone aggregate in the construction process.

CHAPTER 4

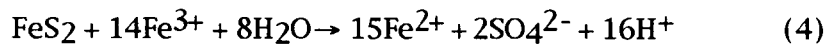
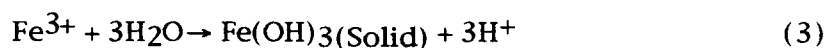
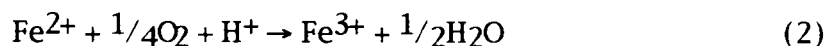
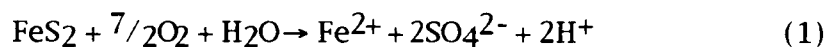
WEATHERING RELATED MINERAL COATINGS

Introduction

Streams and outcrops were examined for mineral coatings and attempts were made to identify any coatings found. The most notable feature is the lack of such coatings in streams draining the study area. The one stream, which is an exception to this, HOOP, displays notable quantities of a white coating on rocks and organic matter in the stream. The identification and source of this coating will be discussed. In addition, coatings from the most heavily encrusted outcrops are discussed.

Background

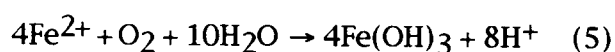
The weathering of iron sulfide minerals results in a release of iron, sulfate, and acidity (Nordstrom, 1982). As an example, Stumm and Morgan, (1981) describe the oxidation of pyrite, FeS_2 , through the following reactions:



(Stumm and Morgan, 1981)

Equation 1 shows that the oxidation of pyrite results in the release of ferrous iron, sulfate and free hydrogen ion (acidity). The oxidation of ferrous iron to

ferric iron (equation 2) provides ferric iron for the formation of a solid phase, ferric hydroxide (equation 3), and provides ferric iron for further pyrite oxidation (equation 4). Barton (1978) indicates that ferric hydroxide can also be formed through the direct oxidation of ferrous iron (equation 5).



The possible iron minerals formed from the weathering process are varied and are discussed in detail by Nordstrom (1982). Transformation from one iron hydroxide mineral species to another is common, and processes such as oxidation, hydrolysis, dissolution, dehydration and evaporation are involved in the transformations (Nordstrom, 1982). These processes in the presence of free cations and anions in solution can result in outcrops and streambeds coated with a varied secondary mineral assemblage. Figure 4-1 illustrates several of the possible pathways and the minerals formed.

Outcrops in areas of sulfide mineralization are often coated with efflorescent minerals. Parnell (1983) describes the crystallization of jarosite and pickeringite on sulfidic schist outcrops in New England. Acidic conditions generated by sulfide weathering enhance the weathering of silicate minerals in the sulfidic schist and promote the release of Al, Fe, Mg, and K (Parnell, 1983). These cations, in the presence of sulfate, and acidic conditions from sulfide weathering may allow the crystallization of jarosite and pickeringite (Parnell, 1983). Jago (1989) studied the geochemical processes associated with leaching of materials used in road fills for the Tellico Plains to Robbinsville Scenic Highway. Rock samples used in the study by Jago (1989) were collected from outcrops located within the boundaries of the current study area. Jago

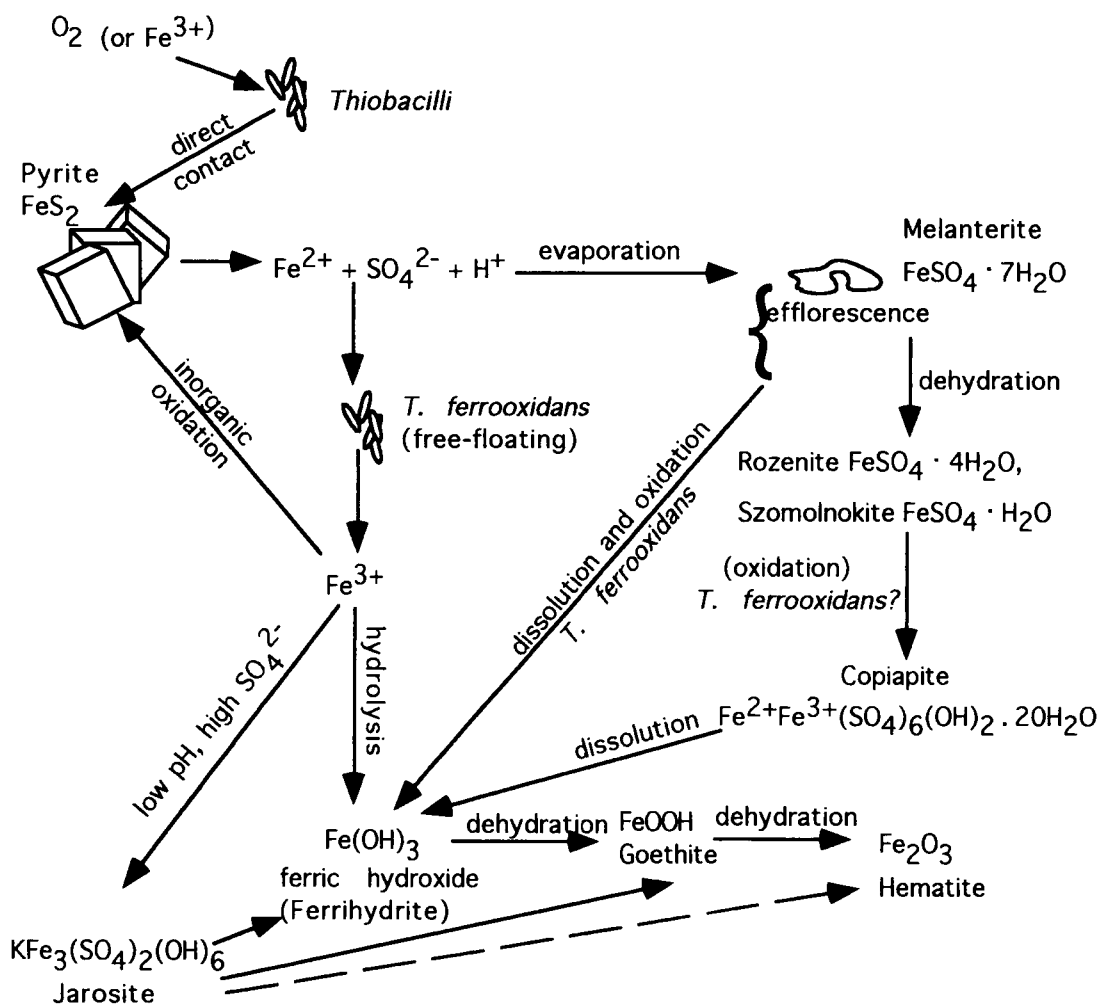


Figure 4-1. Pathways for the formation of common minerals associated with acidic drainage resulting from the weathering of iron sulfide minerals (Redrawn from Nordstrom (1982)).

(1989) used X-ray diffraction to identify several secondary minerals that formed during simulated and natural weathering. These secondary minerals were identified from rocks leached in a laboratory setting and rocks exhumed from an existing road fill (Jago, 1989). Jago (1989) noted, however, that some mineral identifications are tentative due to poor quality diffraction patterns. A summary of minerals identified by Jago (1989) is given in Table 4-1.

Red and brown sludge in streams receiving AD are secondary minerals formed/precipitated during the weathering process (Barton, 1978). In one study goethite and ferrihydrite-like minerals were identified as the dominant mineral precipitates deposited in a stream impacted by AD from a coal mine (Brady and others, 1986). The goethite found in this study may have formed from ferric hydroxide (ferrihydrite). This transformation occurs because ferrihydrite is less thermodynamically stable than either goethite or hematite (Carlson and Schwertmann, 1981). Although ferric hydroxide minerals are common, the formation of other metal hydroxide complexes are possible. Huckabee and others (1975) identified aluminum and manganese hydroxide complexes coating rocks in a drainage in the Great Smoky Mountain National Park. These coatings form a white precipitate on rocks in Beech Flats Creek, a stream which receives drainage from an AD-producing road fill (Huckabee and others, 1975).

Bedrock lithologies along the Tellico Plains to Robbinsville scenic highway contain local concentrations of sulfide minerals. When these rocks are disturbed by road construction, the potential for AD impacts exists. One visible sign of streams being impacted by AD, is the concentration of mineral coatings or precipitates in streams beneath the AD source (Barton, 1978). In

Table 4-1. Secondary minerals identified in leaching columns and road fill materials from Jago (1989).

MINERAL	FORMULA
Yavapiite	$\text{KFe}(\text{SO}_4)_2$
Jarosite	$\text{KFe}(\text{SO}_4)_2(\text{OH})_6$
Alunite	$\text{KAl}_3(\text{SO}_4)_2(\text{OH})_6$
Copiapite	$\text{Fe}^{2+}\text{Fe}^{3+}_4(\text{SO}_4)_6(\text{OH})_2 \cdot 20\text{H}_2\text{O}$
Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
Illite	$(\text{H}_3\text{O}, \text{K})_y(\text{Al}_4 \bullet \text{Fe}_4 \bullet \text{Mg}_4 \bullet \text{Mg}_6)(\text{Si}_{8-y} \bullet \text{Al}_y)\text{O}_{22}(\text{OH})_4$
Siderite	FeCO_3
Melanterite	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$
Ferrihydrite	$\text{Fe}(\text{OH})_3$
Diaspore	AlOOH
Boehmite	AlOOH

Note: Siderite, melanterite, ferrihydrite, diaspore, and boehmite are tentative identifications

the study area the abundance of sulfide minerals is indicated by outcrops coated in yellow, orange, red, or black secondary minerals (Plate 4-1).

Methods

During water sample collection each stream was visibly surveyed at the collection point for the presence of mineral precipitates or coatings. If coatings were identified, a sample of the substrate containing the coating was collected. Three types of samples were collected for this aspect of the study: 1) samples of the coatings/precipitates found on rocks and organic matter along a stream course, 2) samples of the suspended load carried in stream water, and 3) samples of coatings found on road cuts exposed along the highway.

Coatings found on rocks and debris along the stream course were removed from the substrate using a stainless steel dissection pick. The resulting powder was examined under a binocular microscope and visible phases other than the coating were removed. The sample was then placed on a glass slide and analyzed with a Siemens D-500 X-ray diffractometer using $\text{CuK}\alpha$ radiation and a rotation rate of 0.04 degrees/step. For positive identification of the clay minerals, glycolation, thermal treatment at 400° C, and thermal treatment at 550° C were performed. After each of these treatments, the sample was reanalyzed and the patterns compared.

The suspended load of the stream was isolated using a 0.45 μm filter and vacuum apparatus. A three gallon water sample was collected in polyethylene jugs. This sample was passed through the 0.45 μm filter and the residue remaining on the filter was placed on a glass slide, dried at room temperature, and analyzed by X-ray diffraction in the same manner described above.



Plate 4-1. Typical staining on sulfide mineral bearing outcrops in the study area. Note coatings form on both the outcrop (upper half of the photo) and on the paved ditchline (lower half of the photo). Pocket knife (9 cm, 3.5 inches) for scale.

Samples from the road cuts were prepared and analyzed in the same manner as the samples collected from the substrate in the stream. The volume of these samples was typically small and care was taken to position the sample so that a sufficient thickness was present to diffract the X-ray beam.

Results

Substantial mineral coatings were found in only one stream, HOOP (Figure 4-2). At this location a conspicuous white coating (Plate 4-2) appeared downstream of newly constructed road fills. These encapsulation fills and cut slopes above the stream contain rocks with abundant sulfide minerals. X-ray diffraction patterns from the coatings on rocks in the stream bed indicate patterns characteristic of the mineral illite (Figure 4-3). Figure 4-3 contains four diffraction patterns. These patterns were generated after the glycolation and heat treatments and show that the diffraction peaks do not shift, indicating that the minerals is indeed illite (Starkey, 1984).

X-ray diffraction analysis of the suspended load of the stream yields a pattern characteristic of illite (Figure 4-4). This pattern is not as defined as the pattern generated from the outcrop coatings (Figure 4-3). This may result from amorphous material carried along with the illite in suspension or a sample of insufficient thickness to avoid exposure of the amorphous glass slide to the X-Ray beam. Coatings associated with the stream collect on many different substrates (rocks, organic debris, and construction materials) suggesting that the illite was transported in suspension by the stream.

Minerals identified as coatings from the outcrops above HOOP as well as mineral coatings from selected road cuts along the construction project were collected and analyzed by X-ray diffraction. Figure 4-2 shows sampling

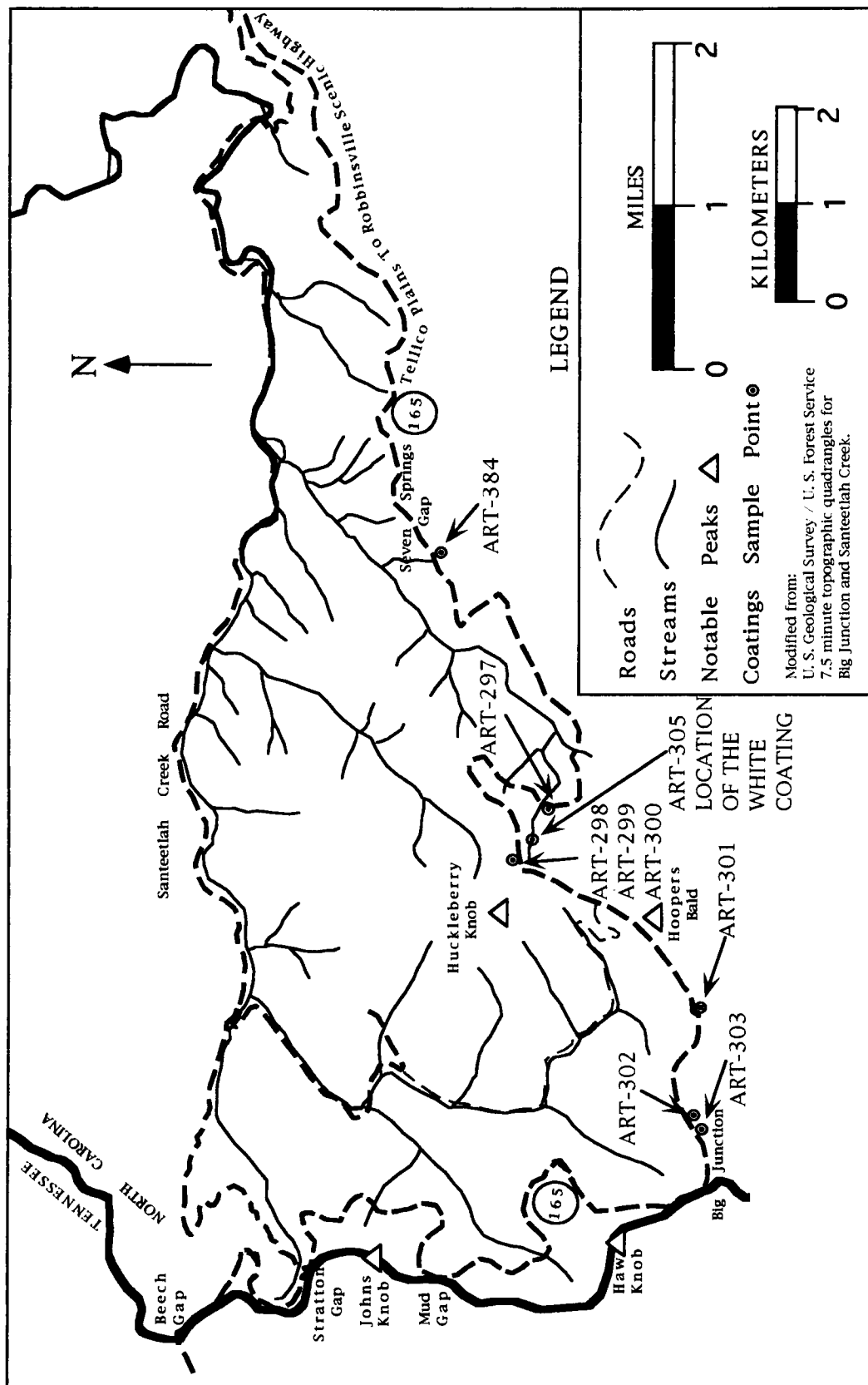


Figure 4-2. Locations of coatings samples collected.



Plate 4-2. Photograph of white coating located at sample site HOOP. Note pocket knife for scale (9 cm, 3.5 inches).

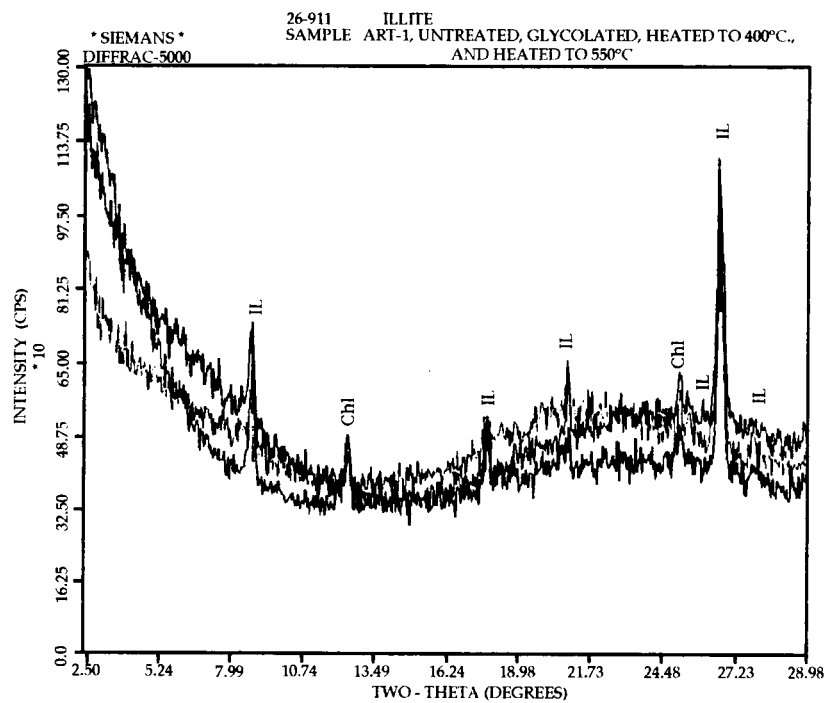


Figure 4-3. X-ray diffraction pattern generated from the white coating located in the stream bed below sample site HOOP. Peaks are characteristic of illite and chlorite. illite = IL and chlorite = Chl.

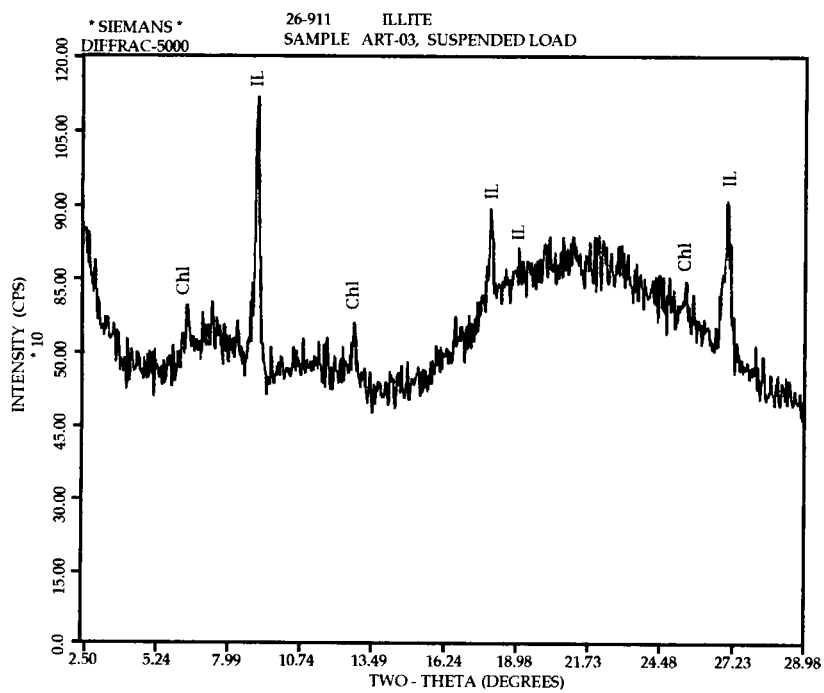


Figure 4-4. X-ray diffraction pattern generated from the sample of the suspended load carried by the stream at sample site HOOP.

The pattern indicates the presence of illite and chlorite. illite = IL and chlorite = Chl.

locations for the mineral coatings collected in this study. X-ray diffraction patterns generated from coatings collected from outcrops above the stream are characteristic of gypsum (Figure 4-5), goethite (Figure 4-6), and calcite and vaterite (Figure 4-7). Other phases may be present as mineral coatings on the outcrops, but definitive diffraction patterns could not be obtained. These possible identifications indicate that melanterite, alunite, jarosite, and yavapiite may be present as outcrop coatings. This agrees with the findings of Jago (1989), who positively identified jarosite, yavapiite, and alunite and tentatively identified melanterite in samples from the study area (Table 4-1).

Discussion

The abundance of illite along the stream course raises the question of its origin. Velde (1977) suggests that illite in detrital sediments may come from at least four sources:

- 1) material crystallized during the weathering process
- 2) reconstituted degraded mica
- 3) detrital illite formed at high temperatures
- 4) detrital illite from sedimentary rocks

Of these four possibilities, three may apply to this study. The one possibility which does not apply, reconstituted degraded mica, requires marine conditions for the formation of illite (Velde, 1977). Sources 3 and 4 above are very similar and will be combined for the following discussion. Therefore, for this discussion, two processes appear to be feasible explanations for the origin of illite found in this study:

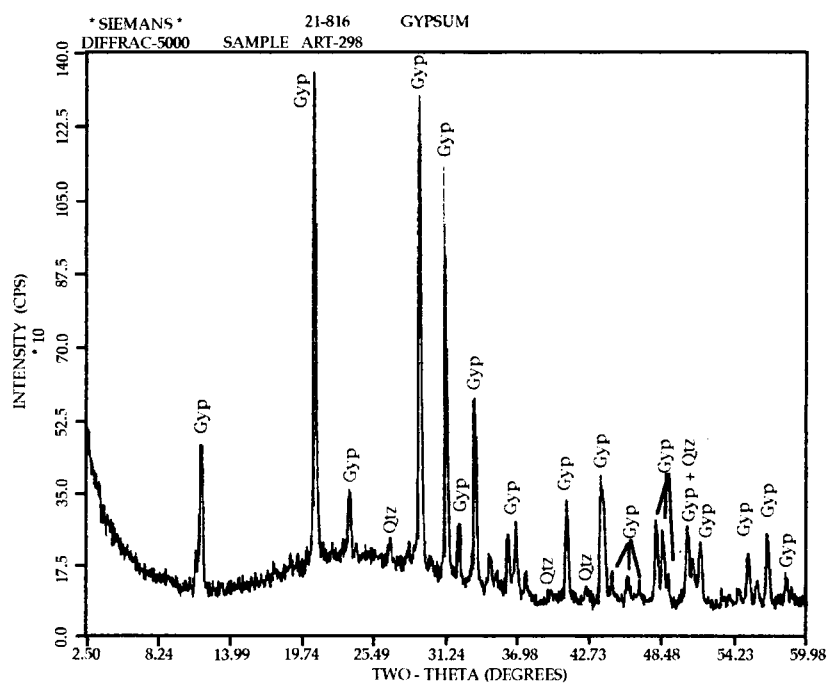


Figure 4-5. X-ray diffraction pattern generated from a sample of outcrop coatings located at sample point ART-298. The pattern is characteristic of gypsum. Gyp = gypsum and Qtz = quartz.

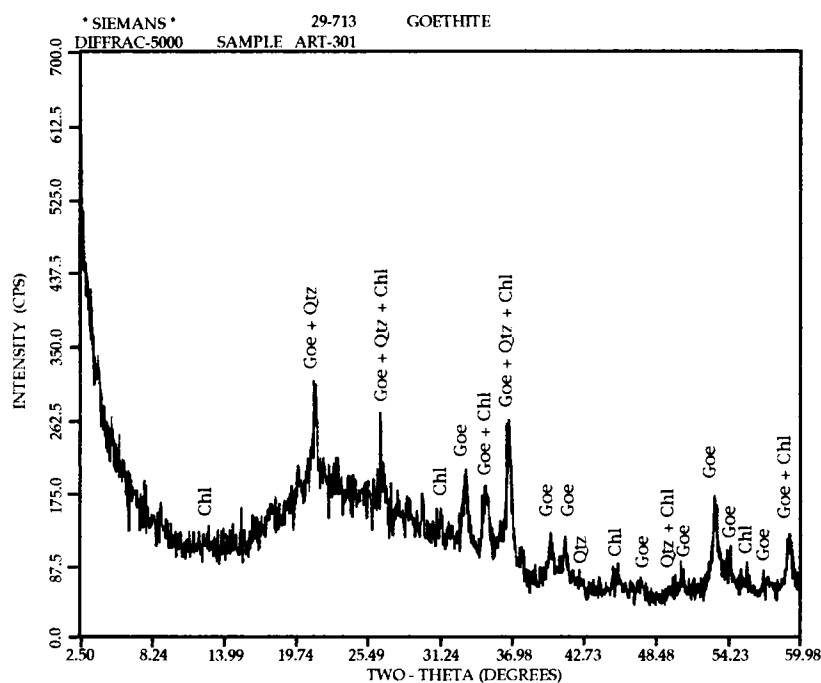


Figure 4-6. X-ray diffraction pattern from a sample of outcrop coating located at sample point ART-301. The pattern contains peaks characteristic of goethite, chlorite, and quartz. goethite = Goe, chlorite = Chl, and quartz = Qtz.

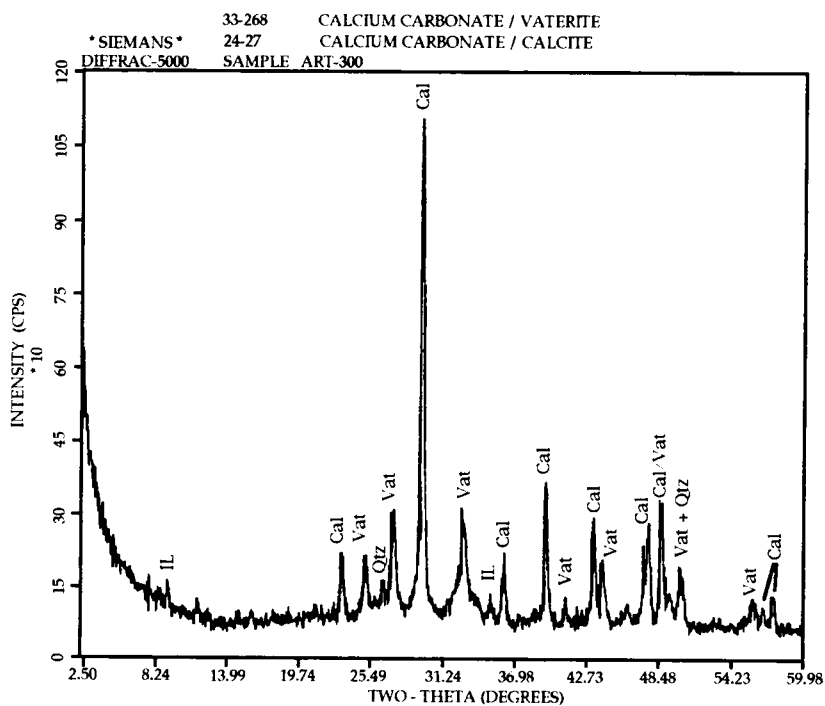


Figure 4-7. X-ray diffraction pattern generated from a sample of outcrop coating located at sample point ART-300. The pattern contains characteristic diffractions for two calcium carbonate minerals calcite and vaterite. calcite = Cal, vaterite = Vat, illite = IL, and quartz = Qtz.

- 1) Weathering of mica minerals to crystallize illite by the removal of potassium and the addition of water to the mica structure (Figure 4- 8).
- 2) Weathering of rocks and the release of illite from a detrital sedimentary or metamorphic origin (Figure 4-8).

Intense weathering caused by naturally derived acid, produced by the oxidation of sulfide minerals can release significant quantities of aluminum, iron, magnesium, calcium, sodium, and potassium from aluminosilicate minerals (Parnell, 1983 and Brady, 1990). Robert and Tessier (1992) noted the importance of inorganic acids and abundant water in accelerating the weathering process. The increased capacity for weathering resulting from wet acidic conditions may accelerate the release of existing minerals or may form new minerals which are removed by erosion and transported by surface water. Illite transported in suspension suggests that the deposition of illite in the stream below HOOP is a possible example of this phenomenon. Another possibility is that minerals may precipitate directly from solution.

During the weathering of rocks in the study area one would expect that the mobilization of cations combined with the presence of sulfate and water would be conditions favorable for the formation of secondary minerals (sulfates and hydroxides). Although X-ray diffraction patterns generated from the outcrop coatings are not characteristic of secondary hydroxide and sulfate minerals, the presence of goethite (Figure 4-6) suggests that ferric hydroxide was present but transformed to a more stable form through dehydration. The other outcrop coatings positively identified in X-ray patterns may be related to the highway construction process. Agricultural lime is often applied to excavated sulfidic rock, if the material is to be

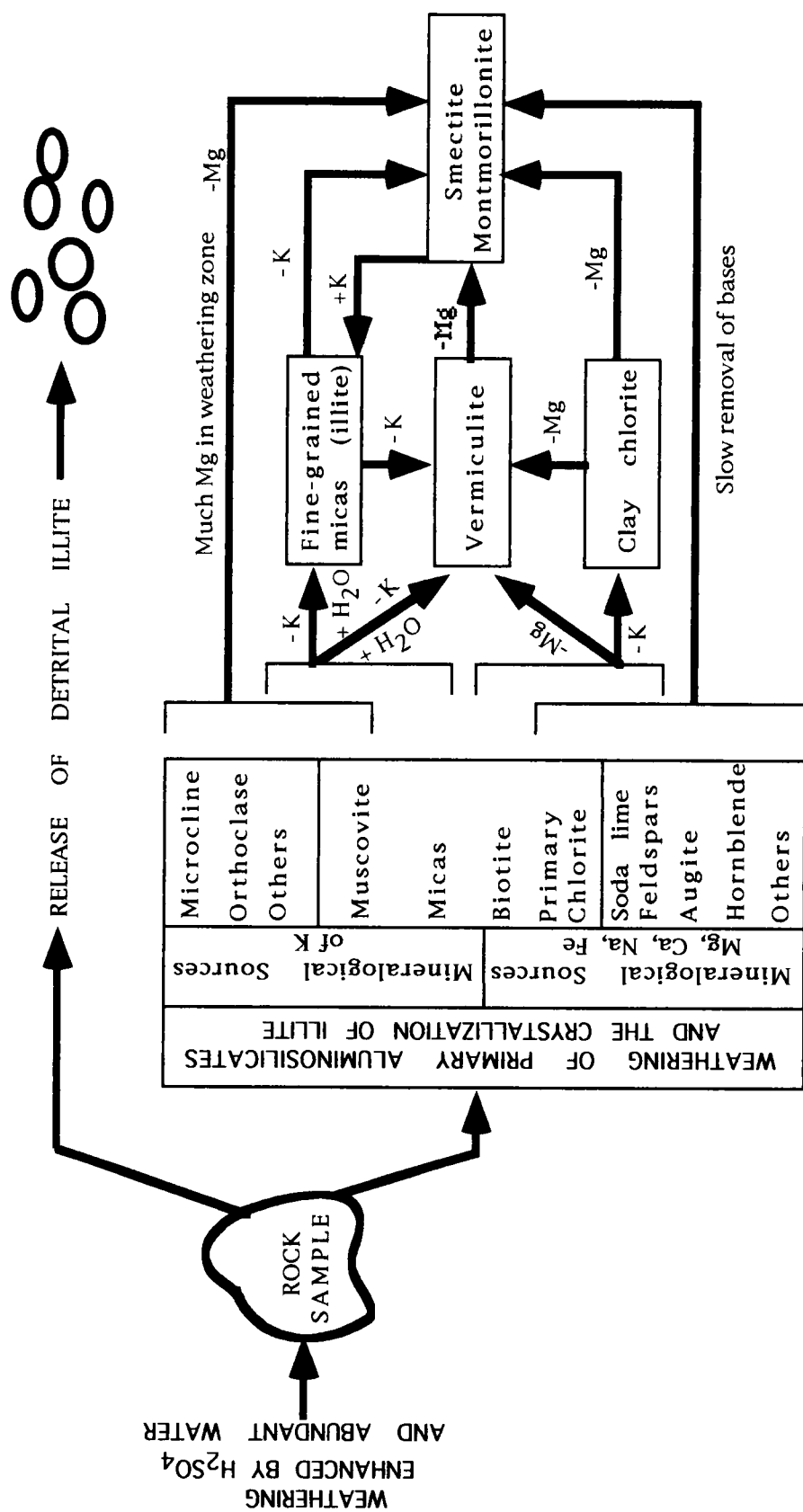


Figure 4-8. Two possible pathways for the deposition or formation of illite in the stream beneath water sample site HOOP (After Brady (1990) and Velde (1977)).

stockpiled for any period of time prior to being encapsulated. Lime is also used extensively as part of the hydroseeding mixture applied to slopes. Under acidic conditions the lime dissolves, neutralizing the acidity. Calcite and vaterite may be precipitated (Figure 4-7). Gypsum forms when the dissolved calcium from the lime reacts with sulfate and water at the outcrop (Figure 4-5).

Conclusion

The abundance of water on outcrops created by construction and the presence of sulfide minerals provide conditions necessary for accelerated weathering. These wet acidic conditions mobilize cations, which in the presence of sulfate and water create new minerals. This process is ongoing as is evidenced by secondary minerals staining the outcrops in shades of yellow, orange, red, or black. One stream segment occurring below sulfide mineral-bearing outcrops and road fills exhibits a conspicuous white coating identified as illite. The illite is related to enhanced weathering where the wet acidic conditions provide the potential for the recrystallization of micas to illite and/or the release of illite already in existence in the rocks. Acidity values measured at sample node HOOP show relatively high acidity concentrations in comparison to other streams in the study (with the exception of sample node JOHN). One sample, collected at JOHN, is considered an outlier in data set which skews the average acidity values above those recorded at HOOP. Considering this, higher acidity values at HOOP are consistent with the suspected increase in weathering at outcrops above the sample point. The coatings on outcrops and the coating found in the stream are thought to result from increased weathering resulting from acidic conditions created during the weathering of

sulfide minerals. The lack of coatings in the other nine streams in this study combined with few stained outcrops suggests that the acidic conditions thought to enhance the formation of the coatings are absent.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The Tellico Plains to Robbinsville Scenic Highway crosses the mountains between Tellico Plains, Tennessee and Robbinsville, North Carolina encountering sulfide mineral-bearing rocks of the Late Precambrian Ocoee Supergroup. Portions of the highway were built prior to widespread knowledge of the adverse environmental impacts associated with road construction in sulfidic rocks. As a result, streams draining these sections of highway suffered the effects of AD. Since that time, road construction practices have improved and construction methods were developed to abate AD. The purpose of this study is to assess the relationship of the bedrock to the potential AD problem and to evaluate the effectiveness of these construction methods at maintaining favorable water quality. This investigation is divided into three parts: 1) A geologic investigation (mapping and collection and analysis of rock samples) to provide better understanding of the natural geologic contribution to water chemistry; 2) Surface water chemistry investigations of both streams draining watersheds containing the highway and streams with no possible influence from the road; and 3) A study of mineral coatings on outcrops and in streams as possible indicators of AD conditions. The mineral coatings were sampled and identified to provide information on possible AD sources and the chemical processes occurring near them.

Geologic mapping identified three rock units exposed in the study area. Rocks in these units were examined petrographically and analyzed by X-ray

fluorescence to determine their mineralogical and bulk chemical compositions for the purpose of identifying geological sources for cations detected in surface waters. The similarity between two of the rock units, both dominated by metagraywacke and metasandstone, combined with the repetition of strata by geologic structures may decrease the chemical signature of the individual rock units on water in contact with bedrock. Exceptions to this are noted. For example, potassium values in water collected at sample node HB are consistently elevated in comparison to other streams in the study. This node is located on a stream near the highway which flows over a single bedrock type containing potassium-bearing minerals (microcline, biotite, and muscovite). Two rock samples, ART-316 and ART-313, collected from the drainage containing HB range in potassium concentration from 0.81% to 7.29% as K_2O respectively (Appendix Table A-2). Weathering is a slow process and may explain the fairly constant distribution of low concentrations of cations seen in water samples collected for this study. Weathering enhanced by the road construction may increase the concentration of cations or variability within the water chemistry data. With the exception of HB, data collected in this study indicate that slow, steady processes are at work to release cations to surface water in the study area. These processes may be related to weathering.

Water chemistry in streams draining construction sites as well as streams receiving no drainage from the highway were evaluated for a period of 11 months. During the study, samples were collected approximately biweekly as conditions permitted. The results of the water chemistry indicate that for most parameters measured, no obvious differences exist between streams draining construction areas and streams draining watersheds

undisturbed by construction. There are two minor exceptions. Data for sulfate and calcium indicate that some influence from the highway is present.

Average sulfate concentrations in streams draining the immediate field area are low, approximately 0 - 1 mg/L. In contrast, sulfate values at sample node HEM are notably higher, averaging around 11 mg/L. HEM is located downstream of a section of the highway built prior to the implementation of AD abating construction practices. This variation in sulfate data is important because it illustrates the lingering effects of AD on surface water chemistry and suggests that similar conditions would be noticeable if current construction methods were not successful at preventing AD. A statistical evaluation of sulfate data from the remaining streams (excluding HEM) indicates no difference between streams draining areas under construction and areas beyond the influence of road.

Variation in the concentration of calcium in most streams receiving drainage from the highway is greater than the variation observed in streams with no influence from the road. This suggests that recent road construction influences the calcium concentration in streams draining watersheds containing the highway. This observation is probably related to the excavation and weathering of calcium-bearing minerals and/or the use of limestone aggregate and agricultural lime as construction materials.

Although some influence from existing and newly constructed segments of the Tellico Plains to Robbinsville Scenic Highway is noted, it appears that current construction practices for dealing with potential AD-producing materials are successful at eliminating impacts to streams draining the construction areas.

Mineral coatings were collected from areas exhibiting wet conditions and bedrock containing abundant sulfide minerals, and were analyzed by X-ray diffraction. The combination of water and sulfide minerals may promote the formation of inorganic acids which can enhance weathering. The mineral coatings collected from outcrops were identified as gypsum, vaterite, calcite, and goethite. The first three minerals are calcium-bearing minerals possibly indicating that agricultural lime applied to cut slopes as fertilizer may be the source of calcium for the formation of these minerals. The oxidation of sulfide minerals in the rock (pyrrhotite and pyrite), provide the sulfate for the formation of gypsum. Ferric hydroxide produced by the weathering of these same iron sulfides often transforms to goethite upon dehydration. Mineral coatings were on rocks found in only one stream in the study area. The coatings are identified as illite. The illite was either formed at the outcrop or is detrital illite released by enhanced weathering due to the wet acidic conditions. Analysis of the suspended load of the stream suggests that the illite is transported by water and deposited along the stream course.

This study is divided into three parts: 1) Geologic mapping shows that three mappable rock units are identified. These rocks are regionally folded into open folds which repeat the rock units across the study area. 2) Water chemistry was monitored to determine if adverse effects related to the highway construction were present. Although the Tellico Plains to Robbinsville Scenic Highway is constructed through bedrock which exhibits locally abundant sulfide mineralization, data collected during this study indicates that AD-abating methodology applied during road construction has been effective at minimizing adverse chemical alterations to the surface water in the study area. For most parameters measured statistical analysis of the

water chemistry data indicates that there is no difference between streams draining watersheds containing the highway and streams not associated with the road. Widespread geologic influences on the water chemistry were not observed in the study area. 3) A study of mineral coatings has determined that although mineral coatings characteristic of AD conditions are found in the study area, their extent is limited to sulfidic outcrops which are often wet from natural drainage. With the exception of sample node HOOP, mineral coatings are absent from rocks in the streams sampled in this study. At sample node HOOP, the mineral coatings are limited to areas near water-soaked sulfide mineral-bearing outcrops which exhibit wet acidic conditions. The data collected for this study indicates that the Tellico Plains to Robbinsville Scenic Highway does not adversely impact surface water draining the construction site.

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APPENDICES

Table A-1. X-ray Fluorescence data for rock samples collected in the study area.

ELEMENT NAME	CALIB. LOW	RANGE HIGH	UNIT	ART-70	ART-93	ART-118	ART-43	ART-120
Na2O	0.066	6.2	%	3.63	1.98	1.42	2.24	2.73
MgO	0.02	3.83	%	2.88	2.04	0.63	1.60	1.87
Al2O3	6.18	39.23	%	15.47	13.40	8.84	11.28	13.14
SiO2	42.35	99.995	%	63.60	63.78	82.01	72.45	73.46
P2O5	0.01	0.69	%	0.29	0.16	0.06	0.10	0.27
S	BY	LECO	%	0.64	0.01	0.00	0.01	0.79
K2O	0.62	15.35	%	1.42	3.97	3.16	2.19	2.02
CaO	0.034	6.92	%	1.68	0.91	0.19	0.58	0.69
Cu	5	120	ppm	0.00	0.00	0.00	0.00	0.00
TiO2	0.01	2.385	%	0.81	0.86	0.57	0.69	0.57
V	2	399	ppm	0.01	0.01	0.00	0.01	0.00
Cr	4	438	ppm	0.01	0.00	0.00	0.00	0.00
MnO	0.002	0.18	%	0.11	0.08	0.05	0.07	0.13
Fe2O3	0.065	13.4	%	6.08	5.99	2.85	4.85	4.13
Co	1	38	ppm	0.00	0.00	0.00	0.00	0.00
Ni	4	94	ppm	0.00	0.00	0.00	0.00	0.00
Zn	5	145	ppm	0.01	0.01	0.00	0.01	0.01
Pb	5	69	ppm	0.00	0.00	0.00	0.00	0.00
Rb	33	2000	ppm	0.01	0.01	0.01	0.01	0.01
Sr	10	480	ppm	0.03	0.02	0.01	0.01	0.01
Y	11	145	ppm	0.01	0.00	0.00	0.00	0.00
Zr	33	790	ppm	0.03	0.05	0.04	0.04	0.03
Nb	4	90	ppm	0.00	0.00	0.00	0.00	0.00
Mo	1	100	ppm	0.00	0.00	0.00	0.00	0.00
Ba	47	2400	ppm	0.03	0.07	0.07	0.05	0.03
TOTALS				96.75	93.35	99.91	96.19	99.89

Table A-2 (continued). X-ray Fluorescence data for rock samples collected in the study area.

ELEMENT NAME	CALIB. LOW	RANGE HIGH	UNIT	ART-373	ART-259	ART-29	BT-1	ART-378
Na2O	0.066	6.2	%	1.99	4.36	3.38	2.42	4.07
MgO	0.02	3.83	%	2.48	2.67	1.16	2.65	2.99
Al2O3	6.18	39.23	%	20.23	14.10	11.89	18.01	14.11
SiO2	42.35	99.995	%	61.72	69.60	71.24	44.72	68.35
P2O5	0.01	0.69	%	0.52	0.35	0.13	0.08	0.23
S	BY	LHCO	%	1.52	1.07	0.01	0.01	0.70
K2O	0.62	15.35	%	4.46	1.01	2.78	0.31	0.72
CaO	0.034	6.92	%	0.96	2.40	1.56	3.27	2.69
Cu	5	120	ppm	0.00	0.00	0.00	0.00	0.00
TiO2	0.01	2.385	%	0.66	0.80	0.59	0.16	0.64
V	2	399	ppm	0.01	0.01	0.00	0.00	0.00
Cr	4	438	ppm	0.01	0.00	0.00	0.01	0.00
MnO	0.002	0.18	%	0.08	0.17	0.07	0.04	0.18
Fe2O3	0.065	13.4	%	5.15	5.83	3.40	4.61	4.47
Co	1	38	ppm	0.00	0.00	0.00	0.00	0.00
Ni	4	94	ppm	0.00	0.00	0.00	0.00	0.00
Zn	5	145	ppm	0.01	0.01	0.00	0.00	0.01
Pb	5	69	ppm	0.00	0.00	0.00	0.00	0.00
Rb	33	2000	ppm	0.01	0.01	0.01	0.00	0.01
Sr	10	480	ppm	0.01	0.02	0.02	0.03	0.03
Y	11	145	ppm	0.01	0.00	0.00	0.00	0.00
Zr	33	790	ppm	0.03	0.03	0.04	0.02	0.02
Nb	4	90	ppm	0.00	0.00	0.00	0.00	0.00
Mo	1	100	ppm	0.00	0.00	0.00	0.00	0.00
Ba	47	2400	ppm	0.06	0.02	0.07	0.04	0.03
TOTALS				99.92	102.46	96.35	76.38	99.25

Table A-2 (continued). X-ray Fluorescence data for rock samples collected in the study area.

ELEMENT NAME	CALIB. LOW	RANGE HIGH	UNIT	GSMNP	ART-368	ART-232	ART-188	ART-185
Na2O	0.066	6.2	%	3.09	2.80	1.49	1.74	2.21
MgO	0.02	3.83	%	7.41	2.19	3.78	2.42	2.66
Al2O3	6.18	39.23	%	22.31	10.97	21.72	17.19	15.49
SiO2	42.35	99.995	%	43.63	69.95	52.10	63.44	65.99
P2O5	0.01	0.69	%	0.15	0.16	0.32	0.39	0.38
S	BY	LECO	%	0.00	0.24	0.60	1.57	1.34
K2O	0.62	15.35	%	0.03	0.46	4.87	4.04	3.10
CaO	0.034	6.92	%	15.60	3.60	0.61	0.69	1.36
Cu	5	120	ppm	0.01	0.00	0.00	0.00	0.00
TiO2	0.01	2.385	%	0.79	0.58	0.99	0.68	0.77
V	2	399	ppm	0.01	0.00	0.01	0.01	0.01
Cr	4	438	ppm	0.02	0.00	0.01	0.01	0.00
MnO	0.002	0.18	%	0.08	0.16	0.19	0.13	0.11
Fe2O3	0.065	13.4	%	5.97	5.32	9.84	6.52	6.88
Co	1	38	ppm	0.00	0.00	0.00	0.00	0.00
Ni	4	94	ppm	0.02	0.00	0.01	0.00	0.00
Zn	5	145	ppm	0.01	0.01	0.02	0.01	0.01
Pb	5	69	ppm	0.00	0.00	0.00	0.00	0.00
Rb	33	2000	ppm	0.00	0.00	0.02	0.01	0.01
Sr	10	480	ppm	0.04	0.03	0.01	0.01	0.01
Y	11	145	ppm	0.00	0.00	0.00	0.00	0.00
Zr	33	790	ppm	0.01	0.03	0.01	0.02	0.03
Nb	4	90	ppm	0.00	0.00	0.00	0.00	0.00
Mo	1	100	ppm	0.00	0.00	0.00	0.00	0.00
Ba	47	2400	ppm	0.06	0.02	0.05	0.04	0.04
TOTALS				99.24	96.52	96.65	98.92	100.40

Table A-2 (continued). X-ray Fluorescence data for rock samples collected in the study area.

ELEMENT NAME	CALIB. LOW	RANGE HIGH	UNIT	ART-169	ART-126	ART-51	ART-32	ART-313
Na2O	0.07	6.20	%	2.83	1.46	1.63	2.56	1.74
MgO	0.02	3.83	%	2.01	0.80	5.55	1.46	3.68
Al2O3	6.18	39.23	%	14.27	11.92	10.16	11.13	22.92
SiO2	42.35	100.00	%	71.23	79.90	68.41	71.48	50.17
P2O5	0.01	0.69	%	0.17	0.14	0.10	0.14	0.41
S	BY	LECO	%	0.01	0.01	0.00	0.01	0.52
K2O	0.62	15.35	%	2.09	1.99	-0.07	3.00	7.29
CaO	0.03	6.92	%	0.93	0.39	7.61	2.05	0.97
Cu	5.00	120.00	ppm	0.00	0.00	0.00	0.00	0.00
TiO2	0.01	2.39	%	0.76	0.28	0.56	0.70	1.25
V	2.00	399.00	ppm	0.01	0.00	0.00	0.01	0.02
Cr	4.00	438.00	ppm	0.00	0.00	0.01	0.00	0.01
MnO	0.00	0.18	%	0.08	0.05	0.76	0.08	0.11
Fe2O3	0.07	13.40	%	5.23	2.75	5.45	4.10	10.27
Co	1.00	38.00	ppm	0.00	0.00	0.00	0.00	0.00
Ni	4.00	94.00	ppm	0.00	0.00	0.01	0.00	0.01
Zn	5.00	145.00	ppm	0.01	0.00	0.01	0.00	0.01
Pb	5.00	69.00	ppm	0.00	0.00	0.00	0.00	0.00
Rb	33.00	2000.00	ppm	0.01	0.01	0.00	0.01	0.02
Sr	10.00	480.00	ppm	0.02	0.01	0.01	0.02	0.02
Y	11.00	145.00	ppm	0.00	0.00	0.00	0.00	0.00
Zr	33.00	790.00	ppm	0.03	0.02	0.02	0.05	0.02
Nb	4.00	90.00	ppm	0.00	0.00	0.00	0.00	0.00
Mo	1.00	100.00	ppm	0.00	0.00	0.00	0.00	0.00
Ba	47.00	2400.00	ppm	0.05	0.05	0.04	0.07	0.11
TOTALS				99.74	99.78	100.26	96.87	99.55

Table A-2 (continued). X-ray Fluorescence data for rock samples collected in the study area.

ELEMENT NAME	CALIB. LOW	RANGE HIGH	UNIT	ART-81	ART-316	ART-76	ART-75	ART-136
Na2O	0.07	6.20	%	2.54	3.17	1.86	1.97	0.82
MgO	0.02	3.83	%	2.81	1.97	4.00	1.80	0.30
Al2O3	6.18	39.23	%	14.35	12.22	21.17	17.79	5.10
SiO2	42.35	100.00	%	68.78	76.80	51.03	71.24	95.19
P2O5	0.01	0.69	%	0.84	0.18	0.38	0.21	-0.02
S	BY	LECO	%	2.65	0.25	0.03	0.31	0.00
K2O	0.62	15.35	%	2.28	0.81	5.54	4.80	0.54
CaO	0.03	6.92	%	0.80	3.05	0.84	0.69	-0.15
Cu	5.00	120.00	ppm	0.00	0.00	0.00	0.00	0.00
TiO2	0.01	2.39	%	0.57	0.62	0.96	0.83	0.09
V	2.00	399.00	ppm	0.01	0.00	0.01	0.01	0.00
Cr	4.00	438.00	ppm	0.00	0.00	0.01	0.00	-0.01
MnO	0.00	0.18	%	0.09	0.15	0.14	0.07	0.03
Fe2O3	0.07	13.40	%	7.26	4.43	10.55	5.40	0.99
Co	1.00	38.00	ppm	0.00	0.00	0.00	0.00	0.00
Ni	4.00	94.00	ppm	0.00	0.00	0.01	0.00	0.00
Zn	5.00	145.00	ppm	0.01	0.01	0.01	0.01	0.01
Pb	5.00	69.00	ppm	0.00	0.00	0.00	0.00	0.00
Rb	33.00	2000.00	ppm	0.01	0.01	0.02	0.01	0.00
Sr	10.00	480.00	ppm	0.01	0.03	0.01	0.01	0.00
Y	11.00	145.00	ppm	0.00	0.00	0.01	0.00	0.00
Zr	33.00	790.00	ppm	0.06	0.03	0.02	0.03	0.01
Nb	4.00	90.00	ppm	0.00	0.00	0.00	0.00	0.00
Mo	1.00	100.00	ppm	0.00	0.00	0.00	0.00	0.00
Ba	47.00	2400.00	ppm	0.05	0.03	0.05	0.09	0.04
TOTALS				103.12	103.76	96.65	105.27	102.94

Table A-2 (continued). X-ray Fluorescence data for rock samples collected in the study area.

ELEMENT NAME	CALIB. LOW	RANGE HIGH	UNIT	ART-221	ART-138	ART-167	ART-150	ART-291
Na2O	0.07	6.20	%	2.99	2.66	2.91	2.14	2.85
MgO	0.02	3.83	%	1.57	1.44	2.12	3.24	18.57
Al2O3	6.18	39.23	%	14.70	11.48	15.54	22.03	12.45
SiO2	42.35	100.00	%	73.26	73.71	72.96	54.67	0.03
P2O5	0.01	0.69	%	0.17	0.15	0.25	0.51	7.26
S	BY	LECO	%	0.00	0.02	0.59	1.11	0.01
K2O	0.62	15.35	%	3.65	2.97	2.75	5.71	1.79
CaO	0.03	6.92	%	0.29	0.96	1.32	1.11	62.87
Cu	5.00	120.00	ppm	0.00	0.00	0.00	0.00	0.00
TiO2	0.01	2.39	%	0.82	0.75	0.48	1.03	0.41
V	2.00	399.00	ppm	0.01	0.01	0.00	0.01	0.00
Cr	4.00	438.00	ppm	0.00	0.00	0.01	0.01	0.02
MnO	0.00	0.18	%	0.07	0.06	0.08	0.11	0.03
Fe2O3	0.07	13.40	%	5.28	4.54	2.76	6.77	0.66
Co	1.00	38.00	ppm	0.00	0.00	0.00	0.00	0.00
Ni	4.00	94.00	ppm	0.00	0.00	0.00	0.01	0.01
Zn	5.00	145.00	ppm	0.01	0.01	0.01	0.01	0.00
Pb	5.00	69.00	ppm	0.00	0.00	0.00	0.00	0.00
Rb	33.00	2000.00	ppm	0.01	0.01	0.01	0.02	0.23
Sr	10.00	480.00	ppm	0.02	0.02	0.02	0.01	0.02
Y	11.00	145.00	ppm	0.00	0.00	0.00	0.00	0.06
Zr	33.00	790.00	ppm	0.04	0.05	0.02	0.02	0.05
Nb	4.00	90.00	ppm	0.00	0.00	0.00	0.00	0.00
Mo	1.00	100.00	ppm	0.00	0.00	0.00	0.00	0.00
Ba	47.00	2400.00	ppm	0.06	0.06	0.05	0.07	0.63
TOTALS				102.95	98.90	101.88	98.59	107.95

Table A-2 (continued). X-ray Fluorescence data for rock samples collected in the study area.

ELEMENT NAME	CALIB. LOW	RANGE HIGH	UNIT	ART-267	ART-71A	ART-60	ART-90
Na2O	0.07	6.20	%	1.24	1.64	2.06	1.91
MgO	0.02	3.83	%	2.96	21.06	3.06	3.09
Al2O3	6.18	39.23	%	25.94	7.49	19.06	21.95
SiO2	42.35	100.00	%	48.47	35.20	56.02	52.65
P2O5	0.01	0.69	%	0.20	0.16	0.24	0.37
S	BY	LECO	%	0.19	0.00	0.11	0.00
K2O	0.62	15.35	%	6.79	0.49	4.99	4.82
CaO	0.03	6.92	%	0.56	28.93	0.61	0.72
Cu	5.00	120.00	ppm	0.00	0.00	0.00	0.00
ThO2	0.01	2.39	%	0.75	0.15	0.94	1.19
V	2.00	399.00	ppm	0.01	0.00	0.01	0.02
Cr	4.00	438.00	ppm	0.01	0.01	0.01	0.01
MnO	0.00	0.18	%	0.09	0.33	0.10	0.07
Fe2O3	0.07	13.40	%	7.64	3.63	9.29	8.79
Co	1.00	38.00	ppm	0.00	0.00	0.00	0.00
Ni	4.00	94.00	ppm	0.01	0.15	0.01	0.01
Zn	5.00	145.00	ppm	0.01	0.00	0.01	0.01
Pb	5.00	69.00	ppm	0.00	0.00	0.00	0.00
Rb	33.00	2000.00	ppm	0.02	0.02	0.02	0.01
Sr	10.00	480.00	ppm	0.01	0.01	0.01	0.01
Y	11.00	145.00	ppm	0.00	0.00	0.00	0.01
Zr	33.00	790.00	ppm	0.01	0.00	0.02	0.05
Nb	4.00	90.00	ppm	0.00	0.00	0.00	0.00
Mo	1.00	100.00	ppm	0.00	0.00	0.00	0.00
Ba	47.00	2400.00	ppm	0.05	0.12	0.06	0.09
TOTALS				94.96	99.39	96.63	95.78

Table A-2. Summary of the techniques suggested in Varian (1979).

ELEMENT	LOW RANGE	INTERFERENCE	CORRECTION
Ca	1-4 mg/L	Air Acetylene or NO/Acet. flame interference	Add Sr or La for AA int. add K for NO/Acet int
Fe	2.5-10 mg/L	Citric Acid Phosphoric acid	Use a NO acetylene flame
K	0.5-2.0 mg/L	Air Acetylene flame	Add CsNO ₃ or CsCl
Mg	0.1-0.4 mg/L	Lots	See Sheet **
Mn	1.0-4.0 mg/L	Air Acet flame PO ₄ , ClO ₄ , Fe, Ni, Co	NO Acet flame or oxidizing Air Acetylene flame
Na	0.15-0.60 mg/L	Ionization	Add KCl or KNO ₃
Ni	3-12 mg/L	Absorption	use different wavelength **
Si	70-280 mg/L	HF, Boric acid, K	Flame adj.
Zn	0.4-1.6 mg/L	None	
Cu	2-8 mg/L		

Notes: NO = Nitrous Oxide, Acet = Acetylene, and int = interference

Table A- 3. Precipitation data (in inches) for the Tennessee Valley Authority

Rain gauge located at Stratton Meadows.

DATE	SUM OF 1 DAY	SUM OF 2 DAYS	SUM OF 3 DAYS	SUM OF 4 DAYS	SUM OF 5 DAYS
8/28/89	0.00	0.10	0.10	0.44	1.83
9/9/89	0.00	0.00	0.0	0.00	0.00
9/23/89	2.63	3.20	3.20	3.20	3.20
10/9/89	0.00	0.00	0.01	0.01	0.01
10/23/89	0.00	0.00	0.12	0.12	0.32
11/8/89	0.24	0.57	1.27	1.27	1.27
11/17/89	0.14	2.55	3.11	3.14	3.14
12/1/89	0.00	0.00	0.01	0.01	0.01
12/14/89	0.00	0.20	0.50	0.50	0.58
12/29/89	0.00	0.00	0.01	0.04	0.04
1/12/90	0.00	0.00	0.00	0.25	0.78
1/26/90	0.75	1.07	1.07	1.07	1.07
2/9/90	0.00	0.01	0.04	0.04	0.18
2/26/90	0.00	0.00	0.00	0.91	0.99
3/12/90	0.01	0.10	1.16	1.67	1.68
3/23/90	0.00	0.00	0.00	0.07	0.07
4/9/90	0.02	0.27	0.55	0.56	0.56
4/20/90	0.00	0.00	0.21	0.21	0.21
5/7/90	0.00	0.00	0.00	0.00	0.00
6/2/90	0.00	0.00	0.00	0.00	0.00
6/16/90	0.00	0.00	0.00	0.00	0.00
6/28/90	0.00	0.00	0.00	0.00	0.50

Notes: 1 Day = day of sampling
 2 Days = day of sampling and day before
 3 Days = day of sampling and two days before
 4 Days = day of sampling and three days before
 5 Days = day of sampling and four days before

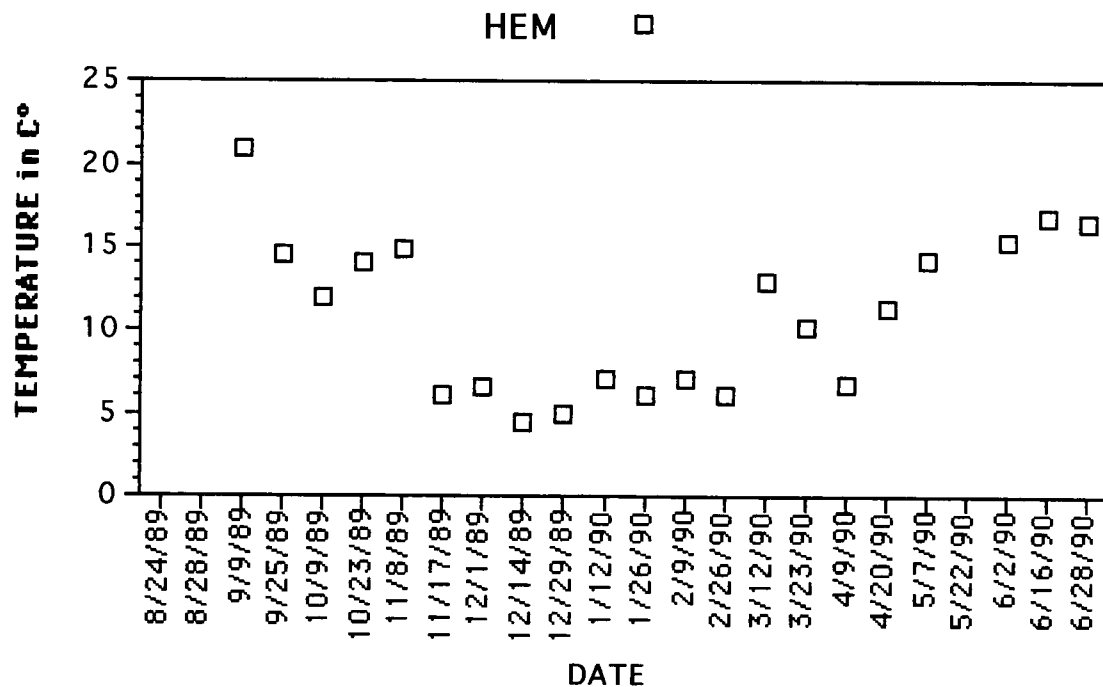


Figure A-1. Temperature measurements for sampling location HEM over the duration of the sample period.

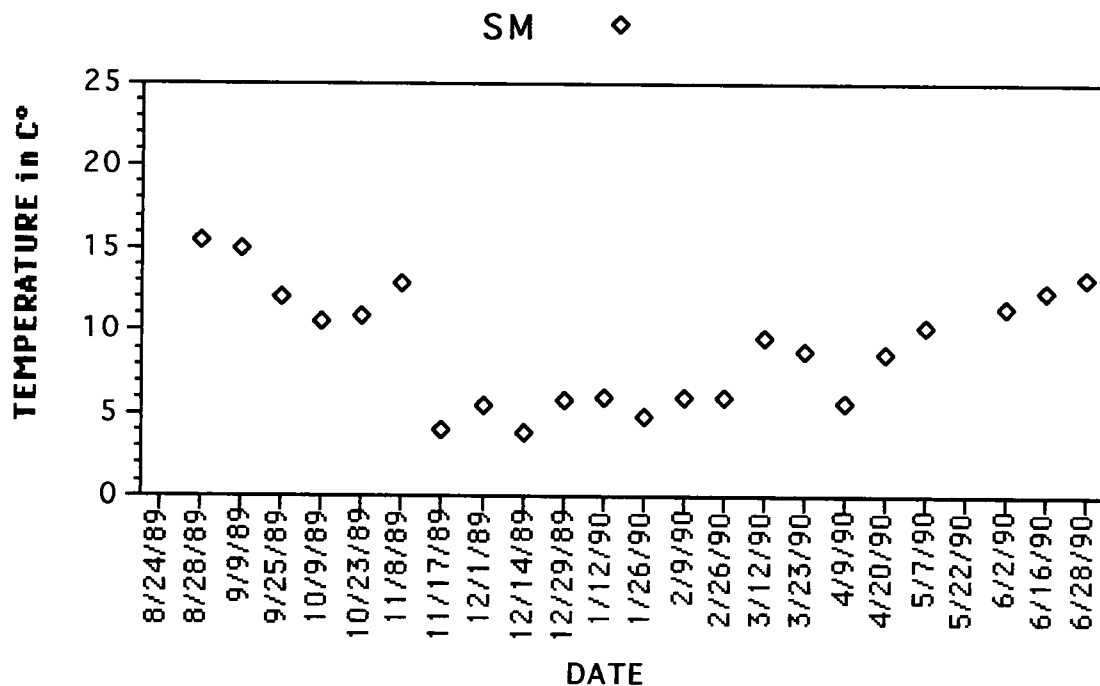


Figure A-2. Temperature measurements for sampling location SM over the duration of the sample period.

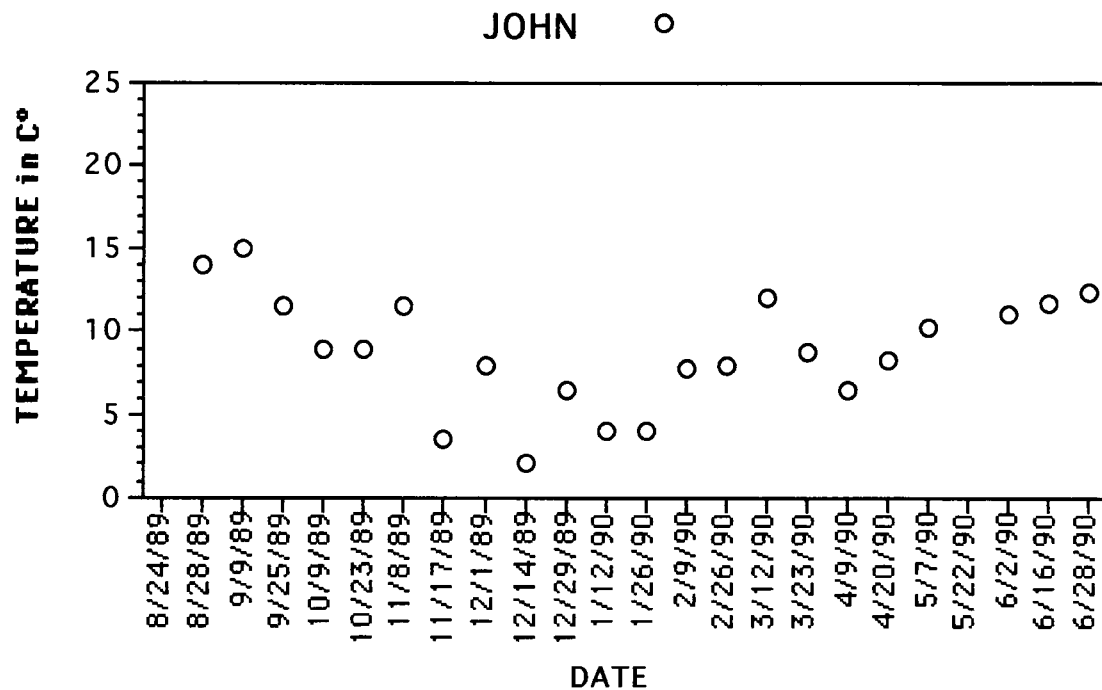


Figure A-3. Temperature measurements for sampling location JOHN over the duration of the sample period.

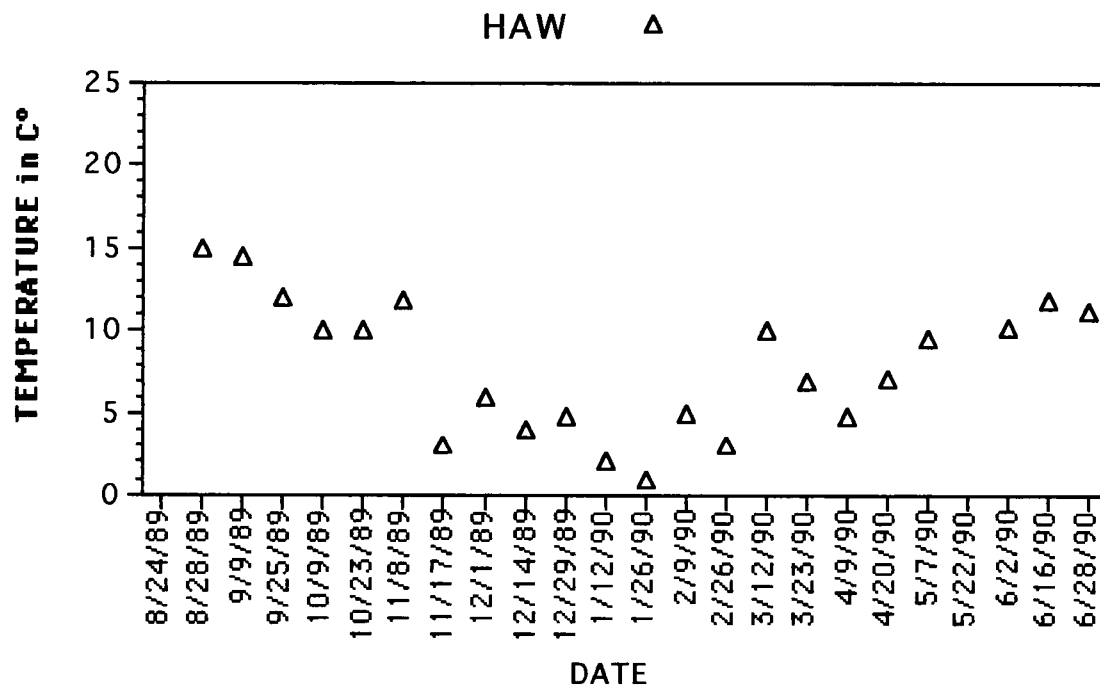


Figure A-4. Temperature measurements for sampling location HAW over the duration of the sample period.

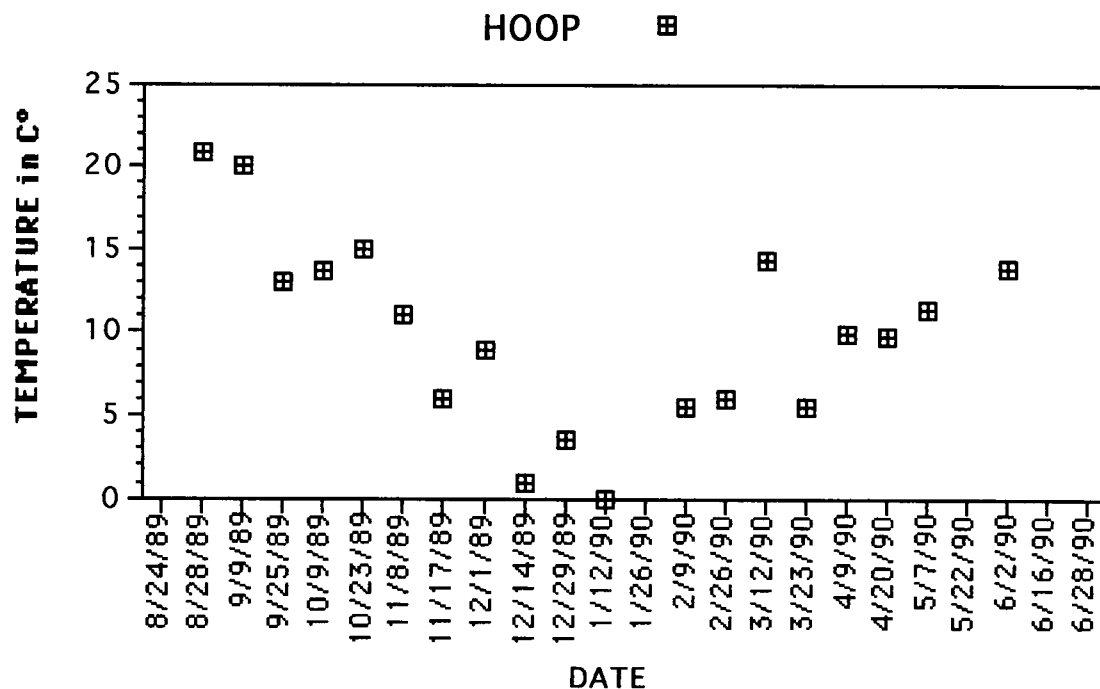


Figure A-5. Temperature measurements for sampling location HOOP over the duration of the sample period.

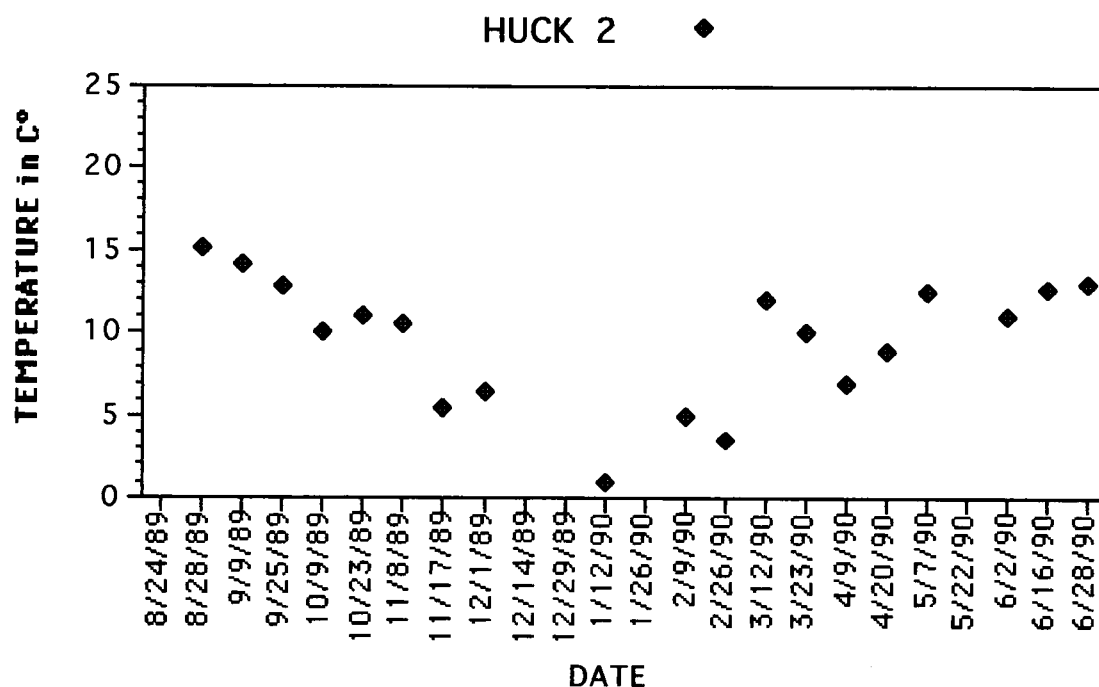


Figure A-6. Temperature measurements for sampling location HUCK2 over the duration of the sample period.

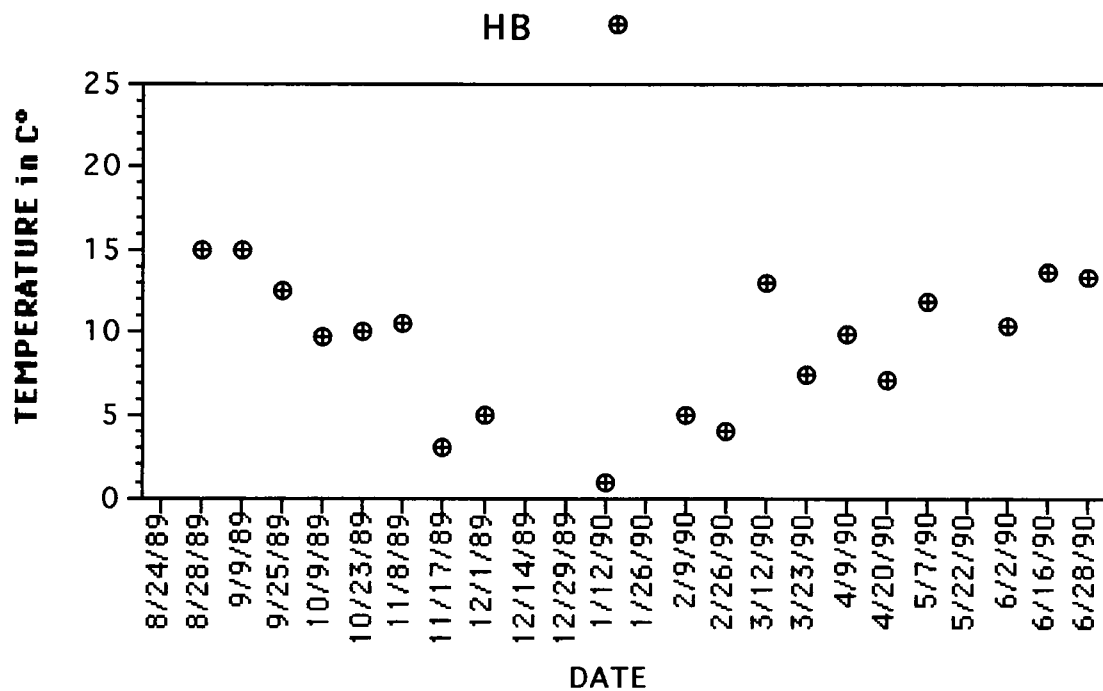


Figure A-7. Temperature measurements for sampling location HB over the duration of the sample period.

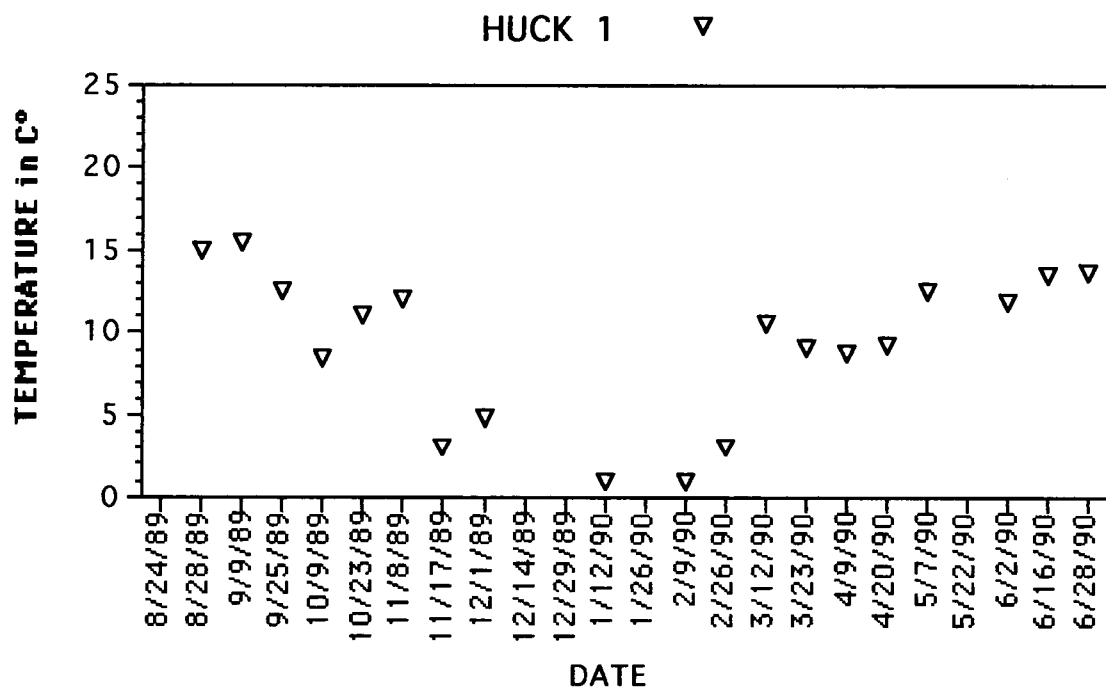


Figure A-8. Temperature measurements for sampling location HUCK1 over the duration of the sample period.

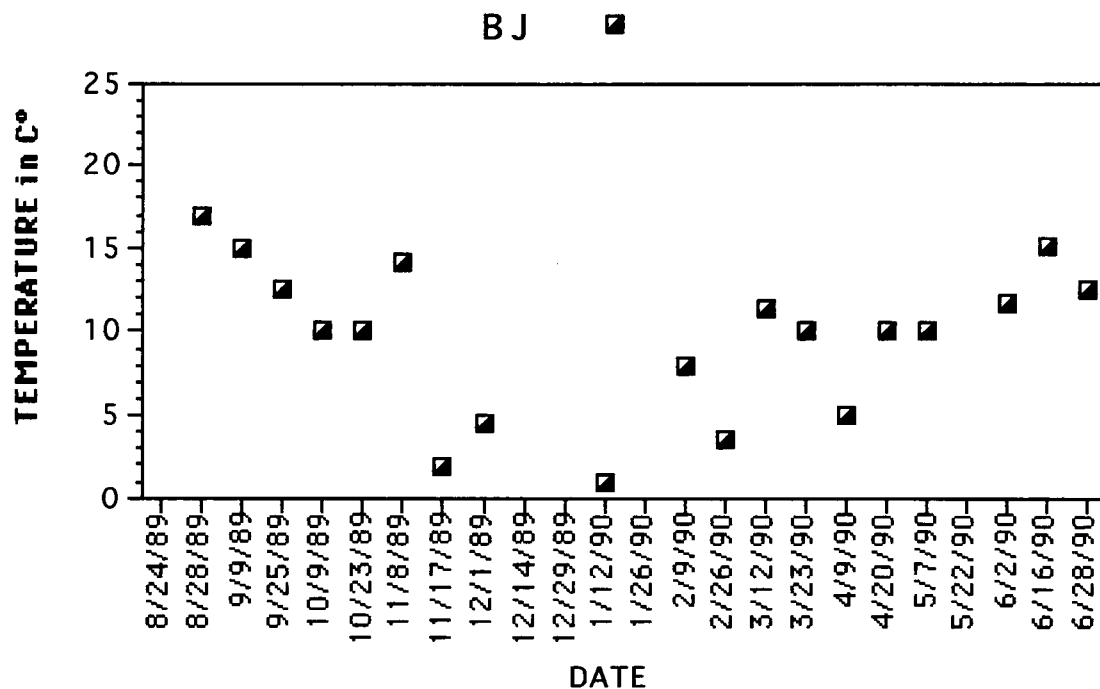


Figure A-9. Temperature measurements for sampling location BJ over the duration of the sample period.

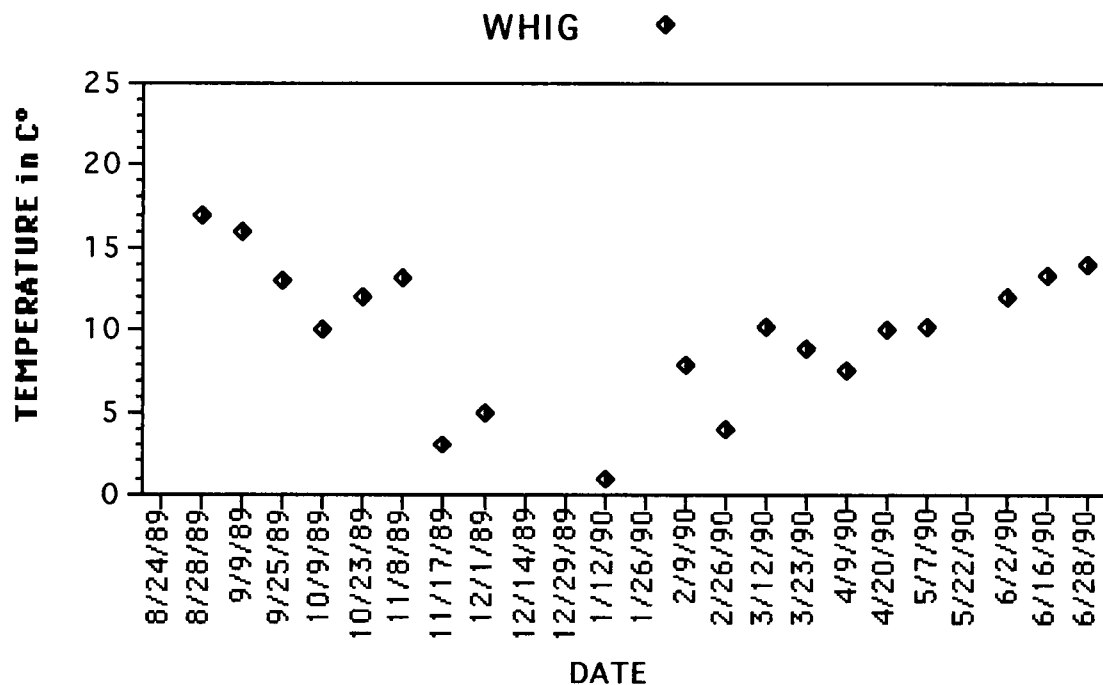


Figure A-10. Temperature measurements for sampling location WHIG over the duration of the sample period.

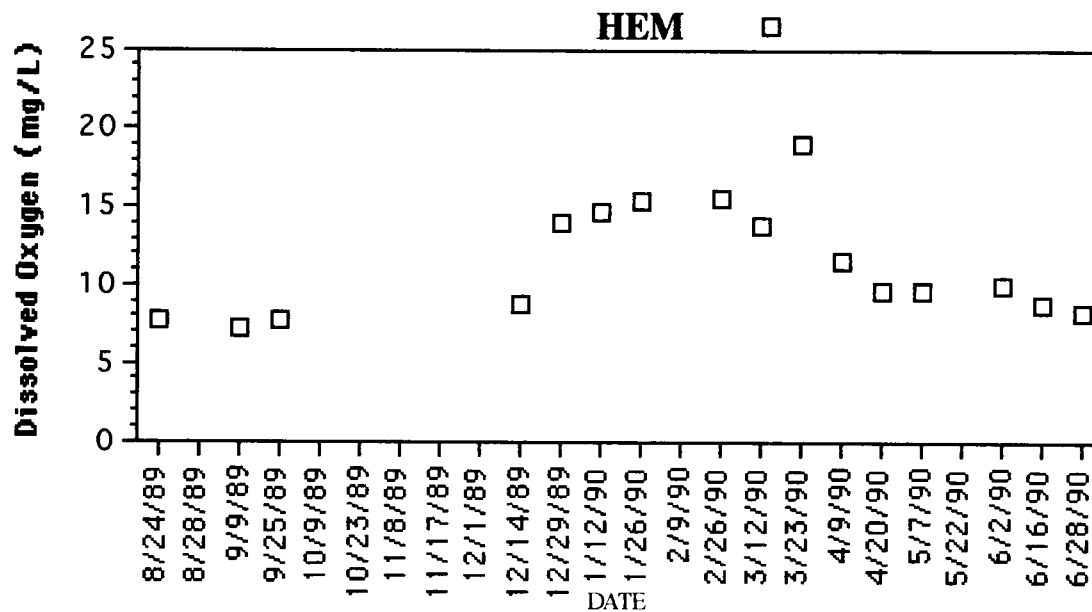


Figure A-11. Dissolved oxygen measurements for sampling location HEM over the duration of the sample period.

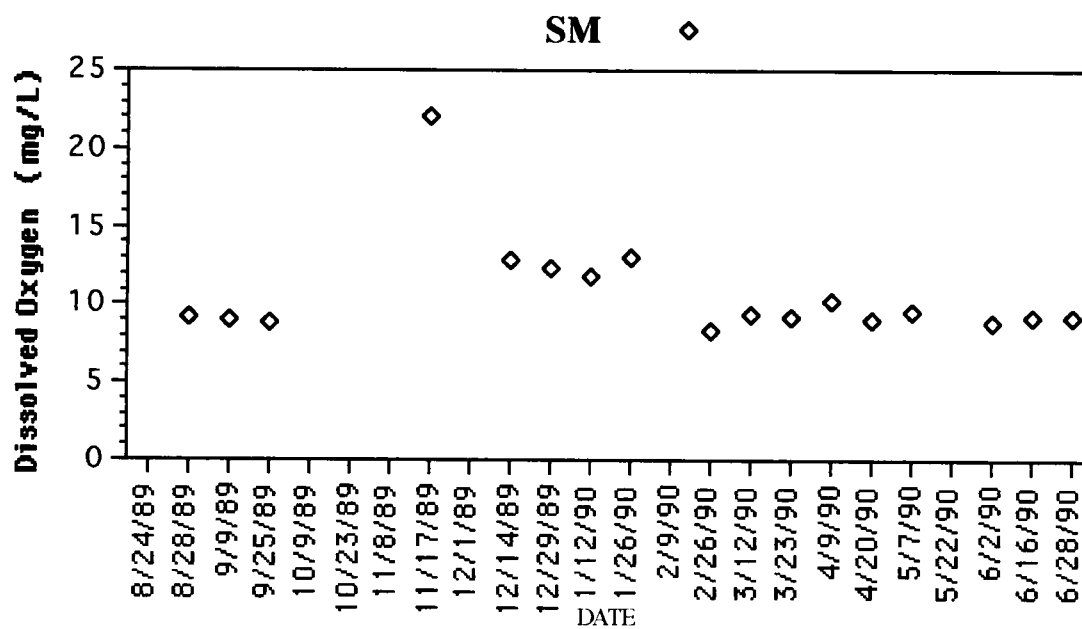


Figure A-12. Dissolved oxygen measurements for sampling location SM over the duration of the sample period.

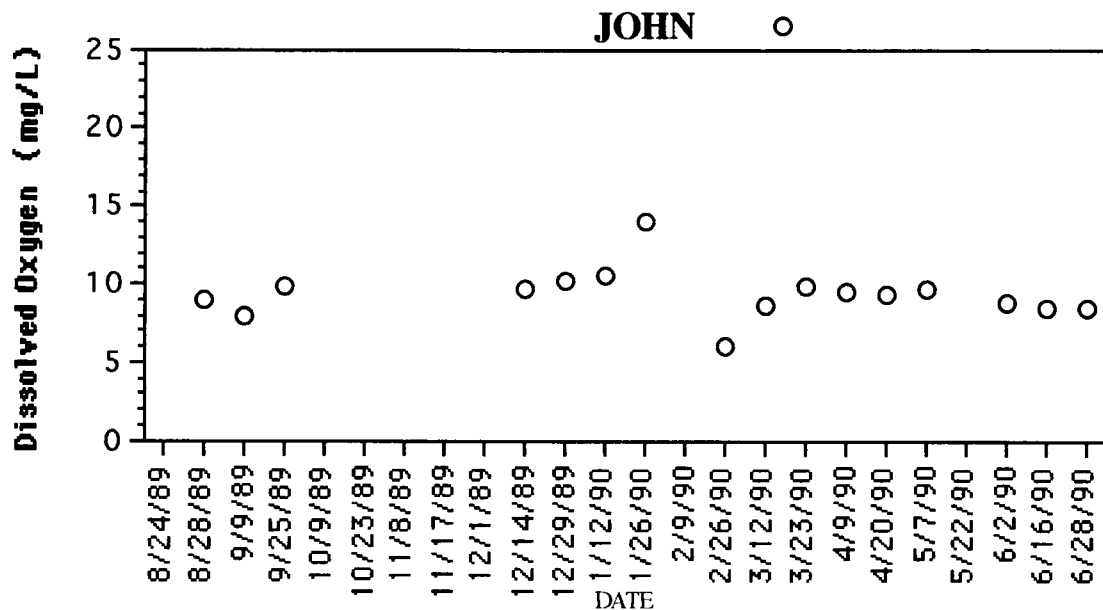


Figure A-13. Dissolved oxygen measurements for sampling location JOHN over the duration of the sample period.

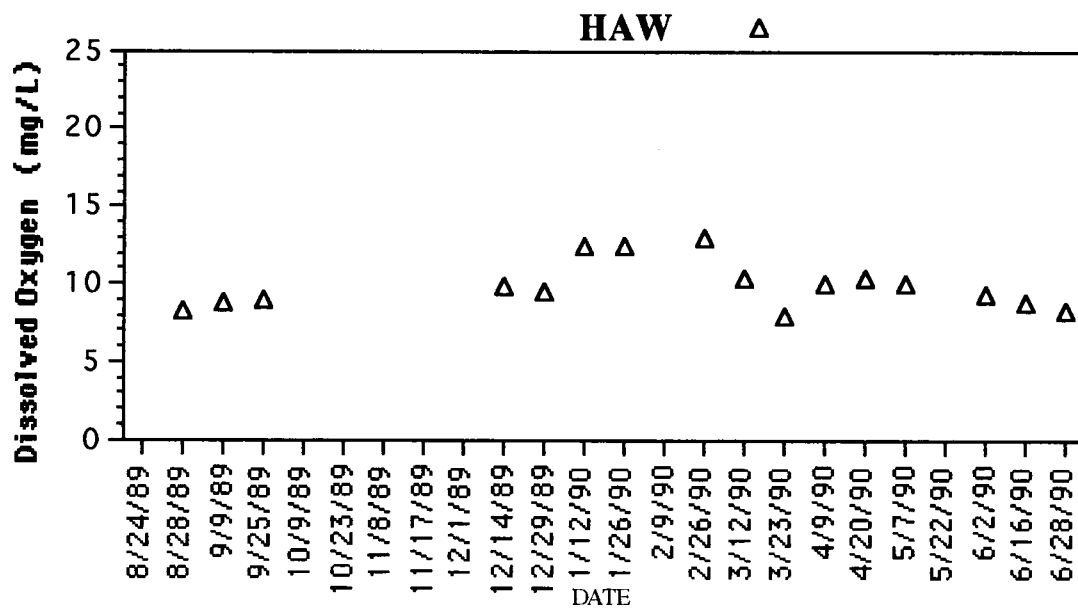


Figure A-14. Dissolved oxygen measurements for sampling location HAW over the duration of the sample period.

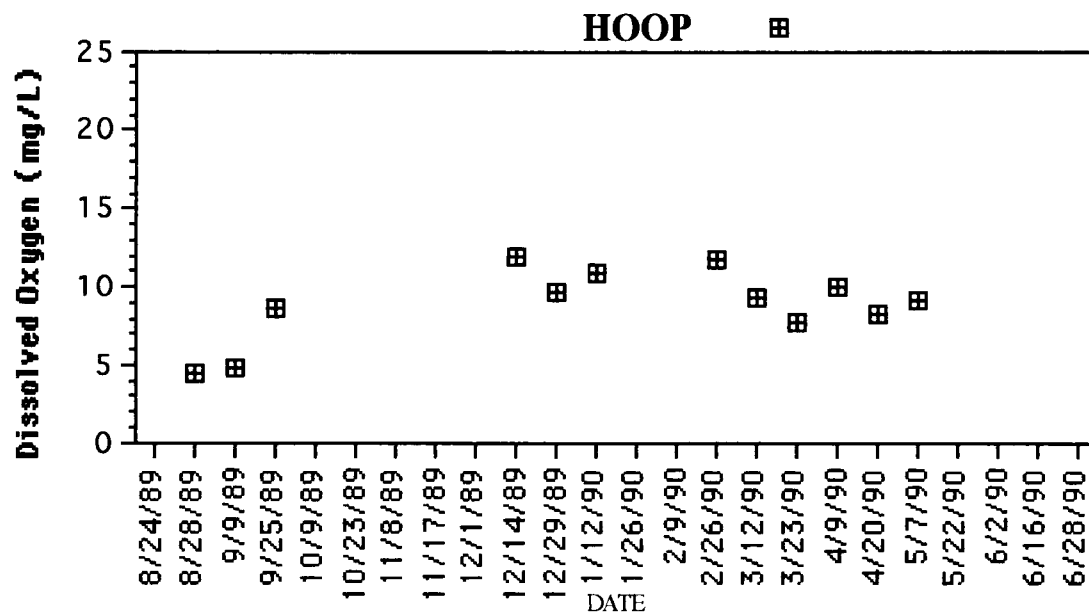


Figure A-15. Dissolved oxygen measurements for sampling location HOOP over the duration of the sample period.

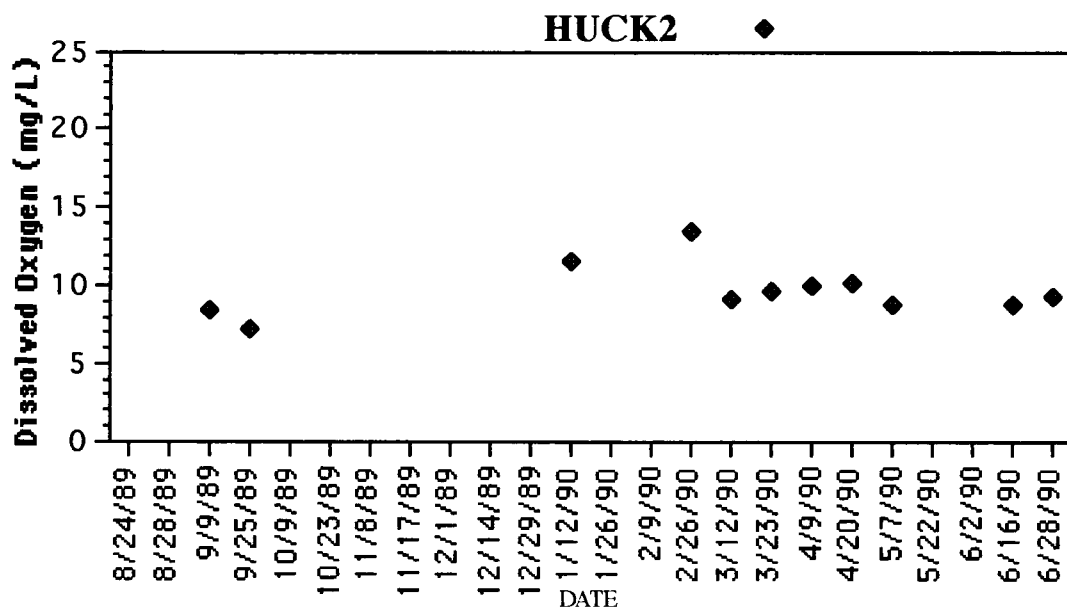


Figure A-16. Dissolved oxygen measurements for sampling location HUCK2 over the duration of the sample period.

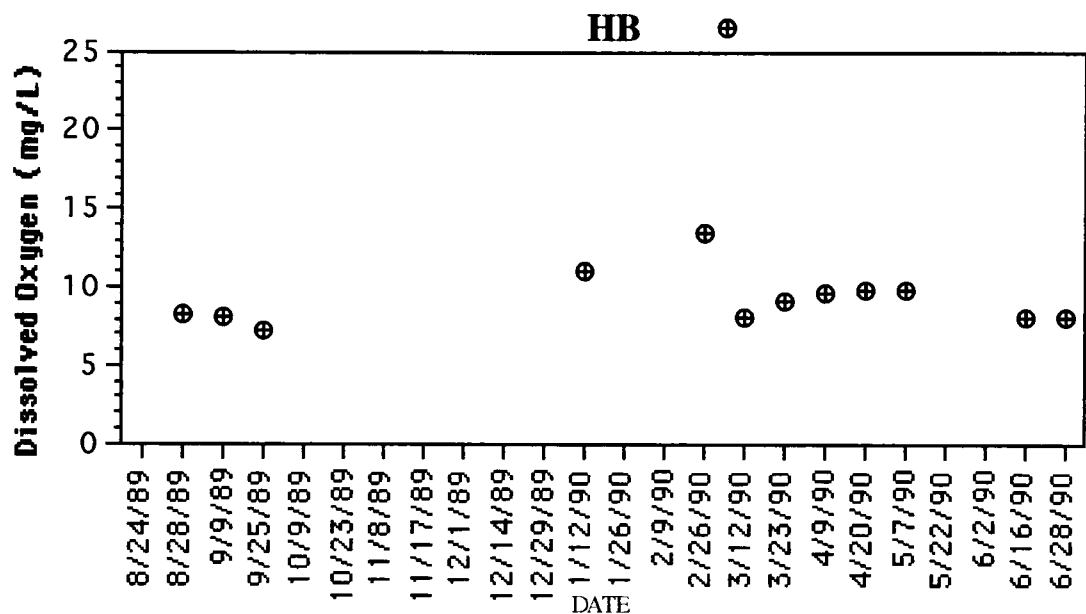


Figure A-17. Dissolved oxygen measurements for sampling location HB over the duration of the sample period.

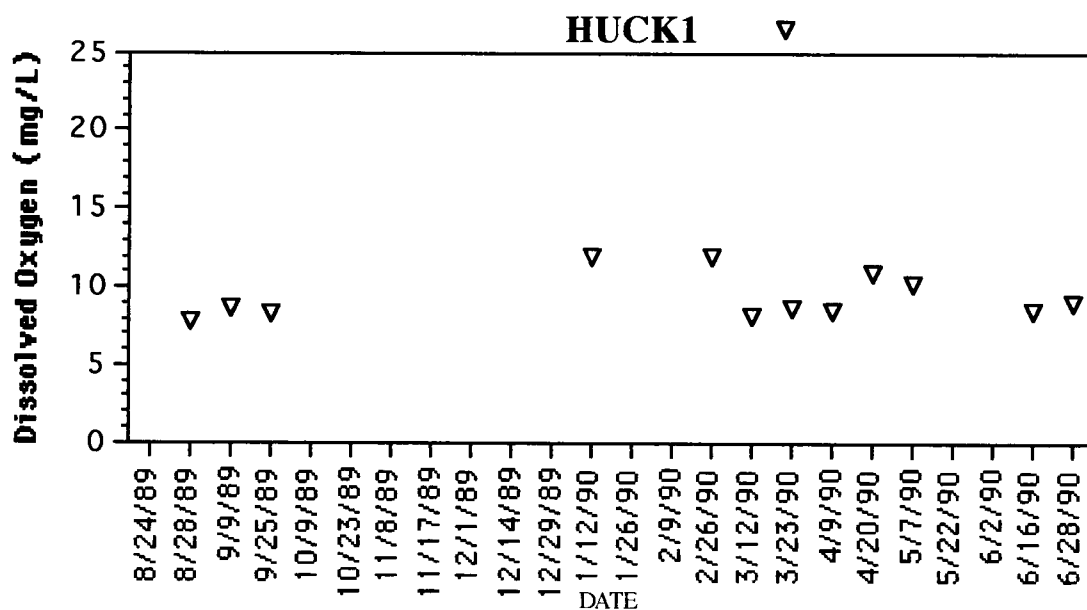


Figure A-18. Dissolved oxygen measurements for sampling location HUCK1 over the duration of the sample period.

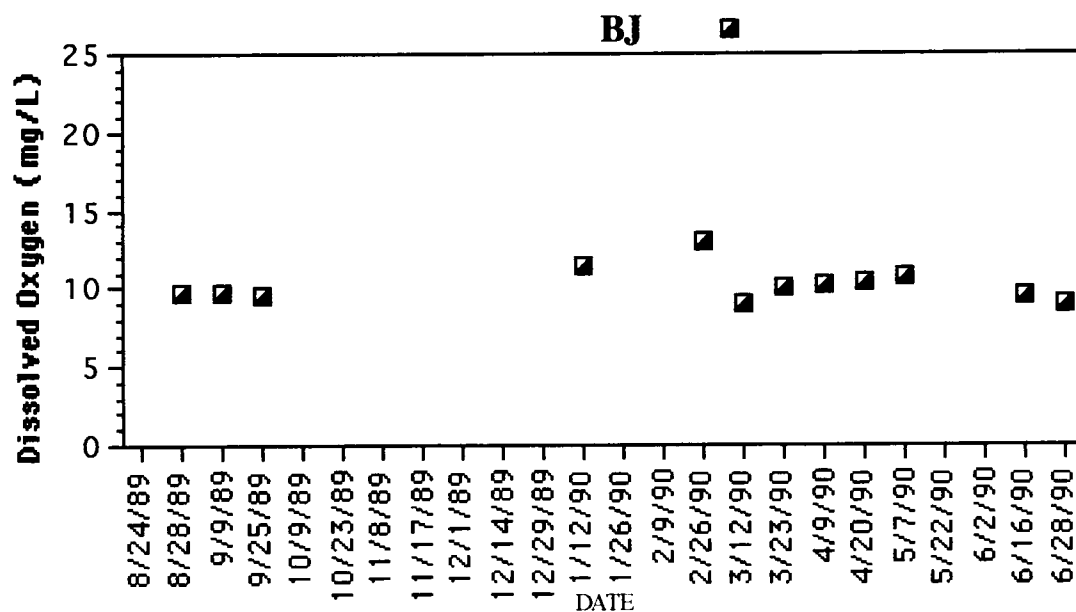


Figure A-19. Dissolved oxygen measurements for sampling location BJ over the duration of the sample period.

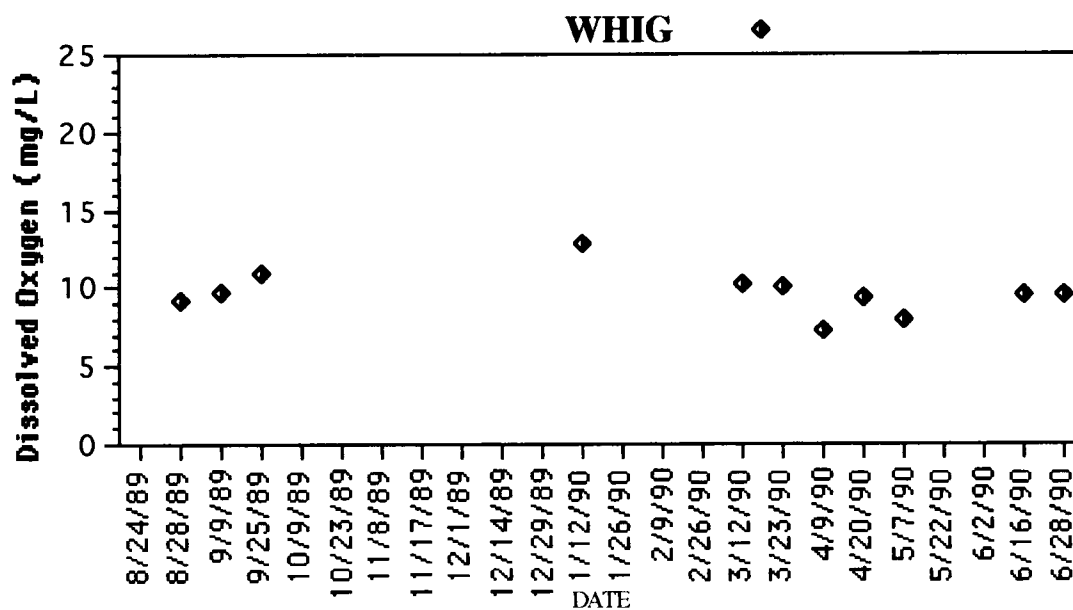


Figure A-20. Dissolved oxygen measurements for sampling location WHIG over the duration of the sample period.

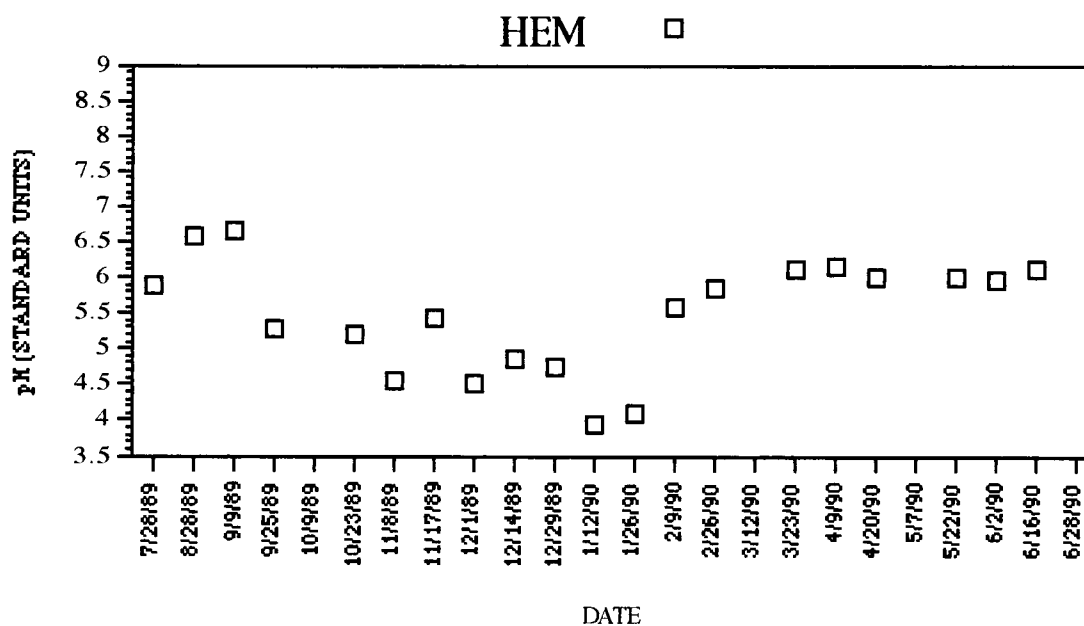


Figure A-21. pH values for sampling location HEM over the duration of the sample period.

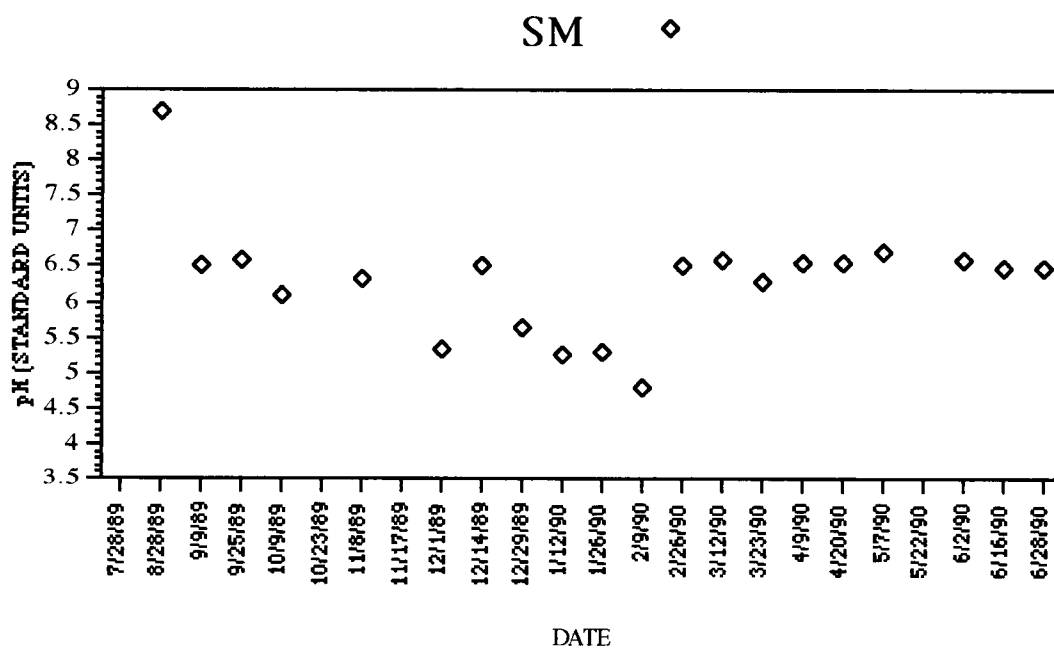


Figure A-22. pH values for sampling location SM over the duration of the sample period.

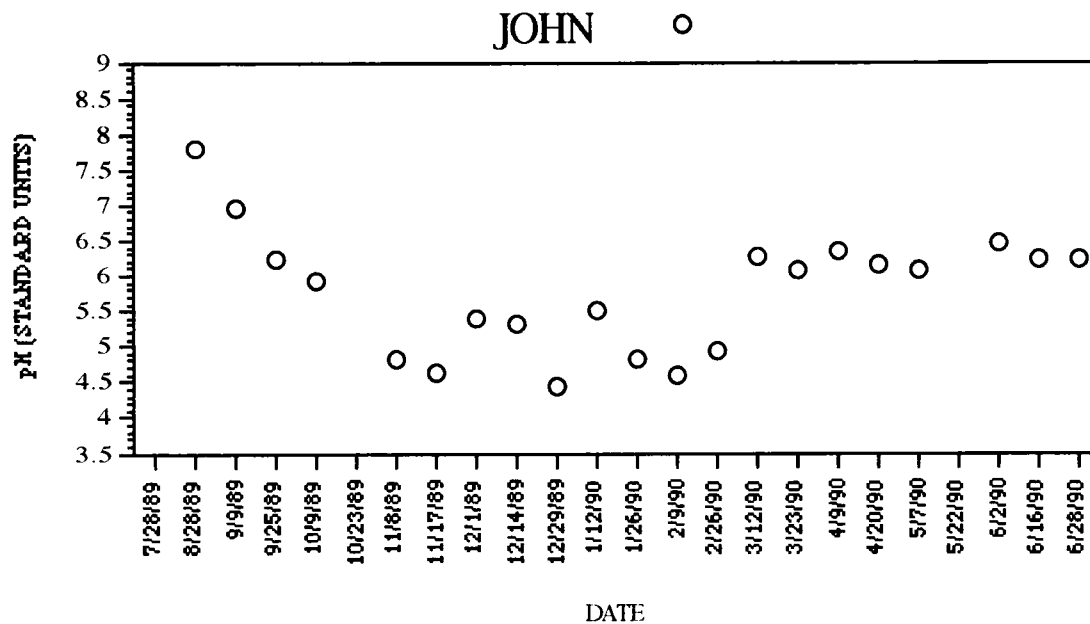


Figure A-23. pH values for sampling location JOHN over the duration of the sample period.

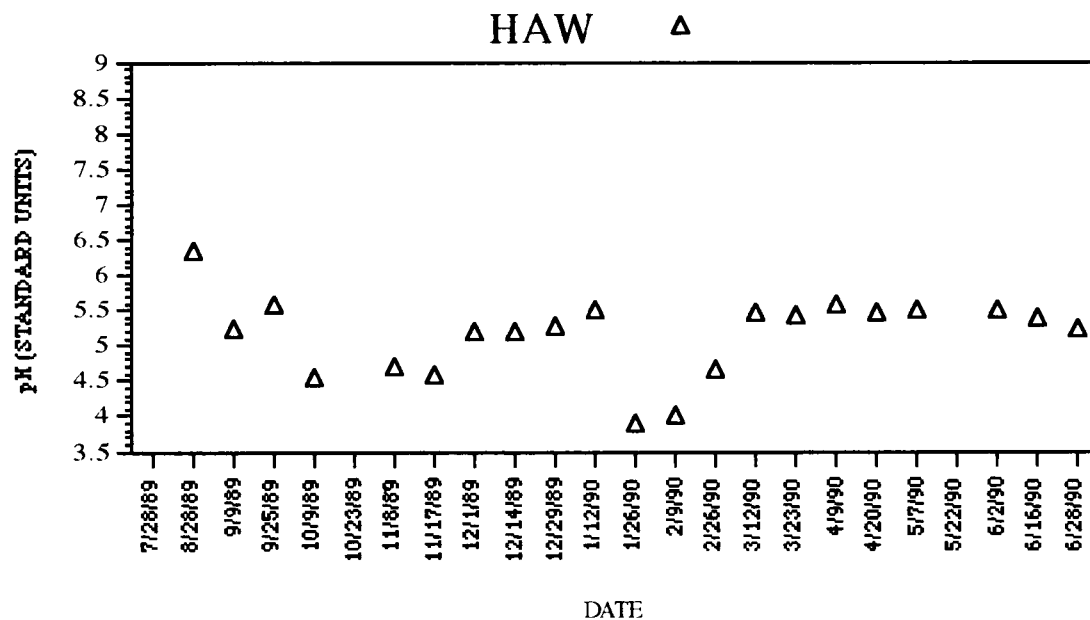


Figure A-24. pH values for sampling location HAW over the duration of the sample period.

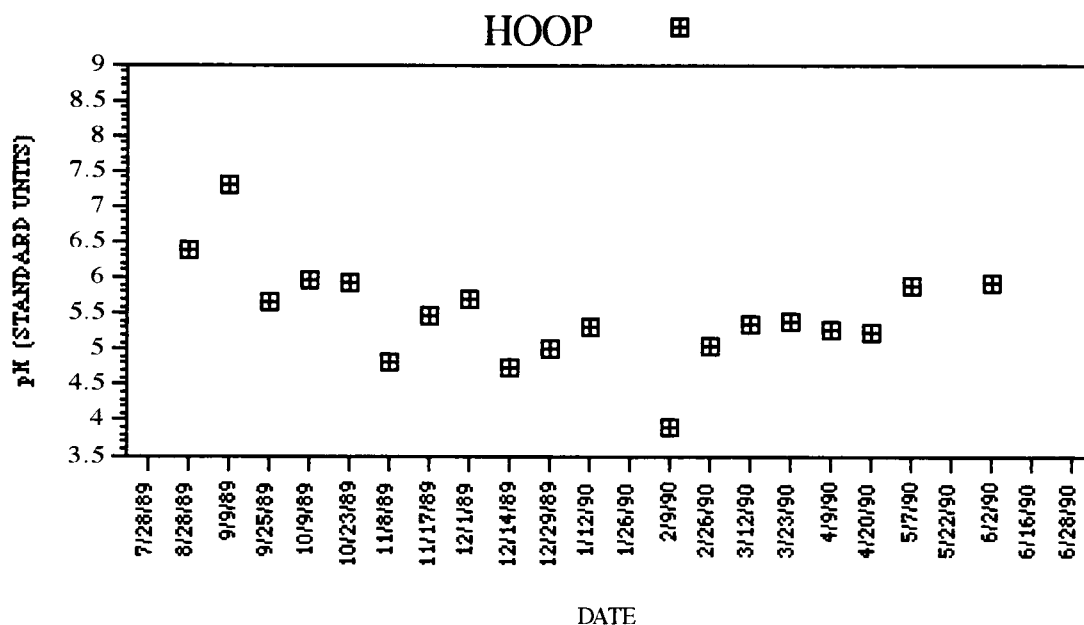


Figure A-25. pH values for sampling location HOOP over the duration of the sample period.

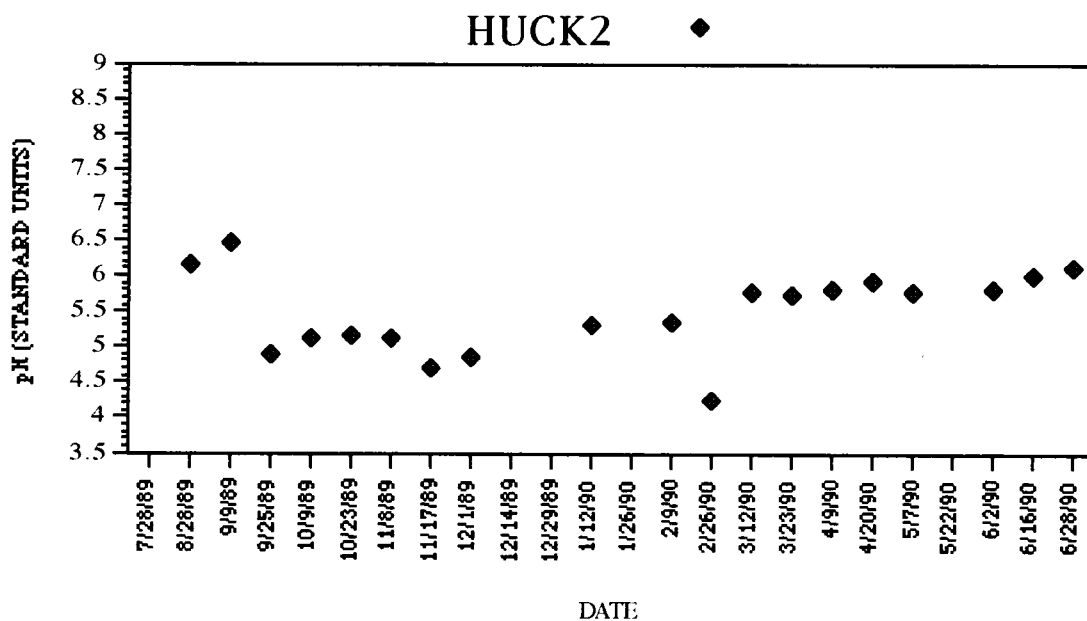


Figure A-26. pH values for sampling location HUCK2 over the duration of the sample period.

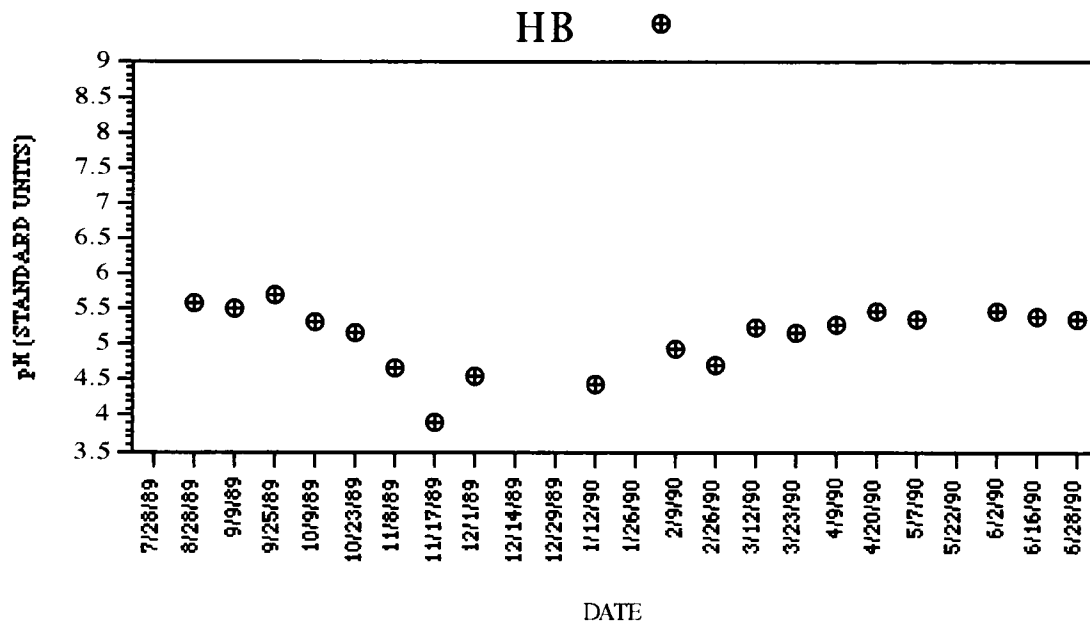


Figure A-27. pH values for sampling location HB over the duration of the sample period.

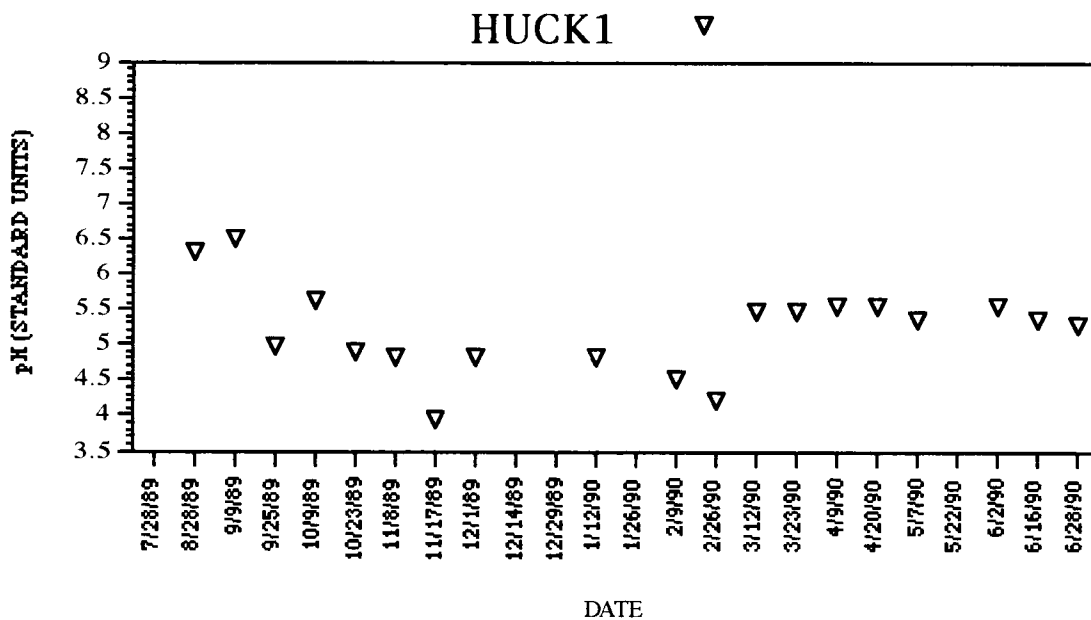


Figure A-28. pH values for sampling location HUCK1 over the duration of the sample period.

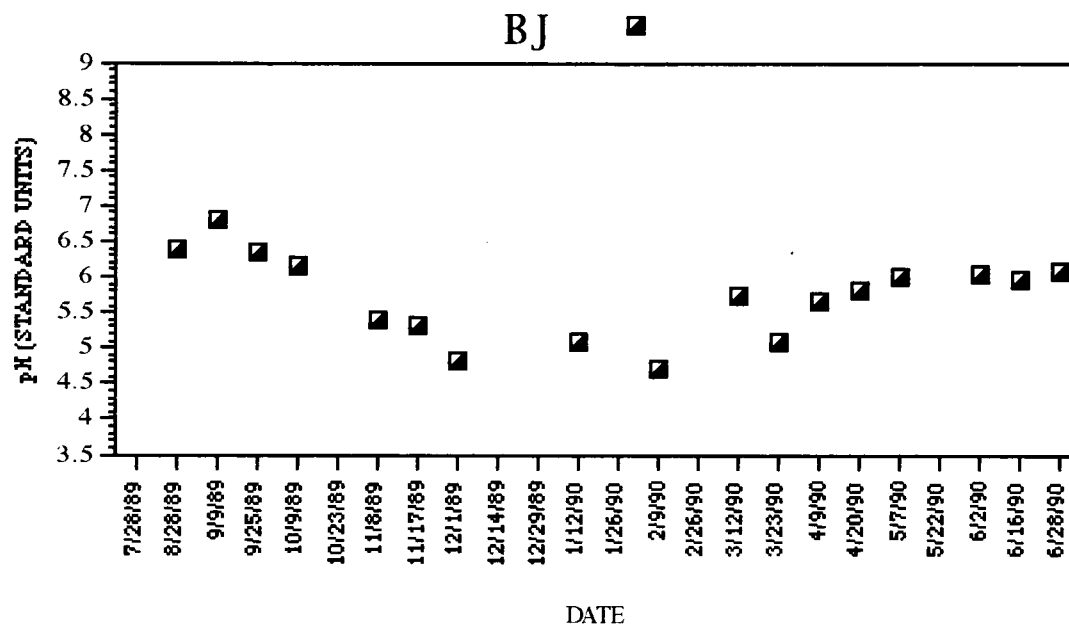


Figure A-29. pH values for sampling location BJ over the duration of the sample period.

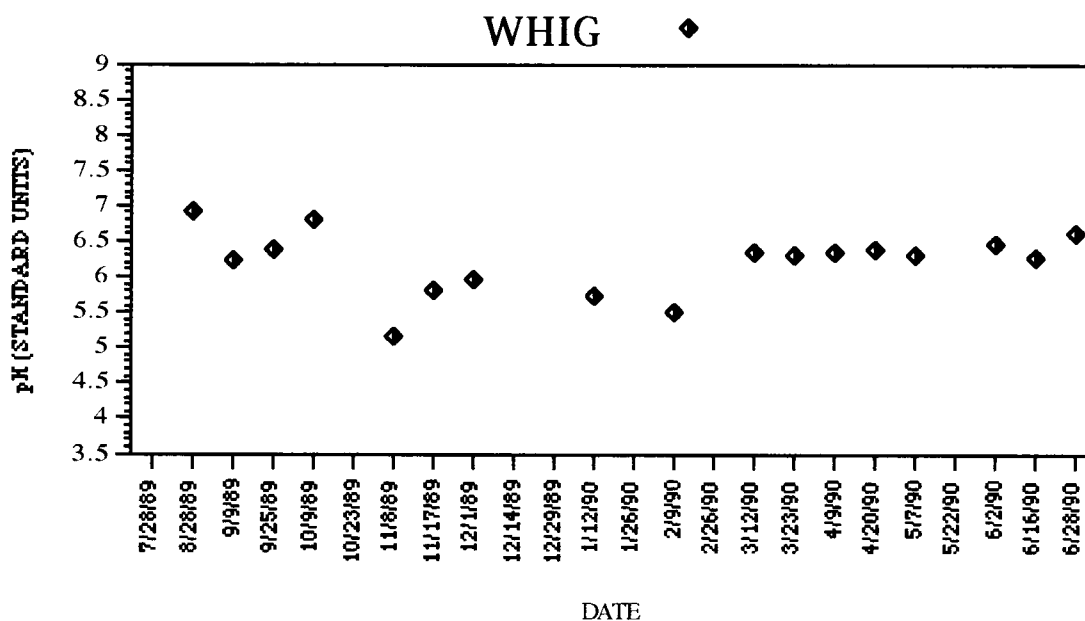


Figure A-30. pH values for sampling location WHIG over the duration of the sample period.

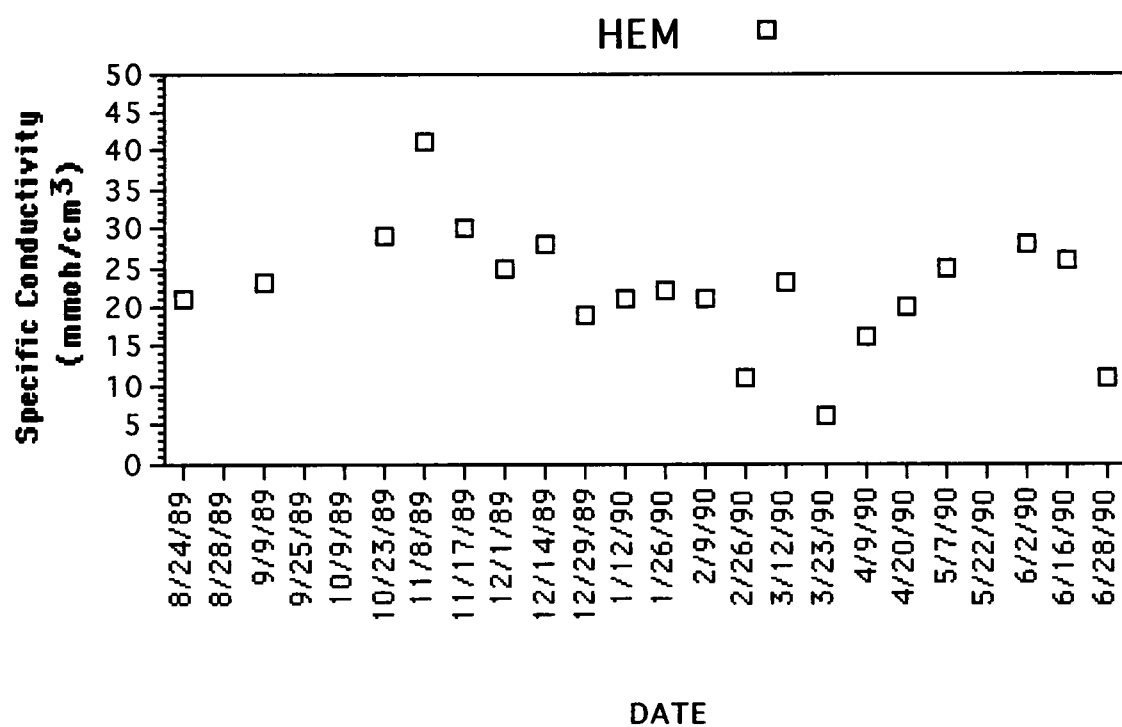


Figure A-31. Specific conductivity values for sampling location HEM over the duration of the sample period.

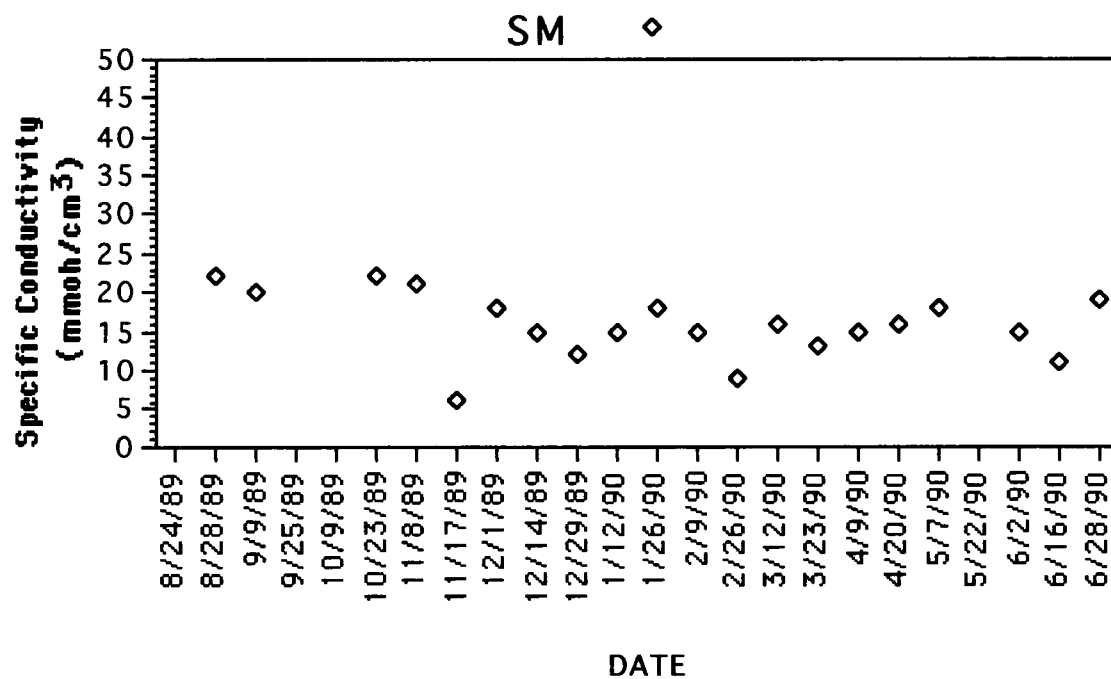


Figure A-32. Specific conductivity values for sampling location SM over the duration of the sample period.

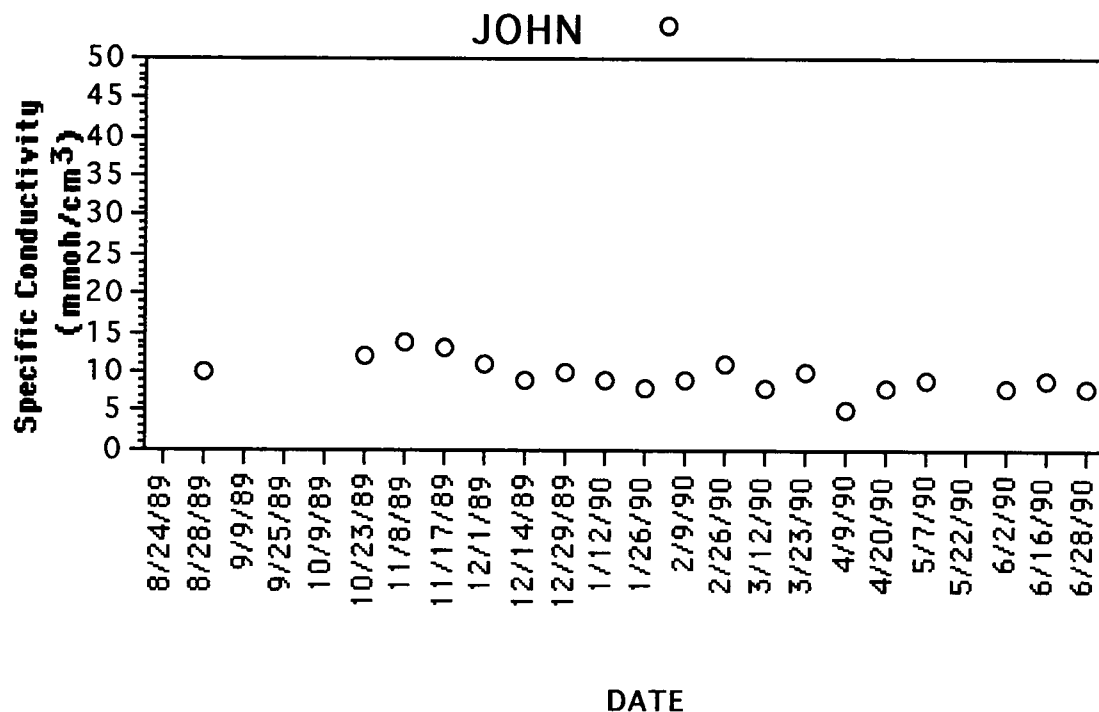


Figure A-33. Specific conductivity values for sampling location JOHN over the duration of the sample period.

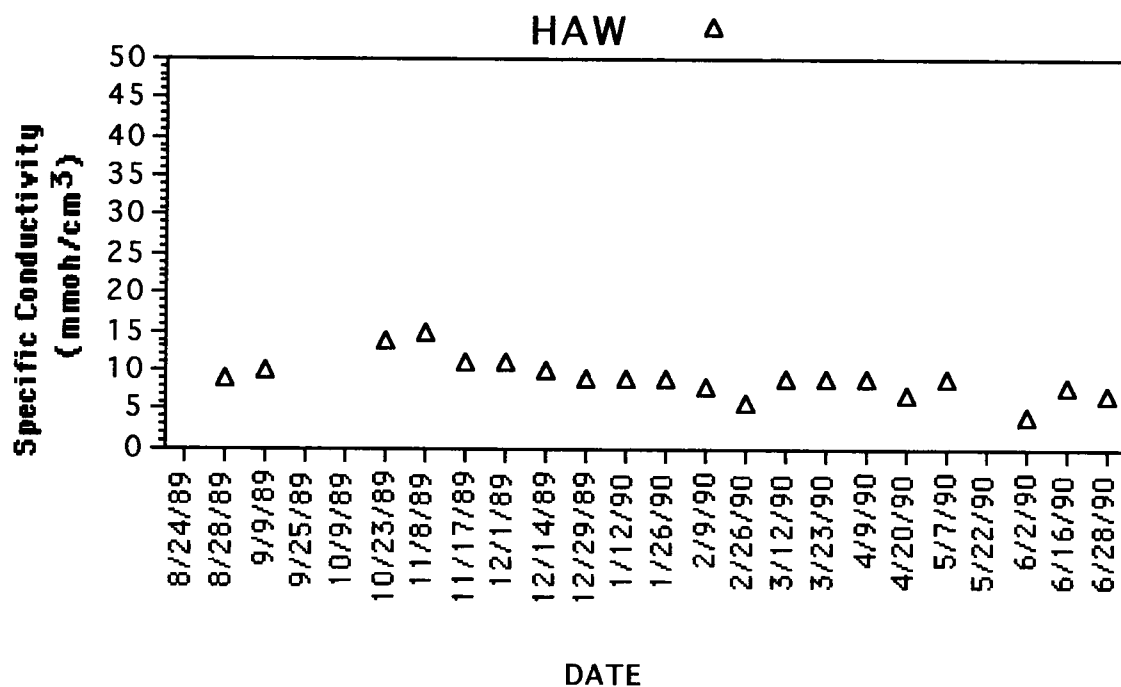


Figure A-34. Specific conductivity values for sampling location HAW over the duration of the sample period.

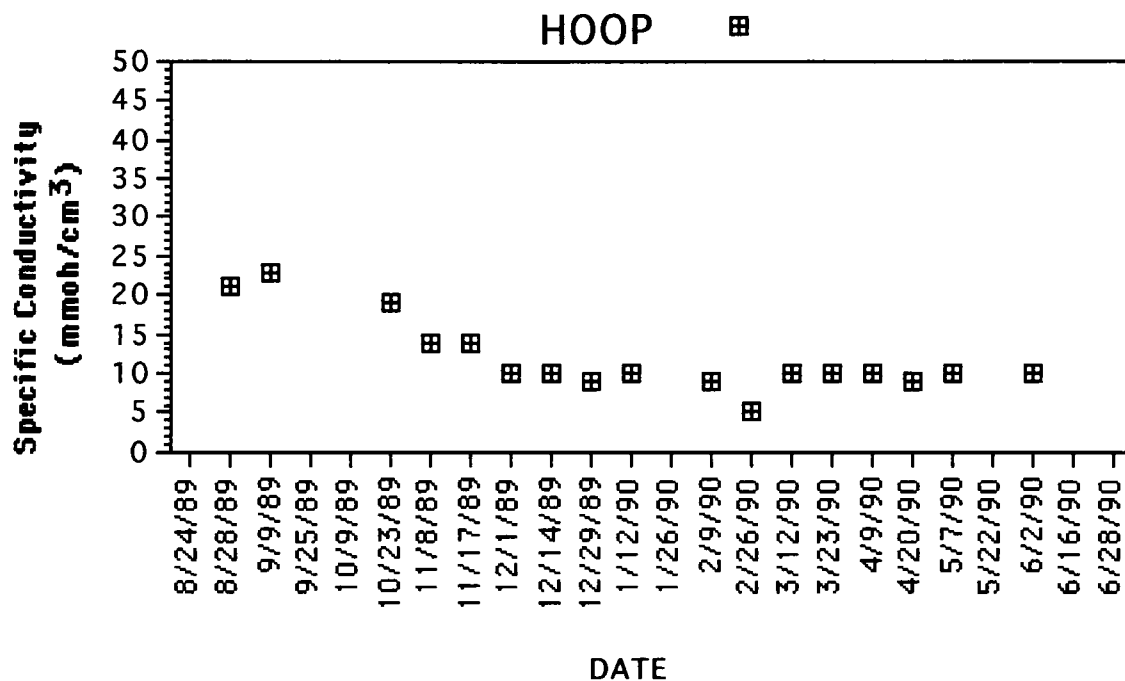


Figure A-35. Specific conductivity values for sampling location HOOP over the duration of the sample period.

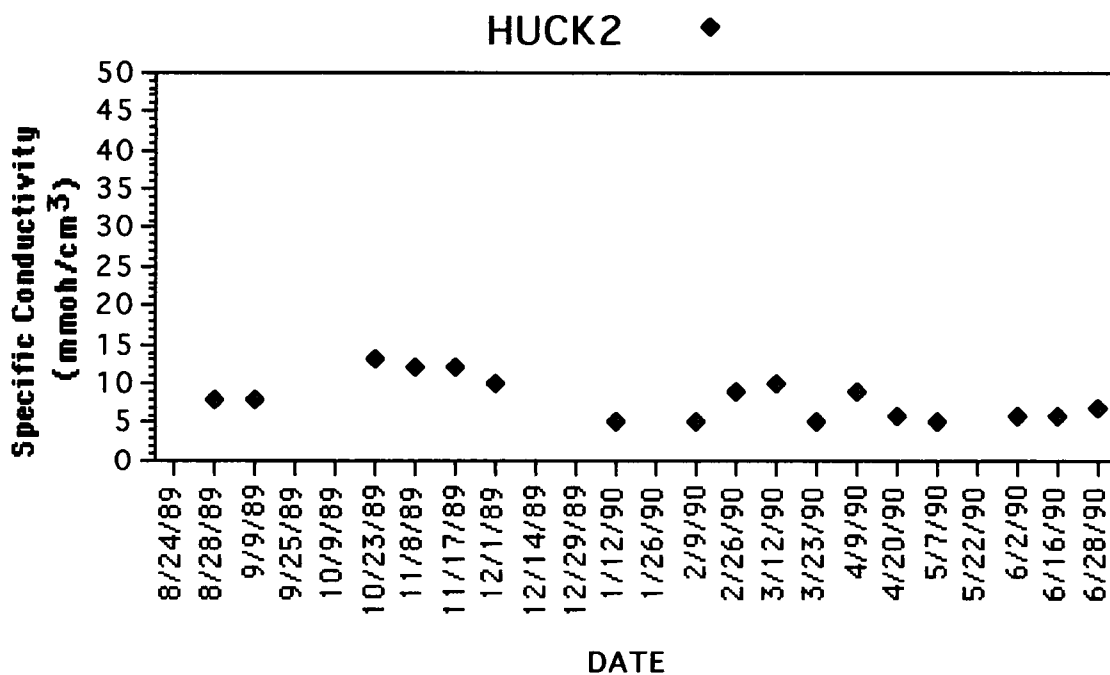


Figure A-36. Specific conductivity values for sampling location HUCK2 over the duration of the sample period.

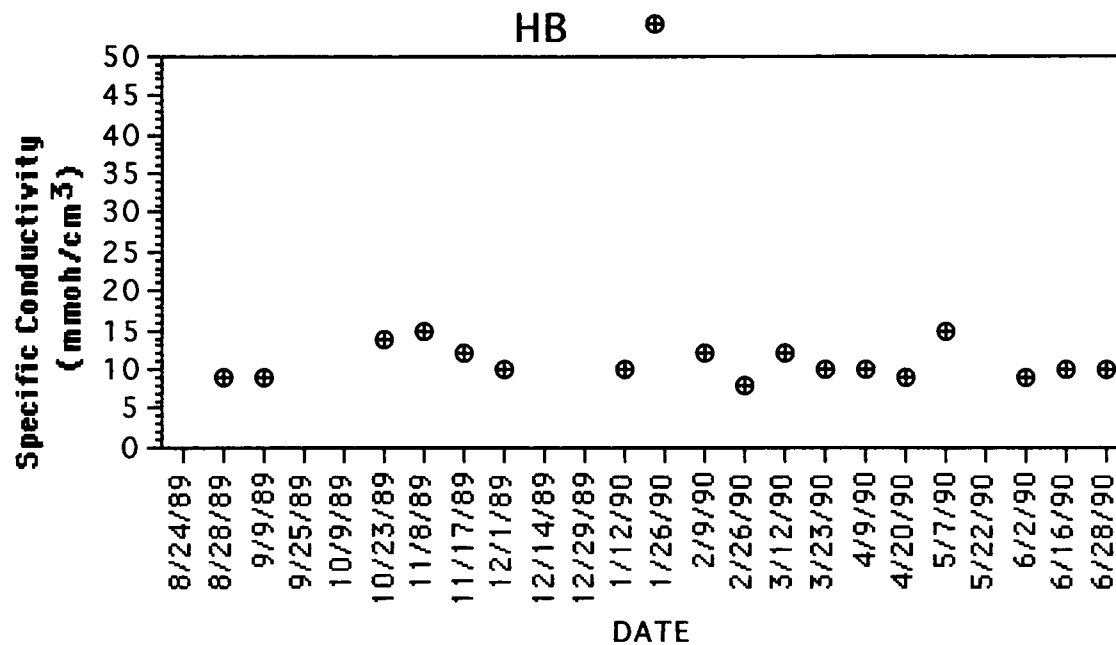


Figure A-37. Specific conductivity values for sampling location HB over the duration of the sample period.

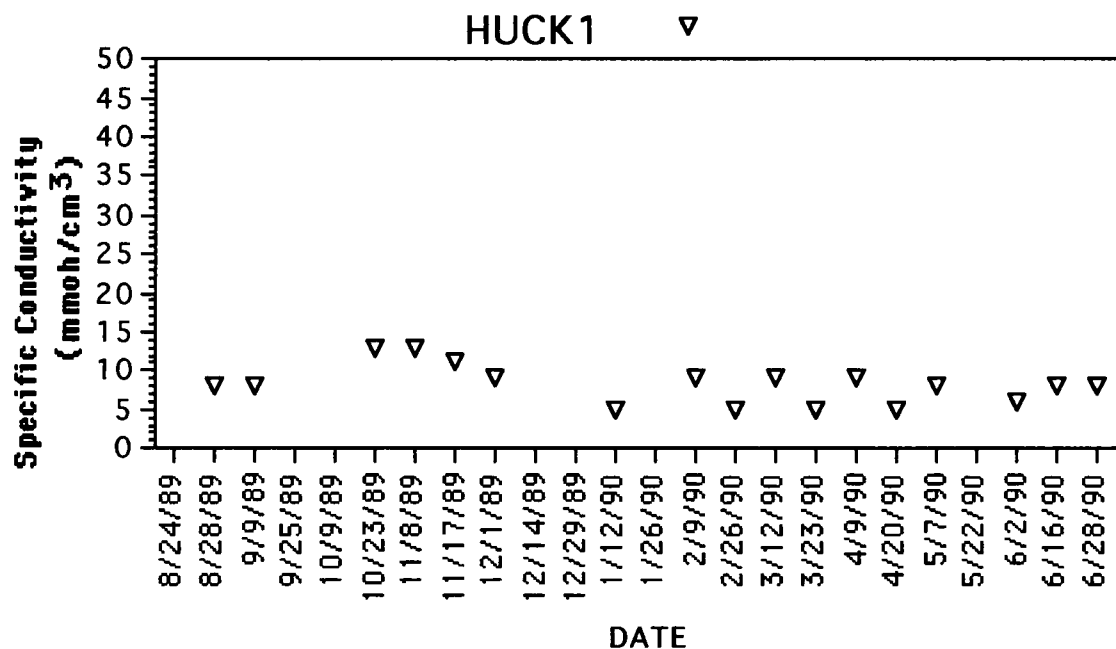


Figure A-38. Specific conductivity values for sampling location HUCK1 over the duration of the sample period.

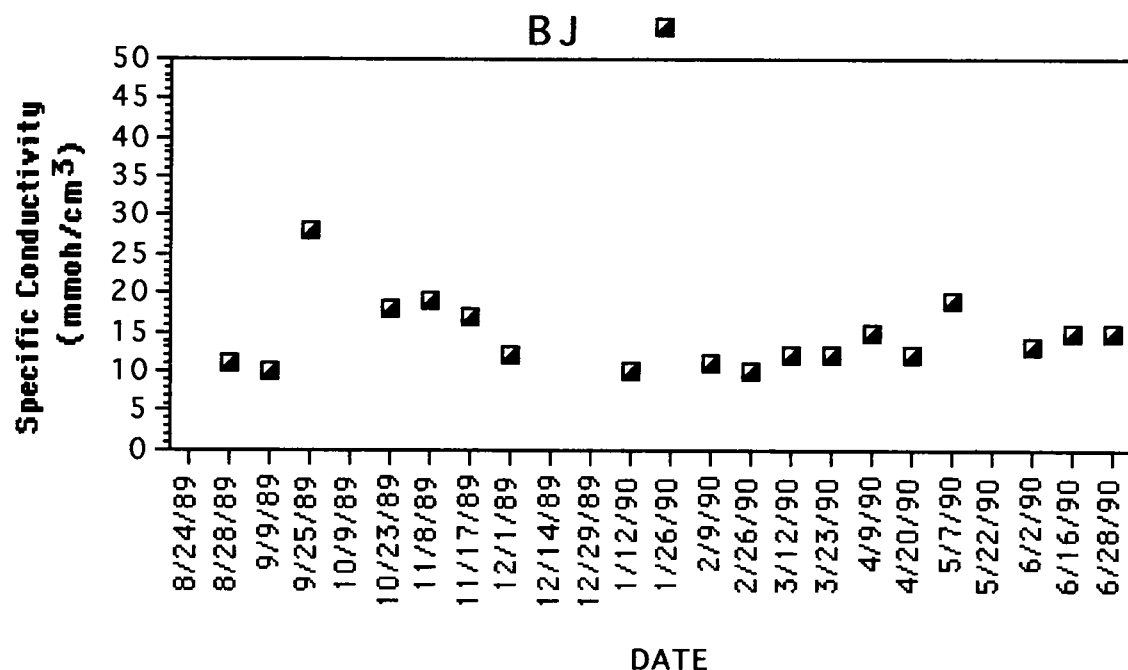


Figure A-39. Specific conductivity values for sampling location BJ over the duration of the sample period.

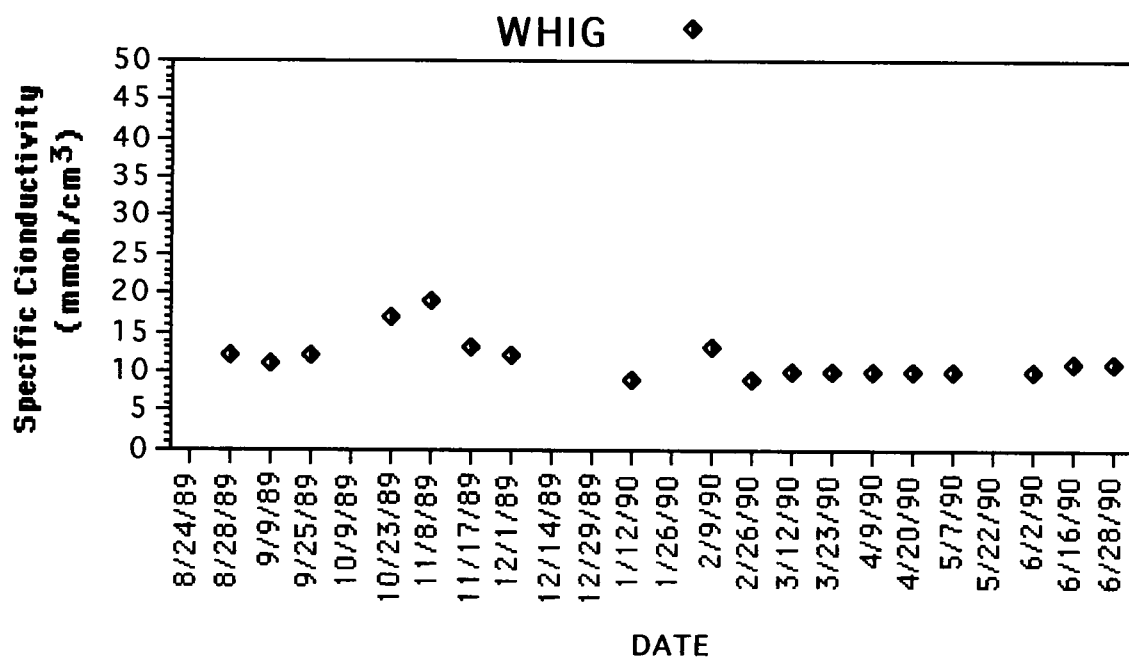


Figure A-40. Specific conductivity values for sampling location WHIG over the duration of the sample period

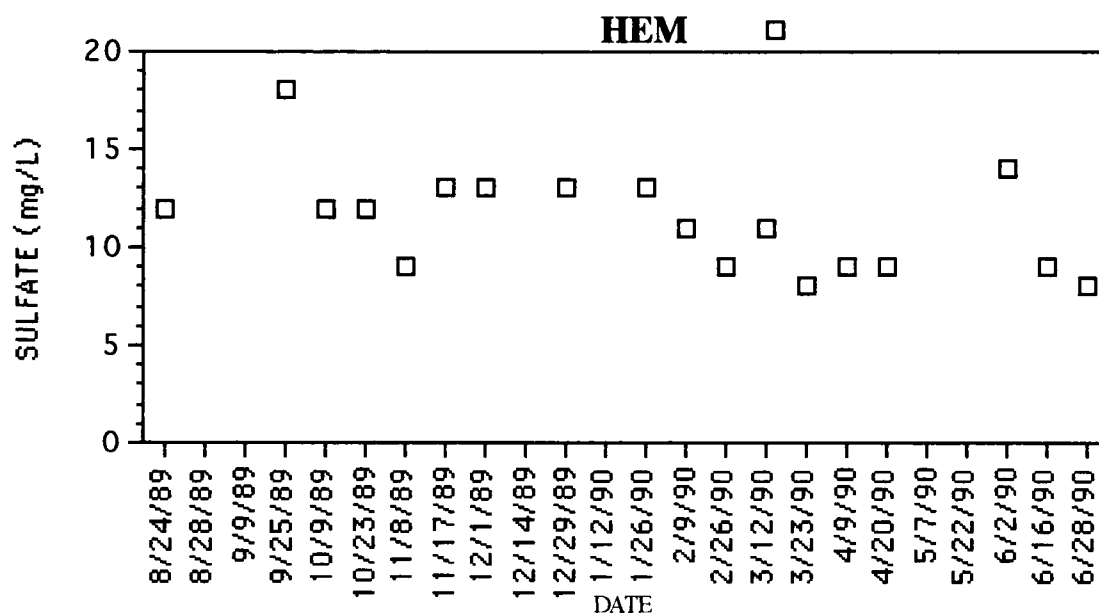


Figure A-41. Sulfate results for sampling location HEM over the duration of the sample period.

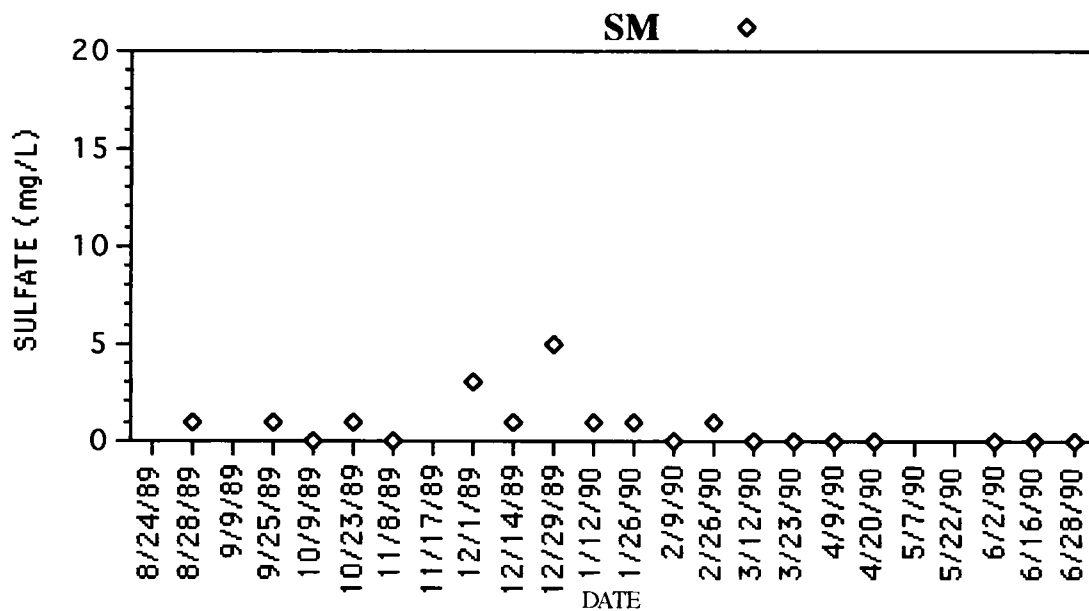


Figure A-42. Sulfate results for sampling location SM over the duration of the sample period.

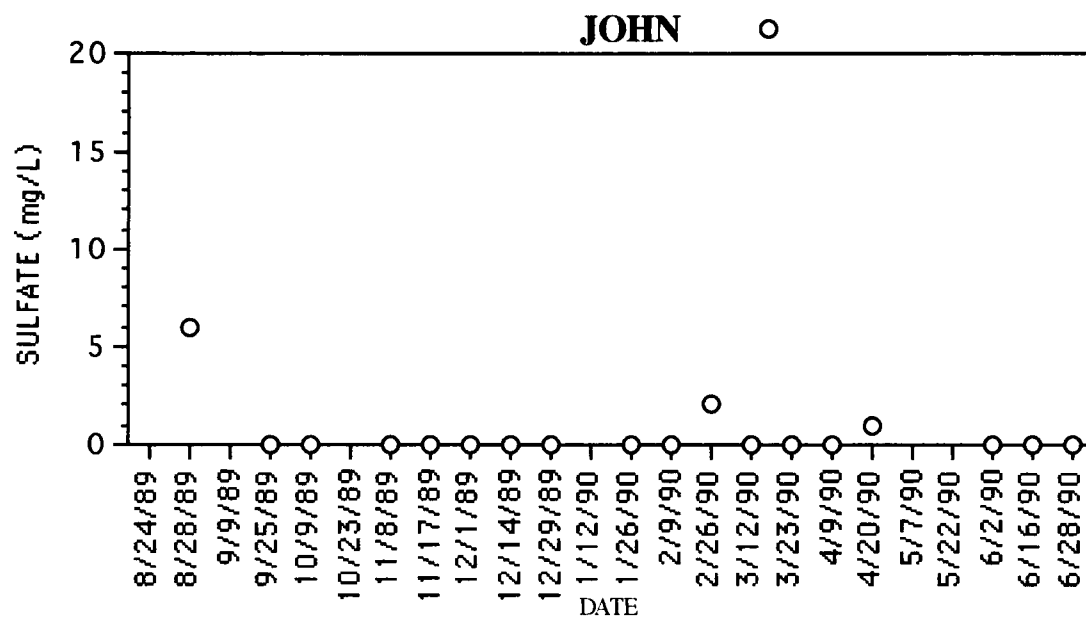


Figure A-43. Sulfate results for sampling location JOHN over the duration of the sample period.

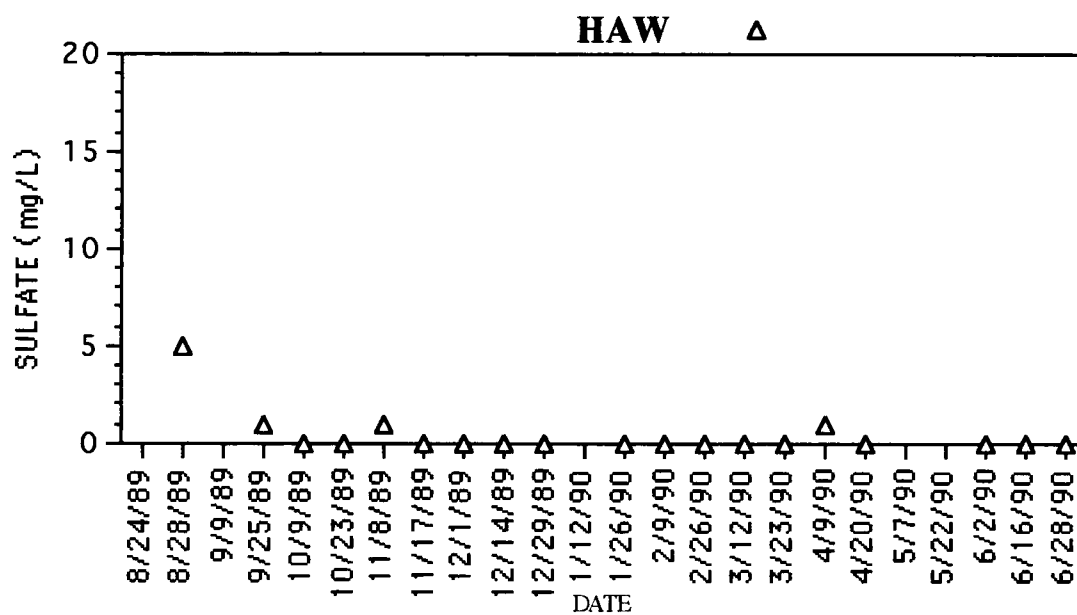


Figure A-44. Sulfate results for sampling location HAW over the duration of the sample period.

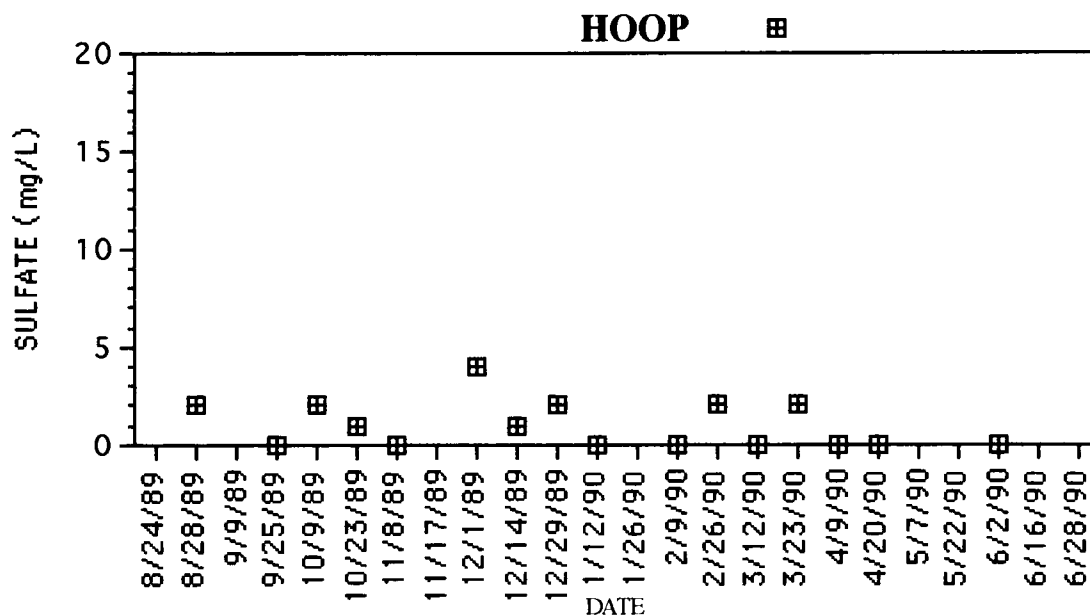


Figure A-45. Sulfate results for sampling location HOOP over the duration of the sample period.

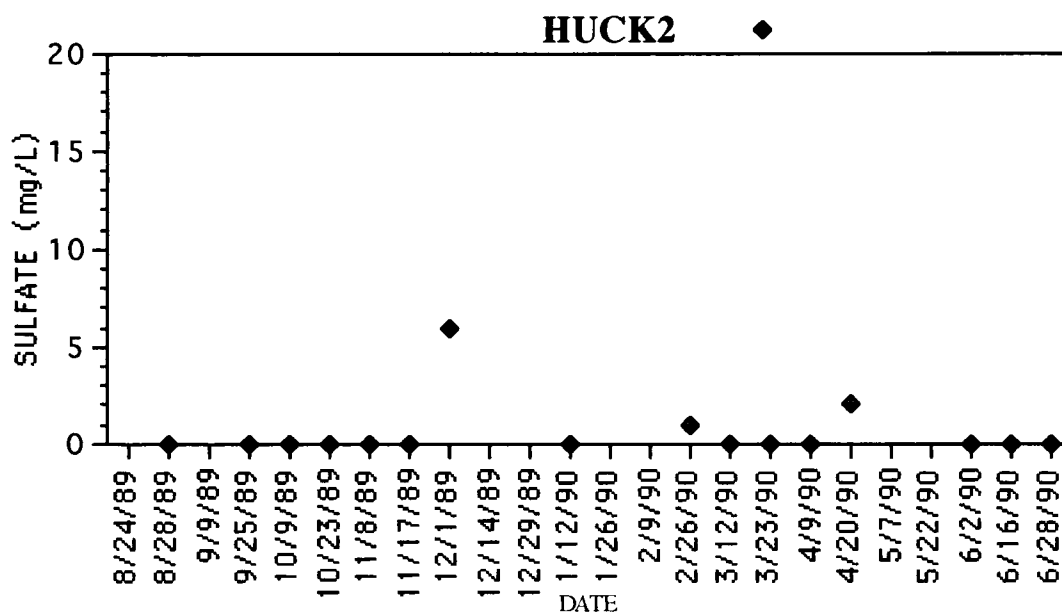


Figure A-46. Sulfate results for sampling location HUCK2 over the duration of the sample period.

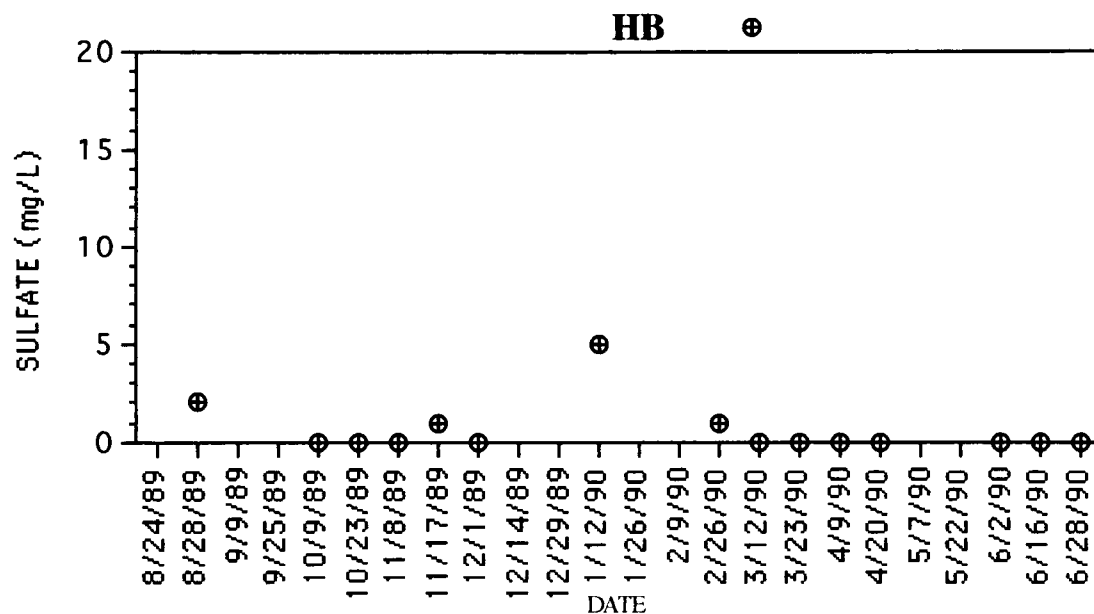


Figure A-47. Sulfate results for sampling location HB over the duration of the sample period.

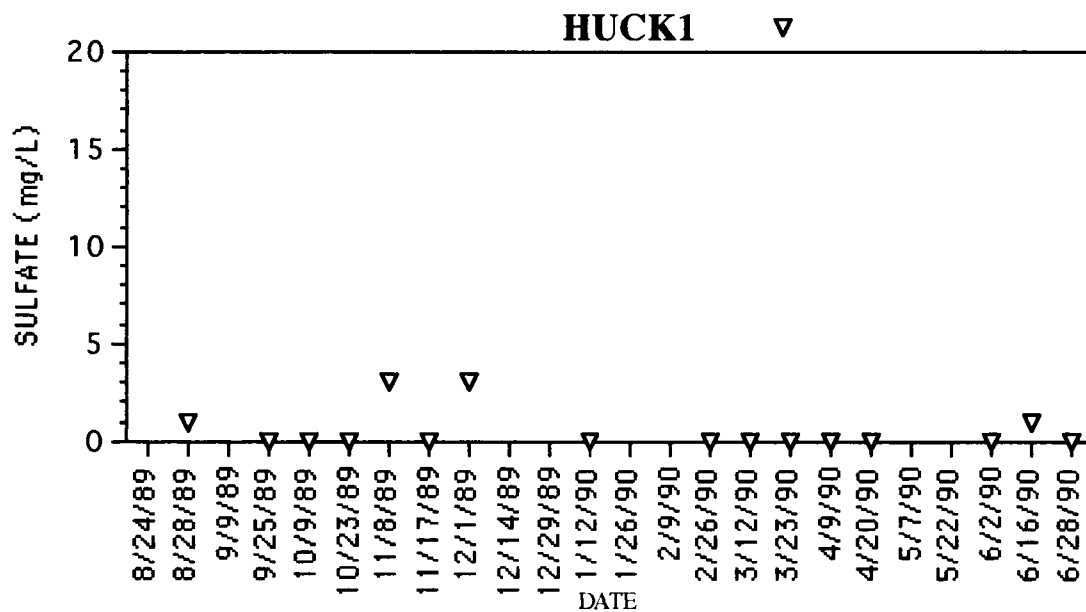


Figure A-48. Sulfate results for sampling location HUCK1 over the duration of the sample period.

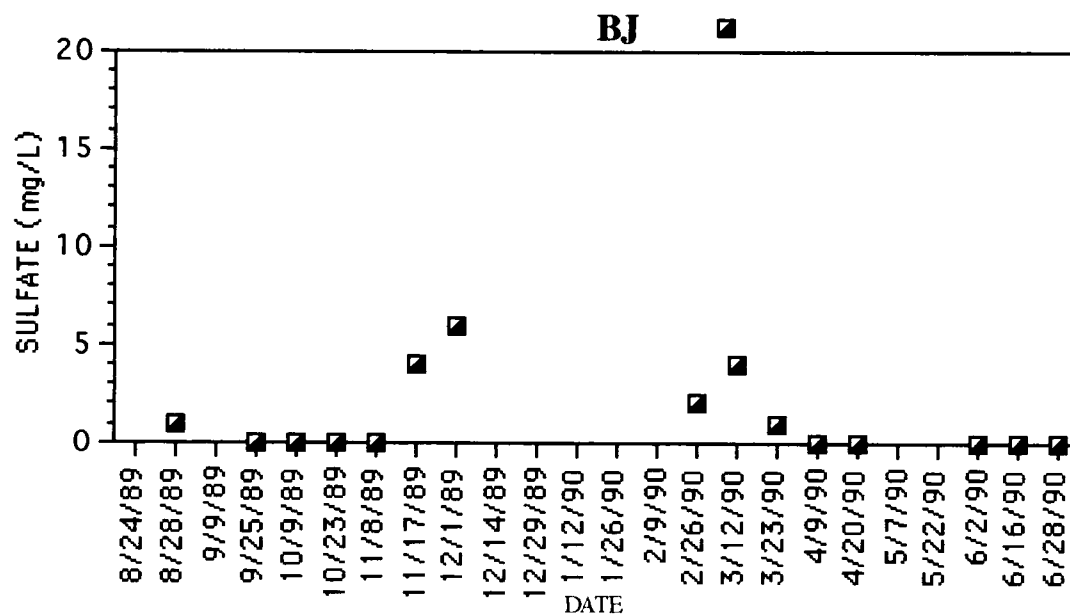


Figure A-49. Sulfate results for sampling location BJ over the duration of the sample period.

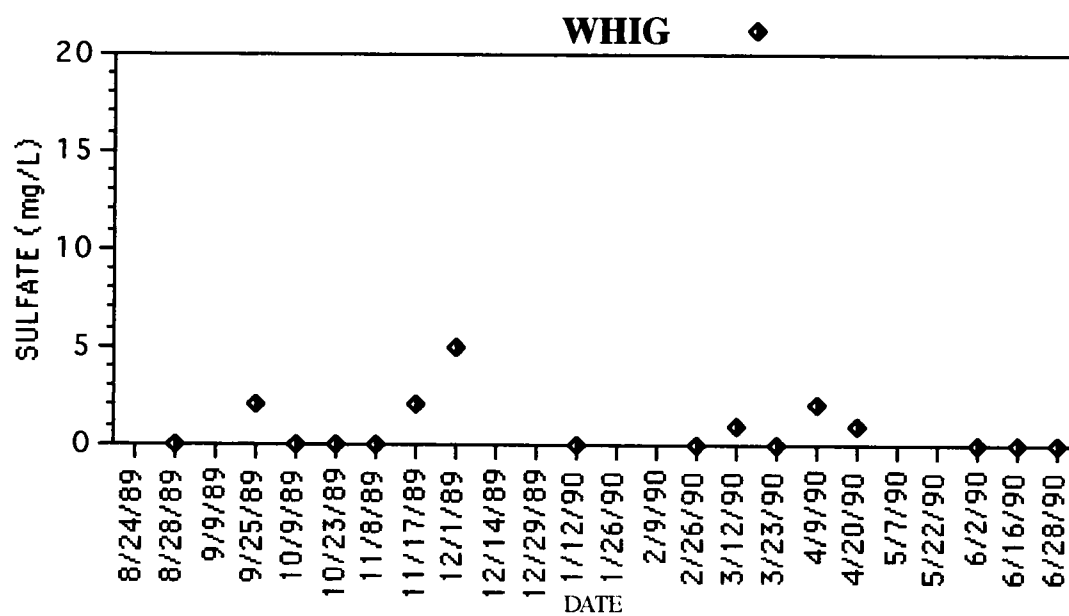


Figure A-50. Sulfate results for sampling location WHIG over the duration of the sample period.

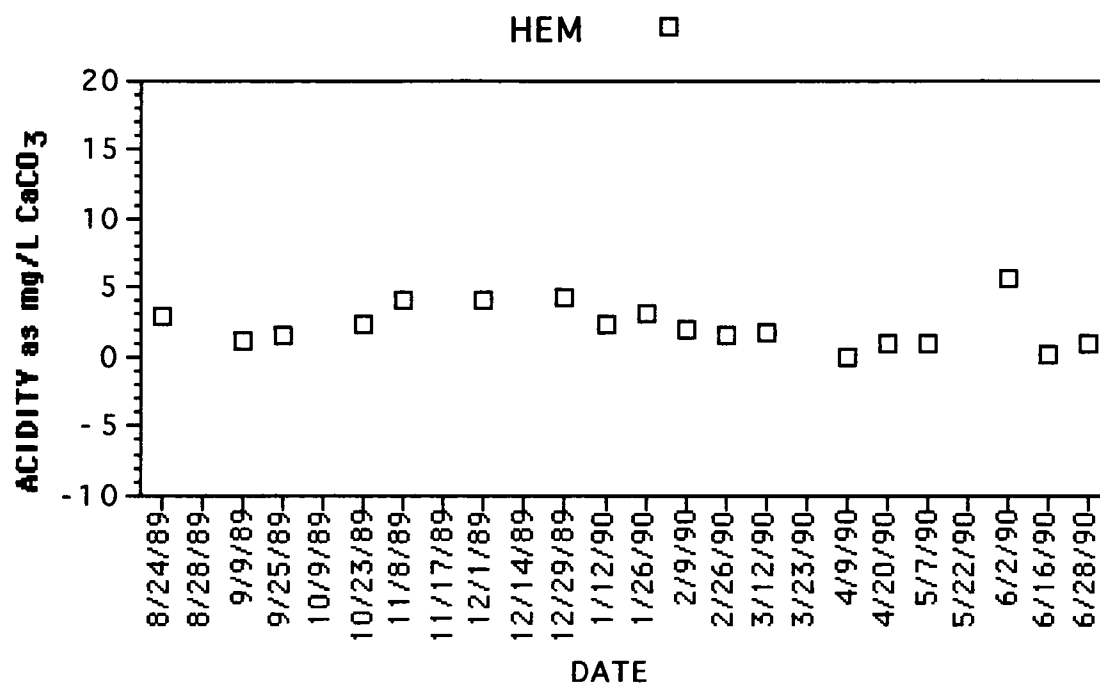


Figure A-51. Acidity values for sampling location HEM over the duration of the sample period.

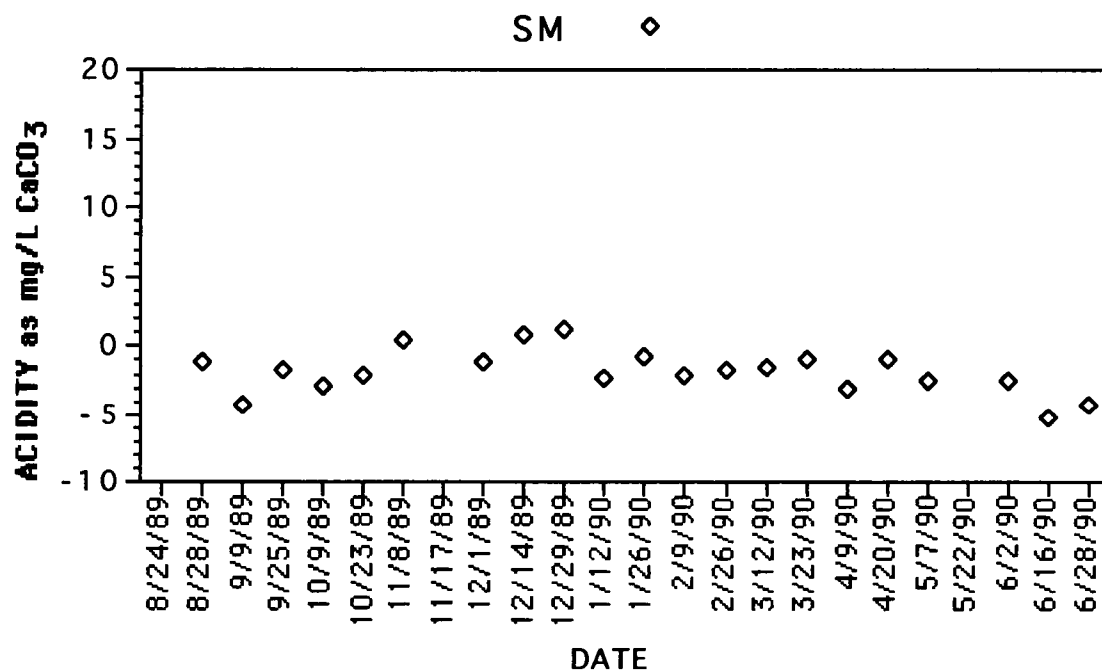


Figure A-52. Acidity values for sampling location SM over the duration of the sample period.

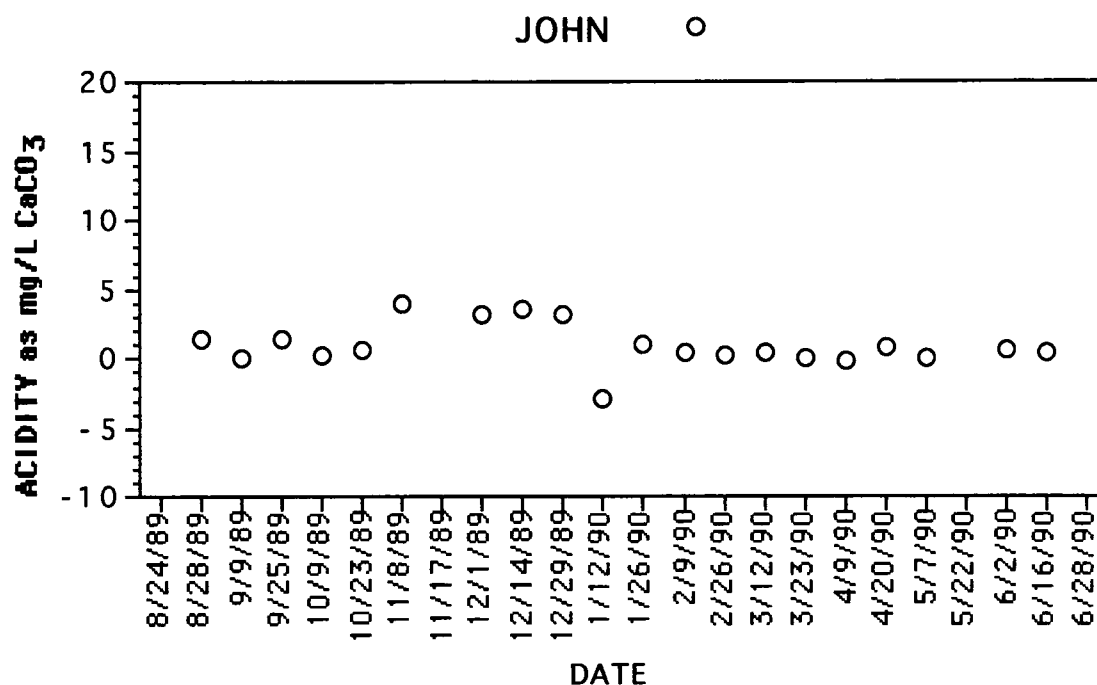


Figure A-53. Acidity values for sampling location JOHN over the duration of the sample period.

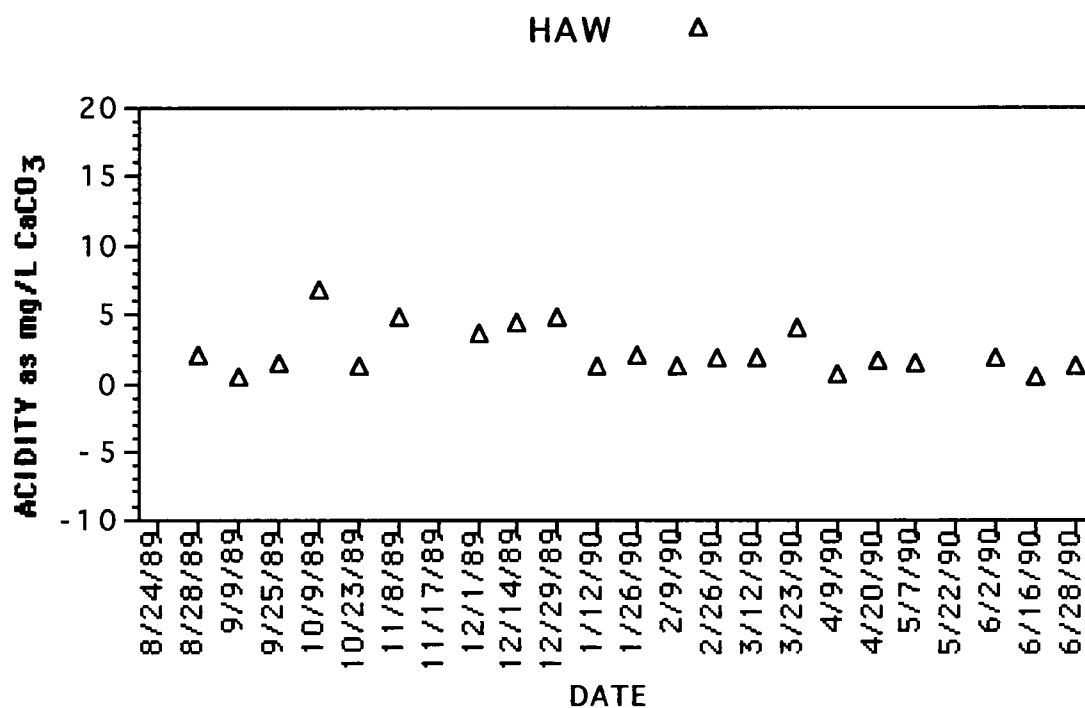


Figure A-54. Acidity values for sampling location HAW over the duration of the sample period.

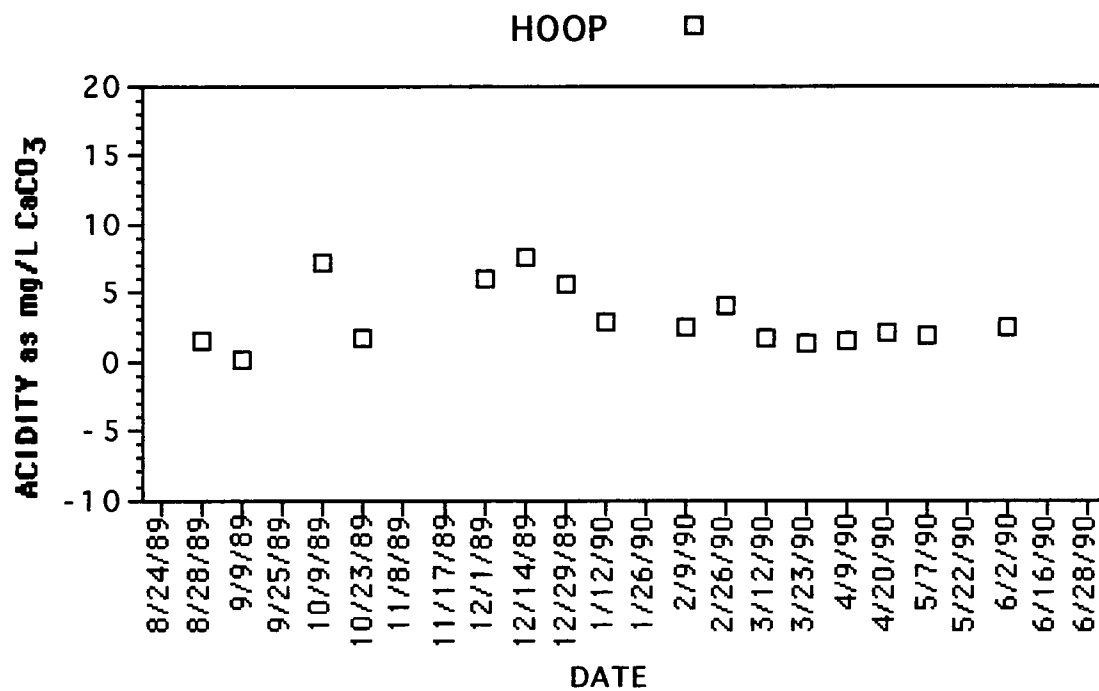


Figure A-55. Acidity values for sampling location HOOP over the duration of the sample period.

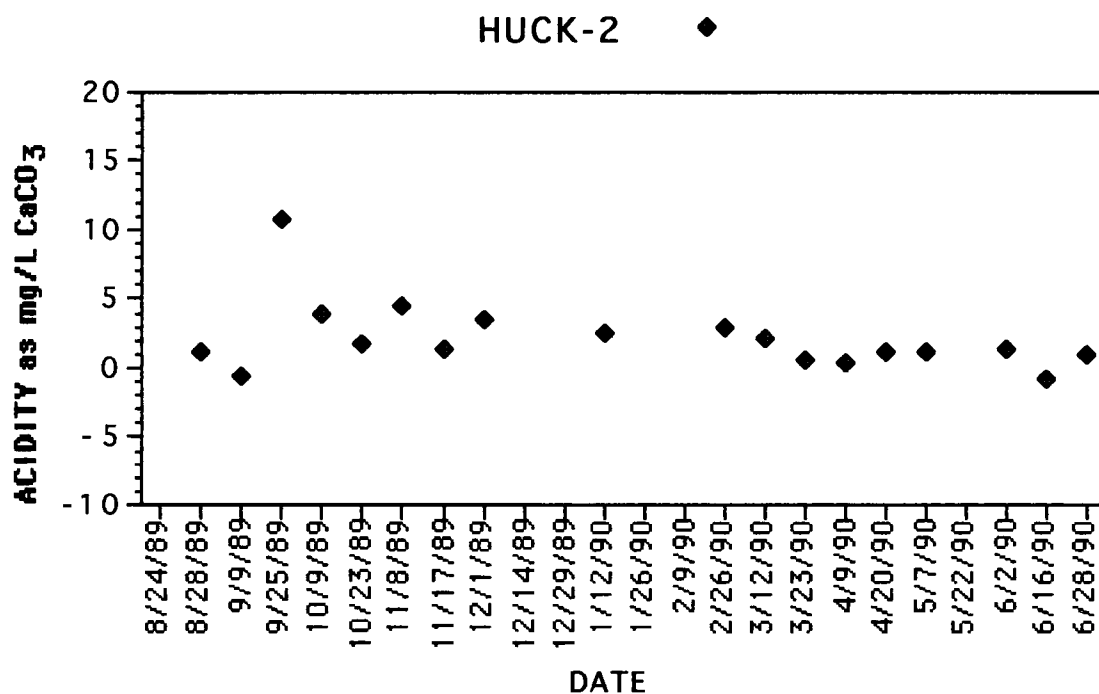


Figure A-56. Acidity values for sampling location HUCK2 over the duration of the sample period.

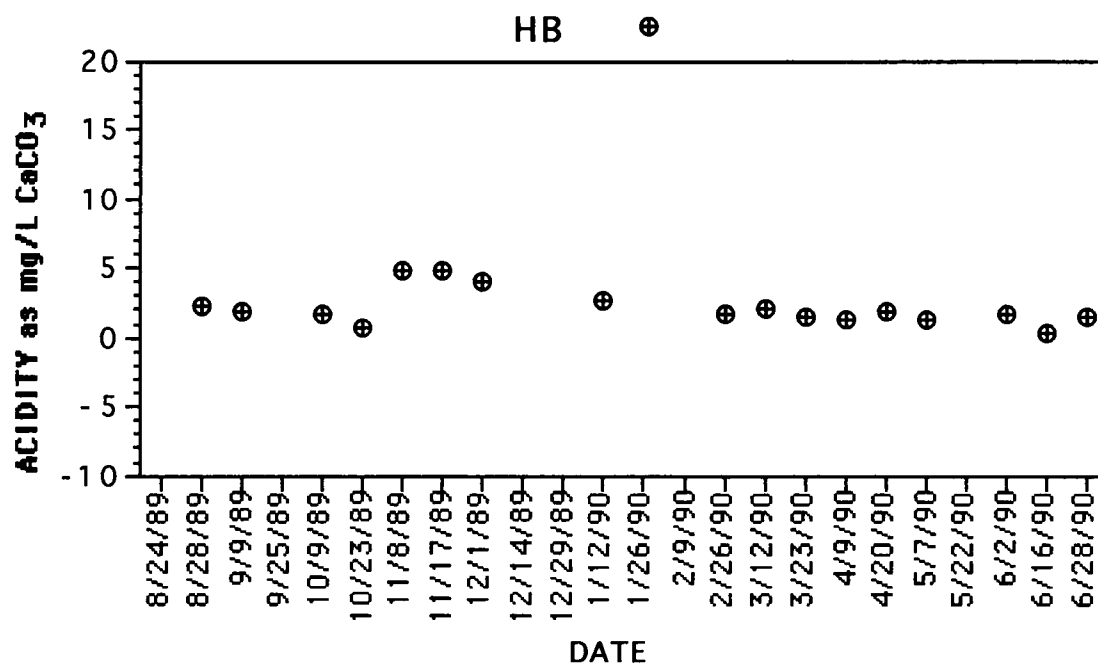


Figure A-57. Acidity values for sampling location HB over the duration of the sample period.

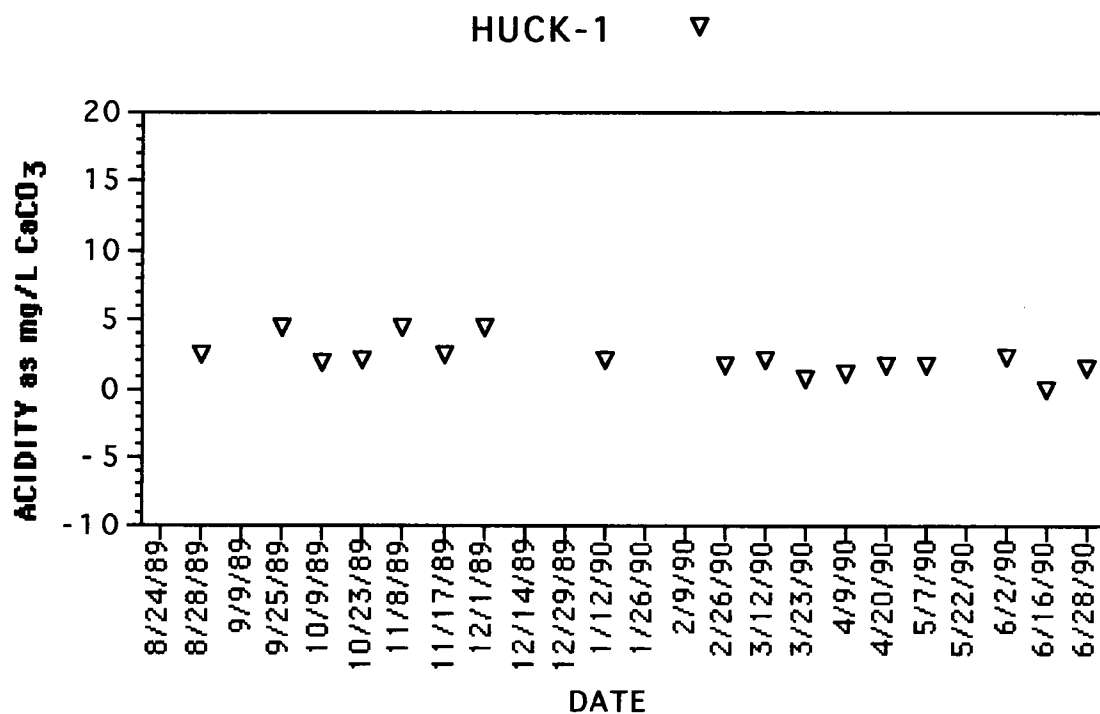


Figure A-58. Acidity values for sampling location HUCK1 over the duration of the sample period.

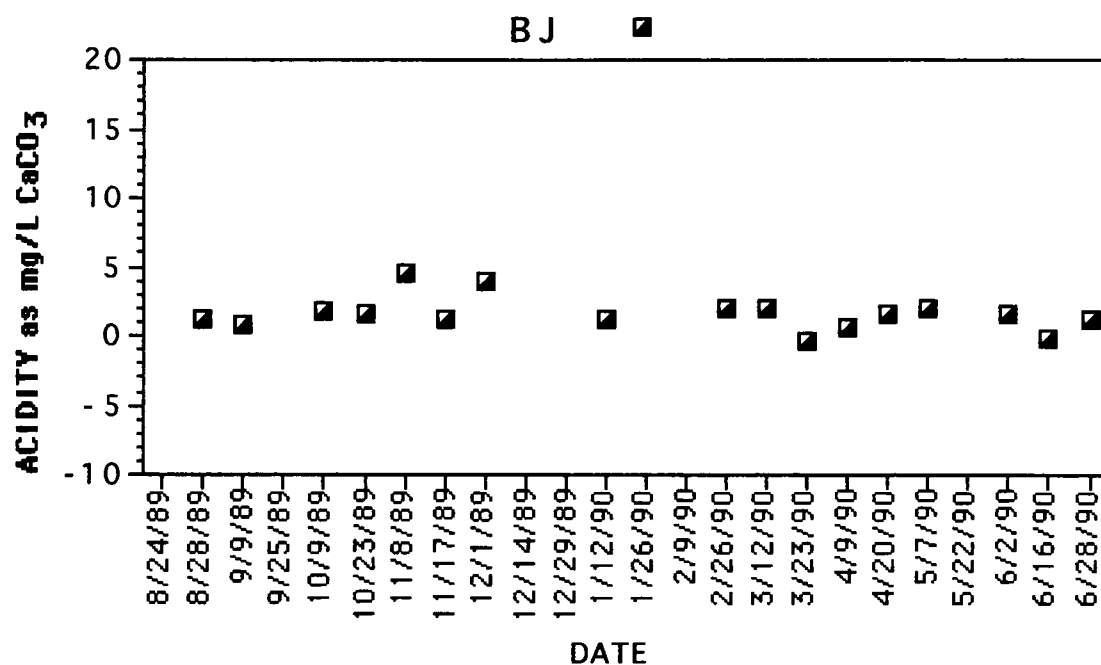


Figure A-59. Acidity values for sampling location BJ over the duration of the sample period.

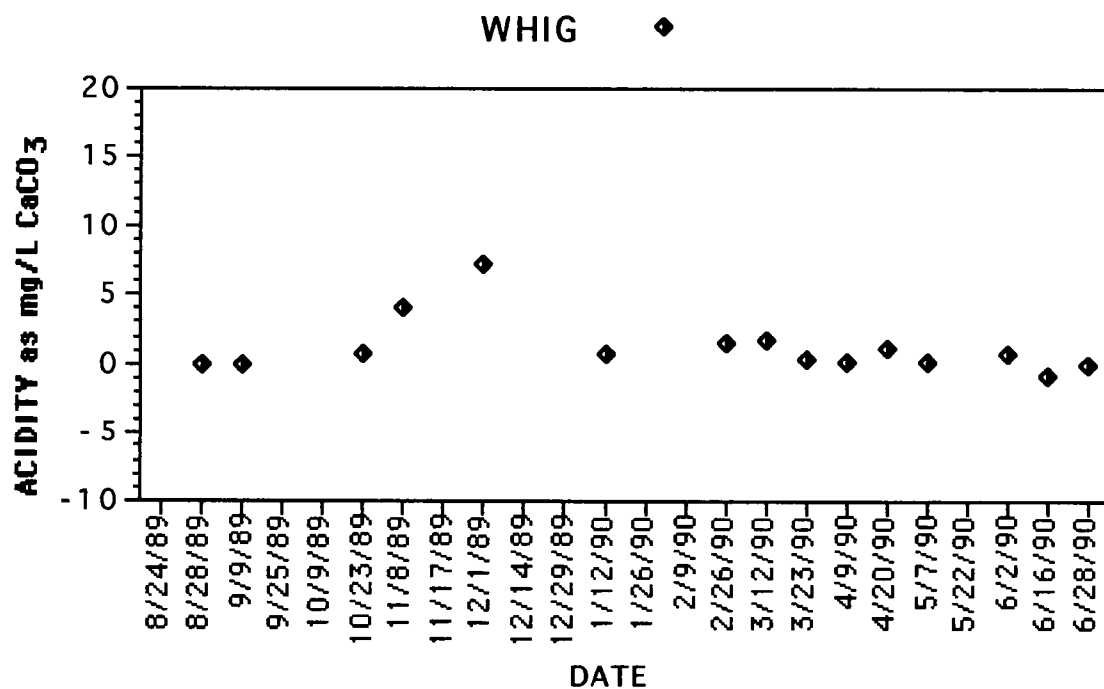


Figure A-60. Acidity values for sampling location WHIG over the duration of the sample period.

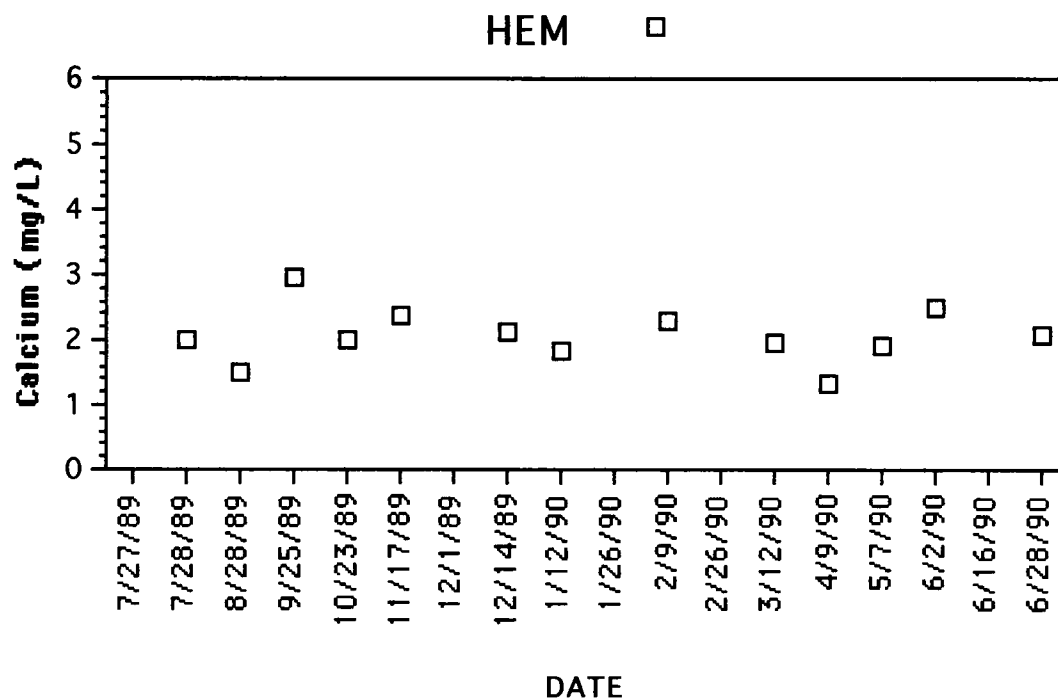


Figure A-61. Calcium values for sampling location HEM over the duration of the sample period.

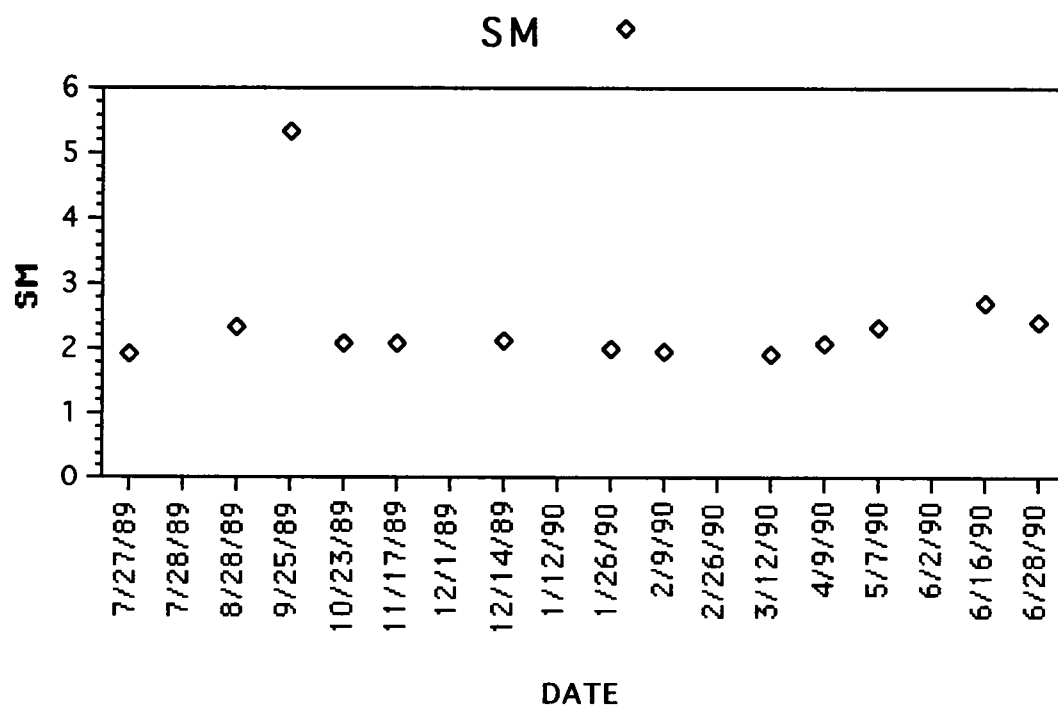


Figure A-62. Calcium values for sampling location SM over the duration of the sample period.

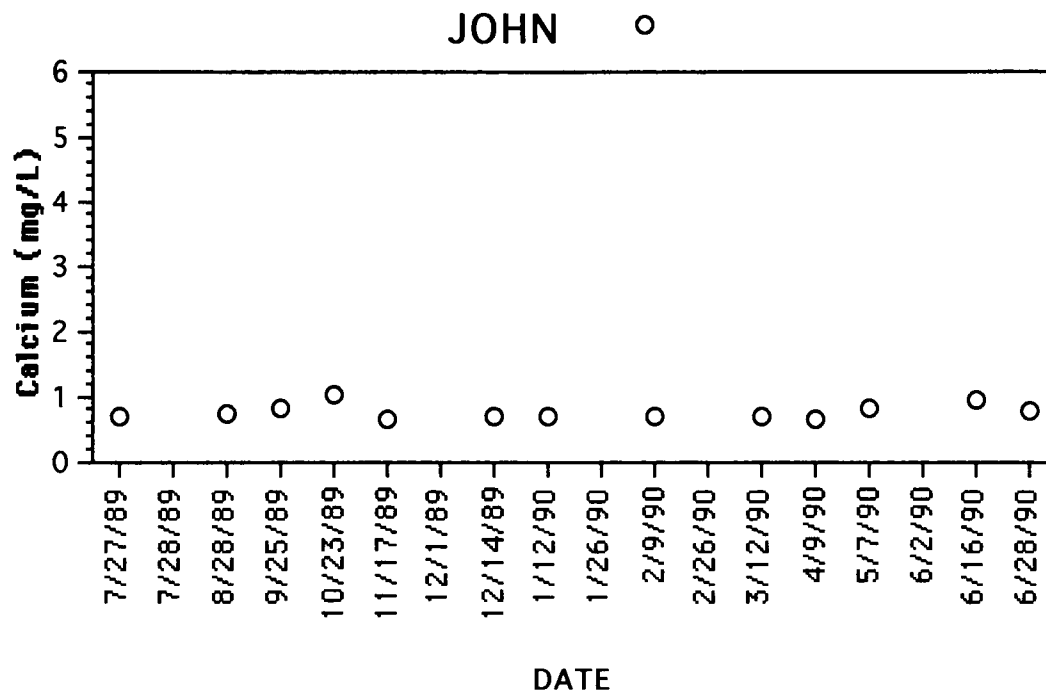


Figure A-63. Calcium values for sampling location JOHN over the duration of the sample period.

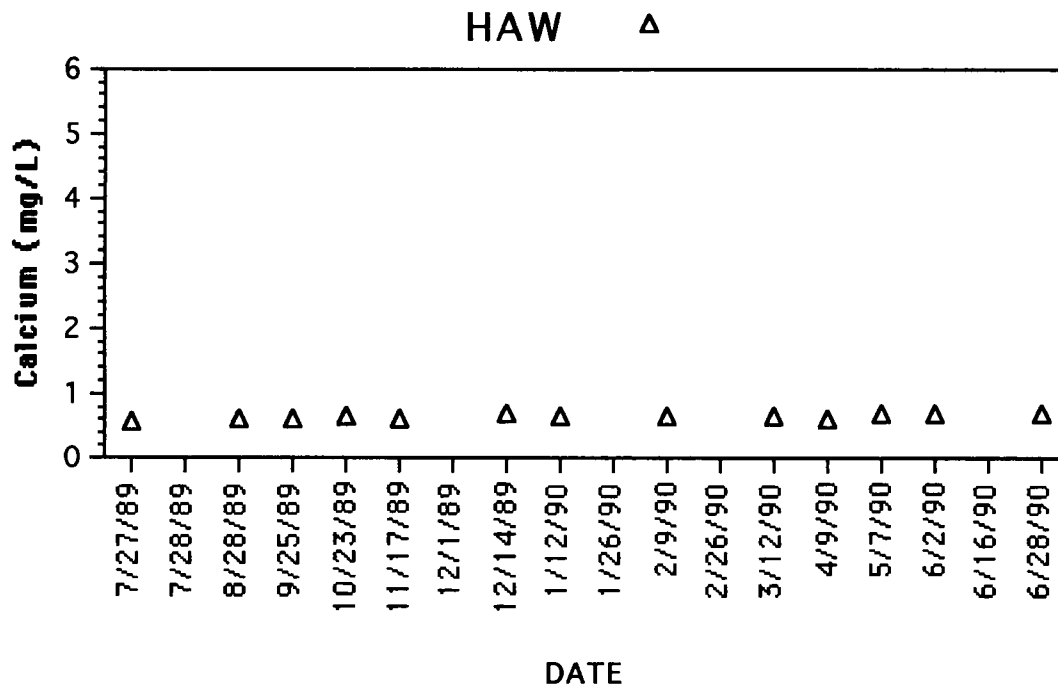


Figure A-64. Calcium values for sampling location HAW over the duration of the sample period.

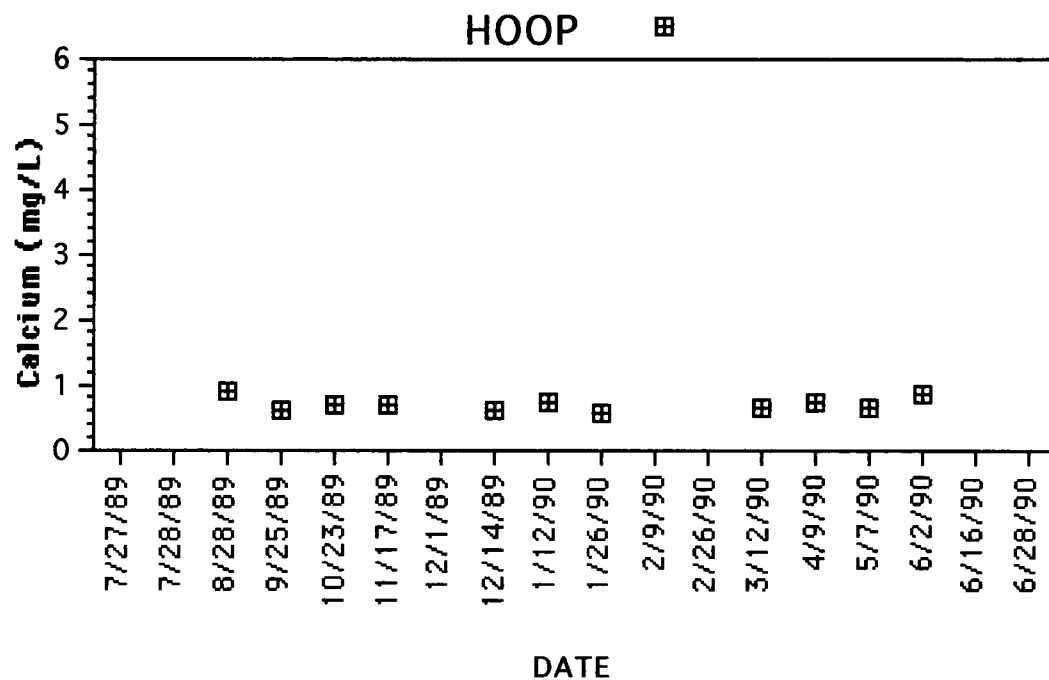


Figure A-65. Calcium values for sampling location HOOP over the duration of the sample period.

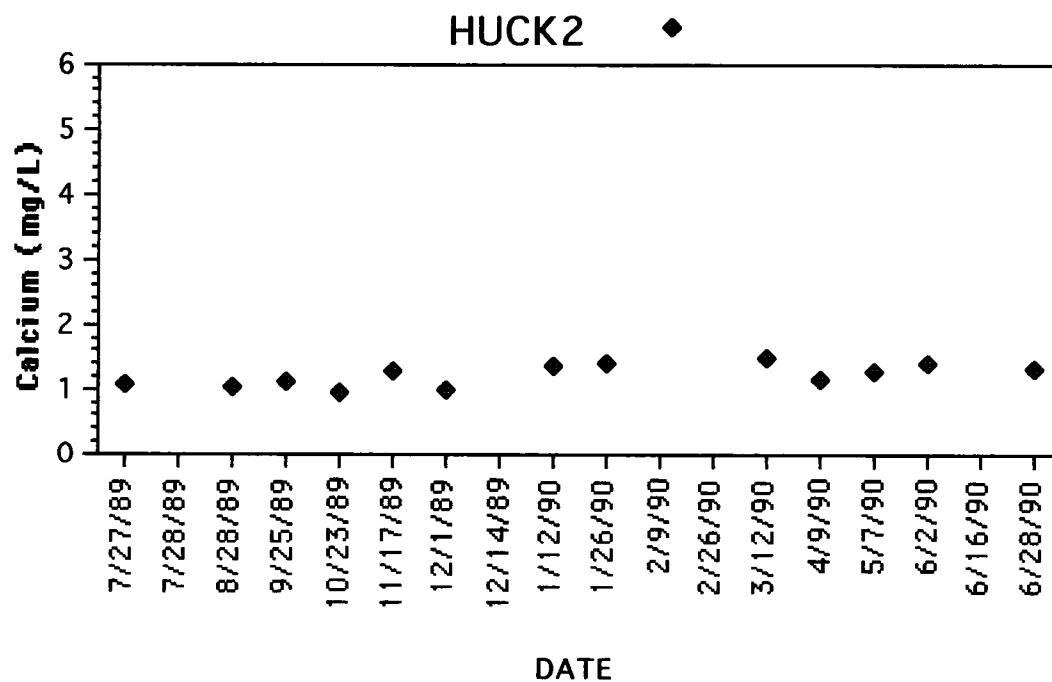


Figure A-66. Calcium values for sampling location HUCK2 over the duration of the sample period.

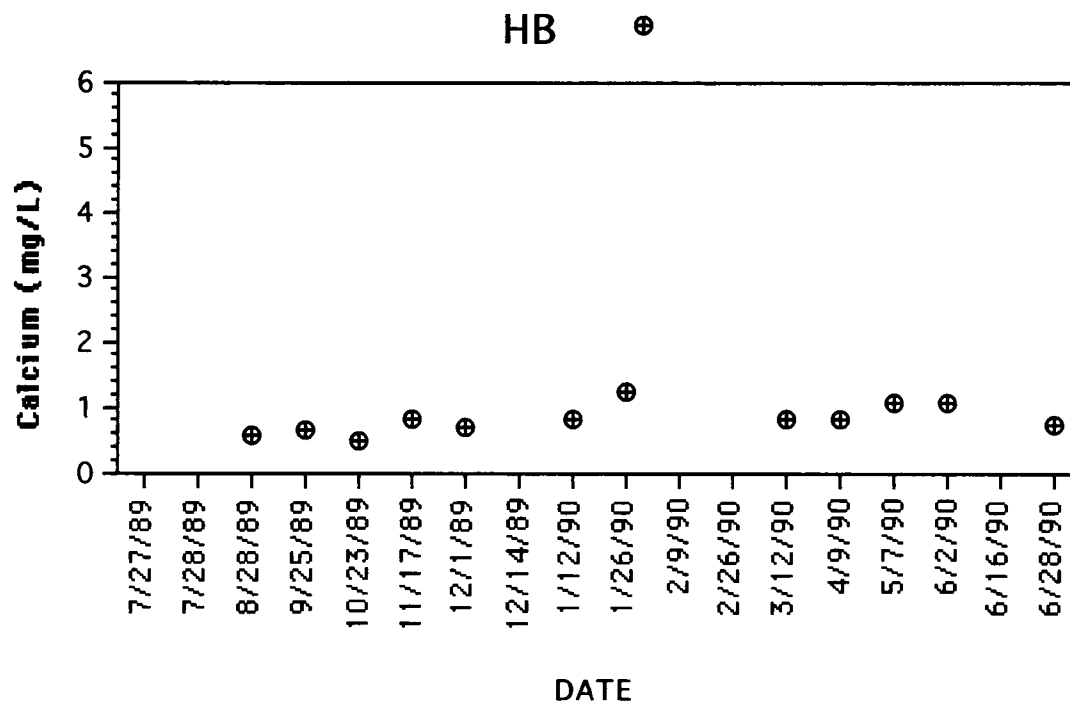


Figure A-67. Calcium values for sampling location HB over the duration of the sample period.

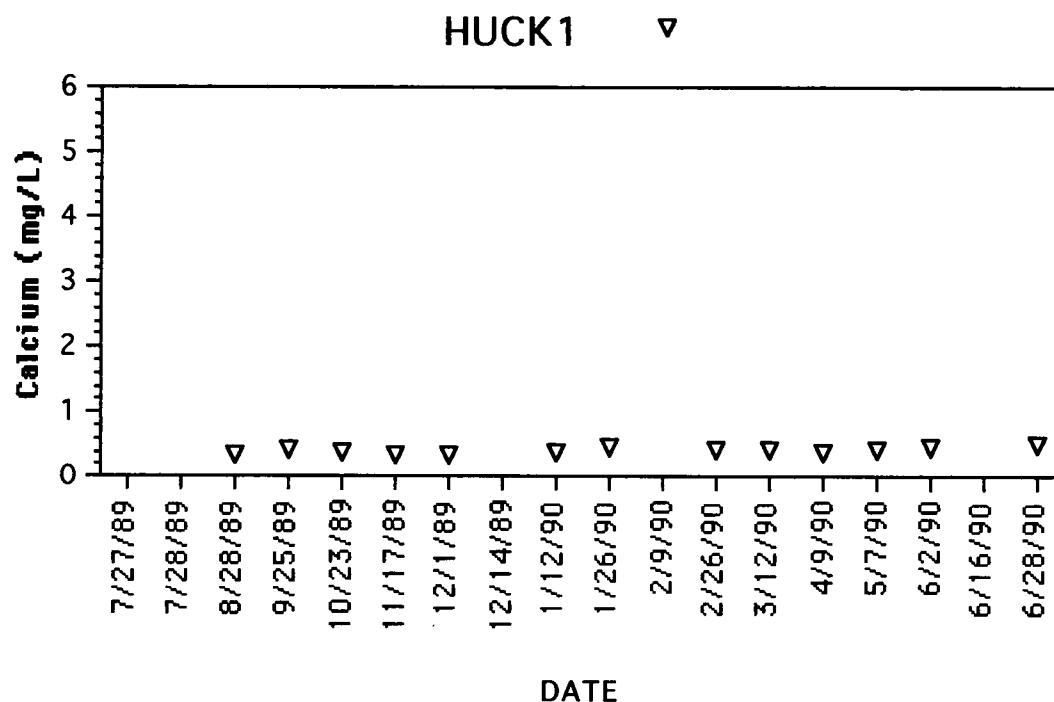


Figure A-68. Calcium values for sampling location HUCK1 over the duration of the sample period.

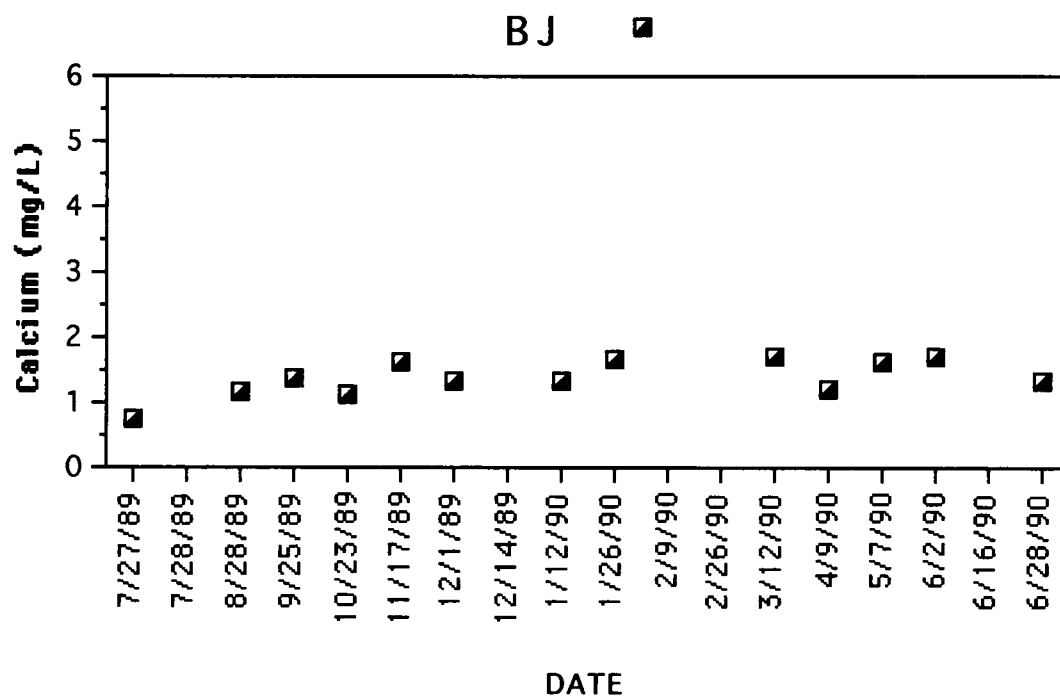


Figure A-69. Calcium values for sampling location BJ over the duration of the sample period.

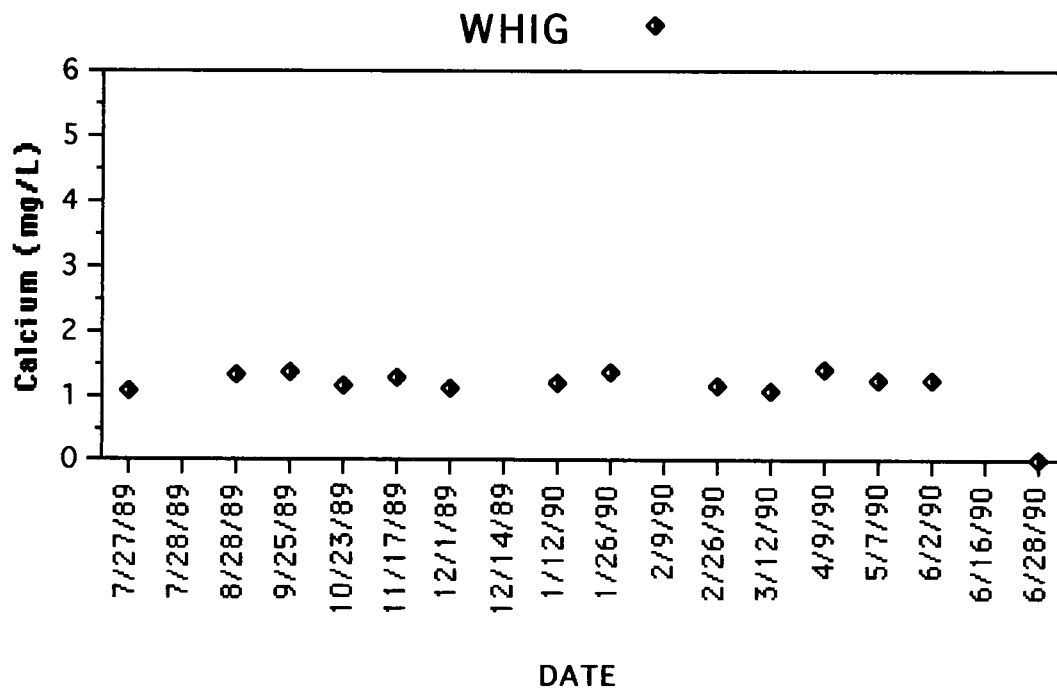


Figure A-70. Calcium values for sampling location WHIG over the duration of the sample period.

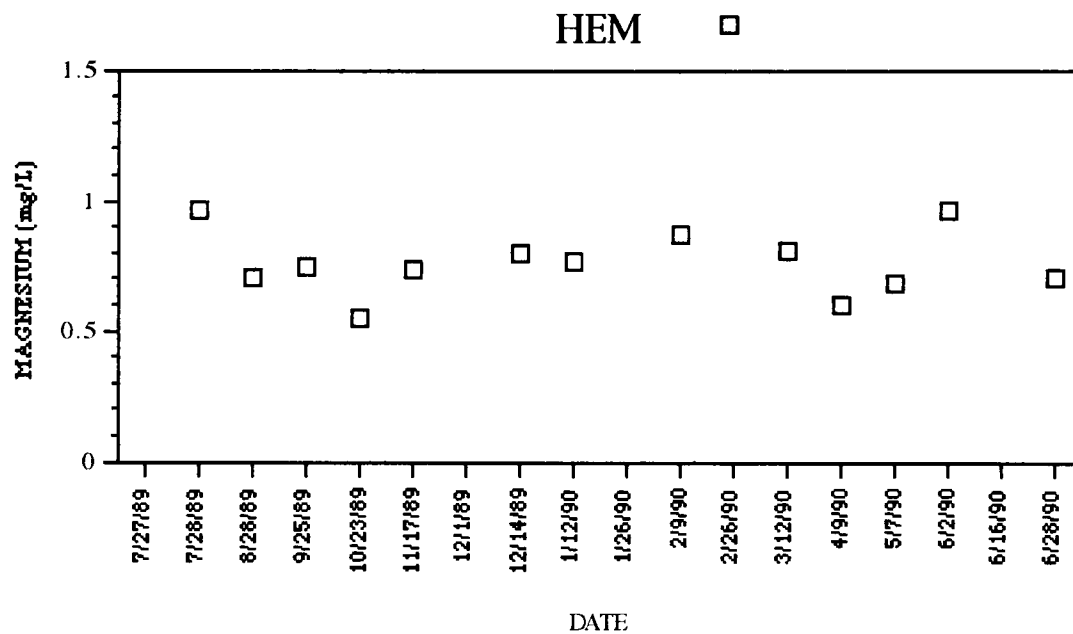


Figure A-71. Magnesium values for sampling location HEM over the duration of the sample period.

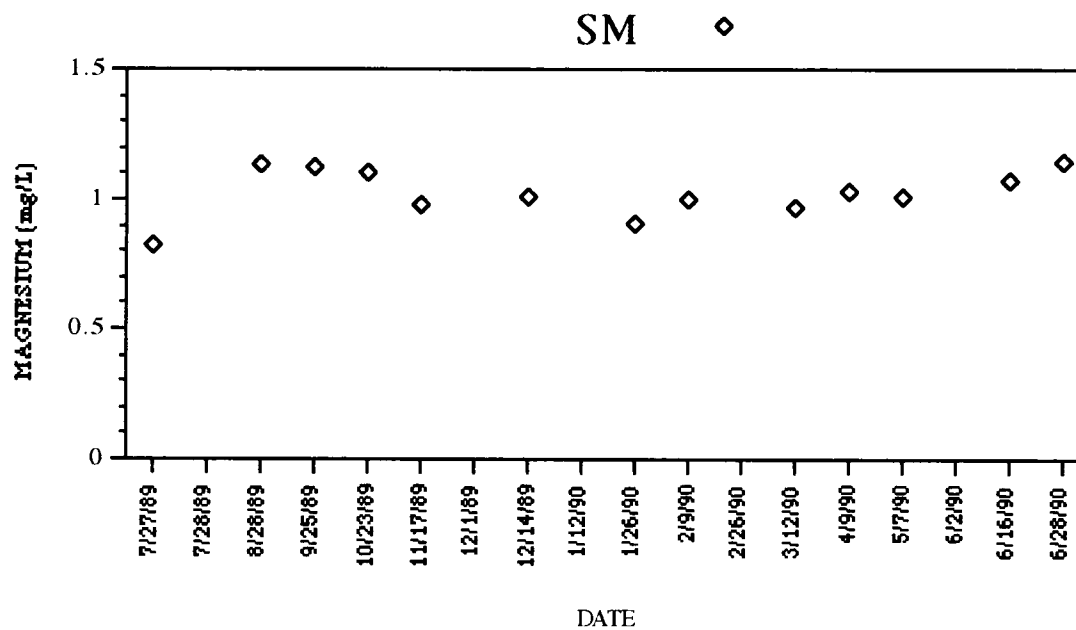


Figure A-72. Magnesium values for sampling location SM over the duration of the sample period.

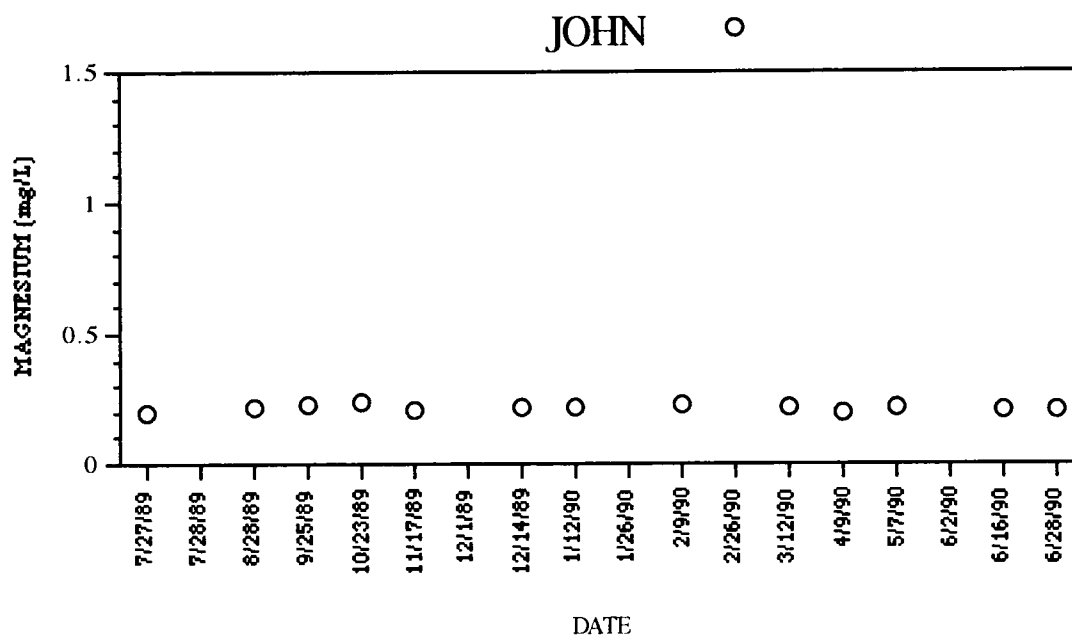


Figure A-73. Magnesium values for sampling location JOHN over the duration of the sample period.

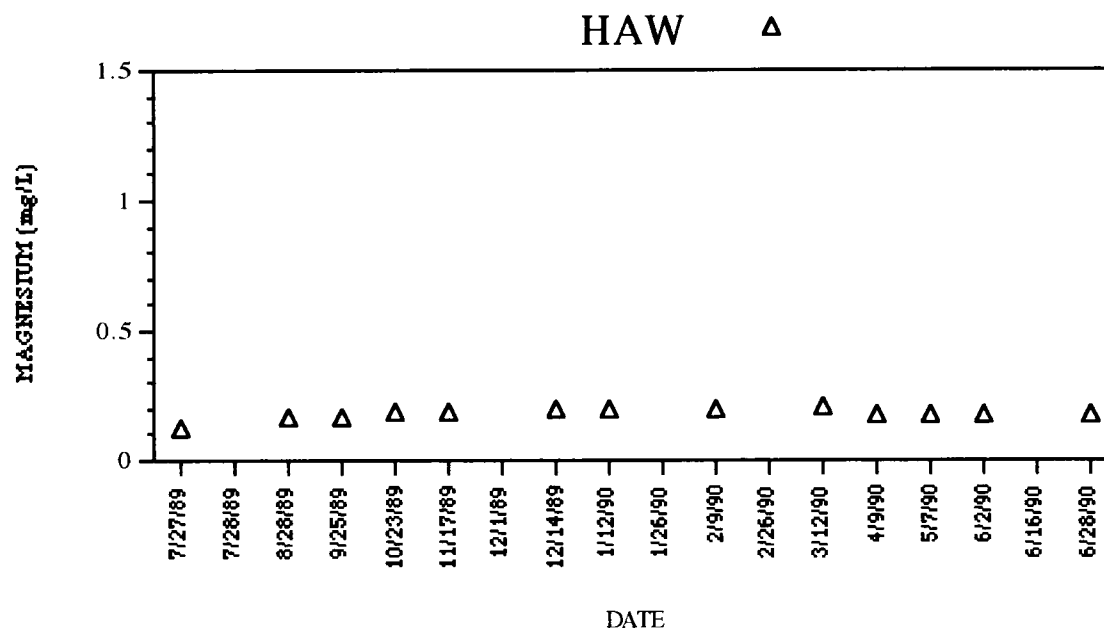


Figure A-74. Magnesium values for sampling location HAW over the duration of the sample period.

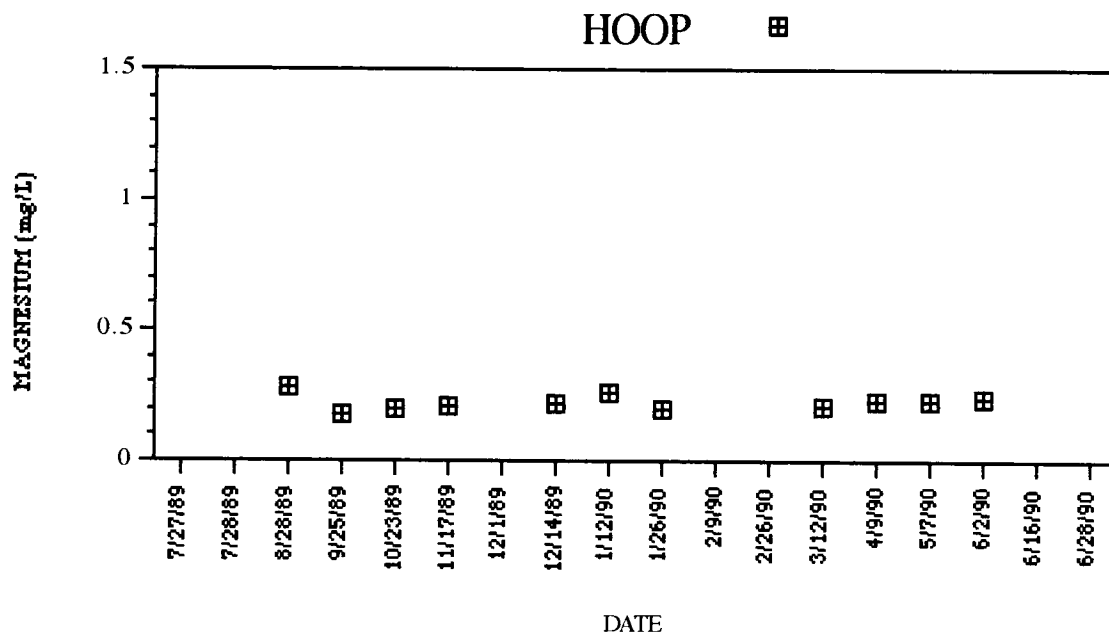


Figure A-75. Magnesium values for sampling location HOOP over the duration of the sample period.

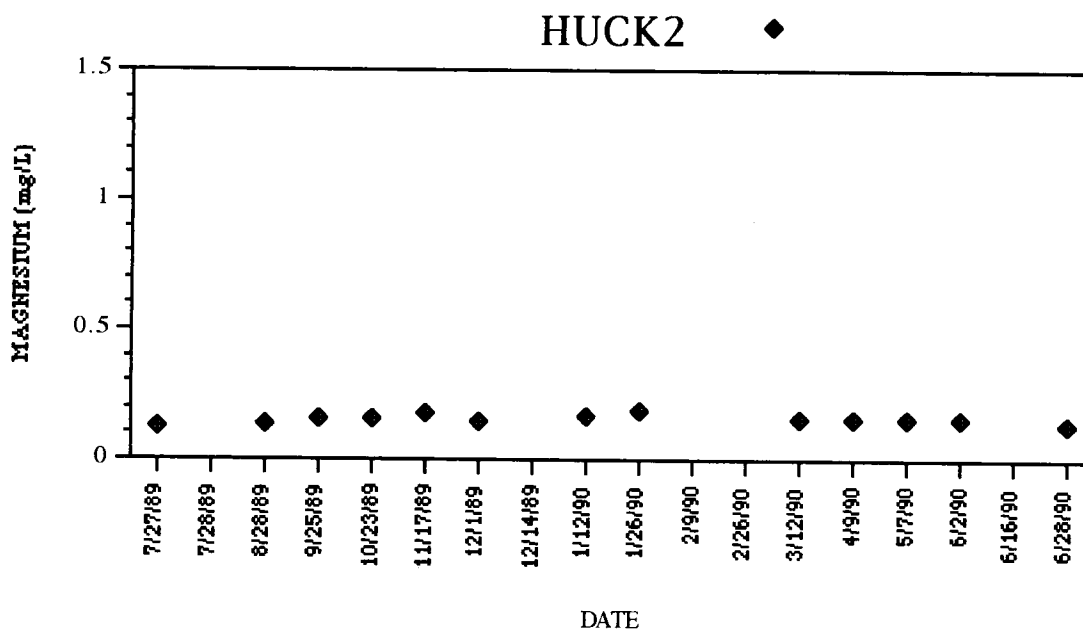


Figure A-76. Magnesium values for sampling location HUCK2 over the duration of the sample period.

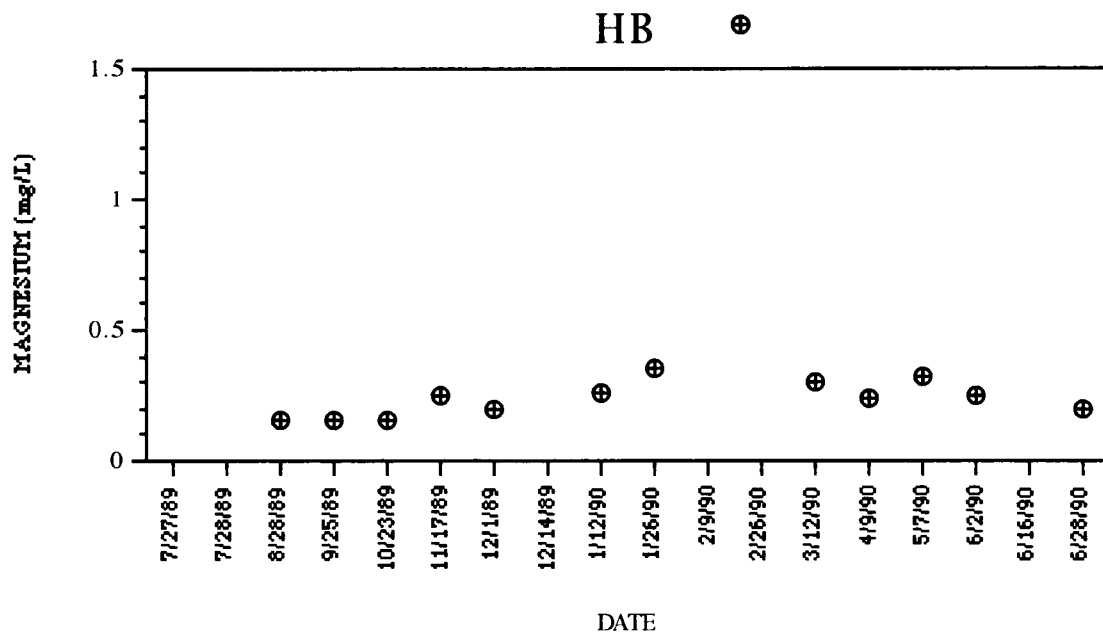


Figure A-77. Magnesium values for sampling location HB over the duration of the sample period.

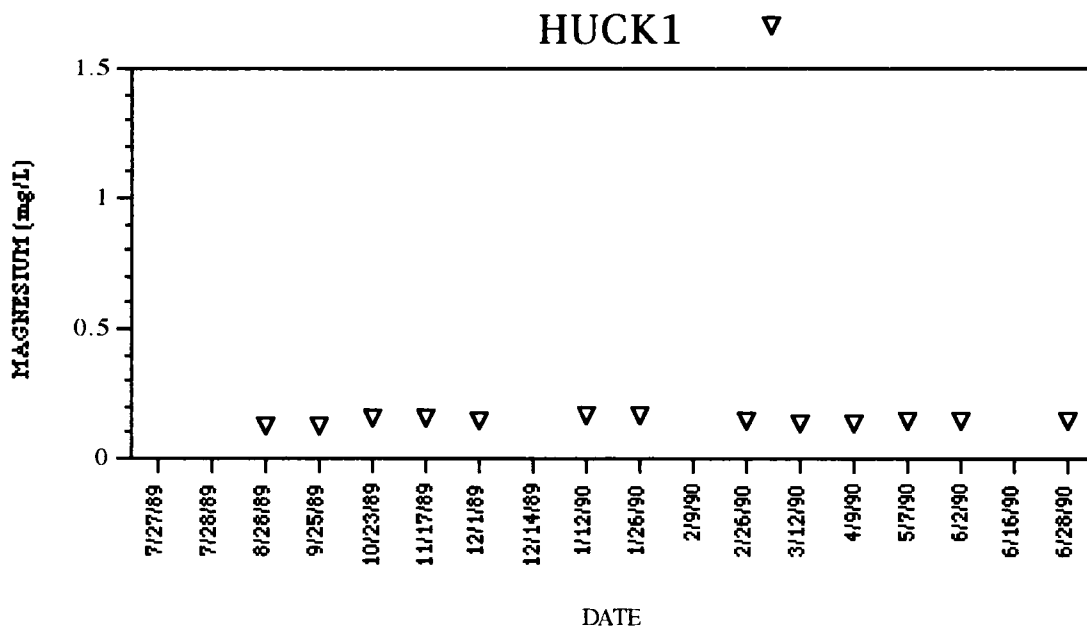


Figure A-78. Magnesium values for sampling location HUCK1 over the duration of the sample period.

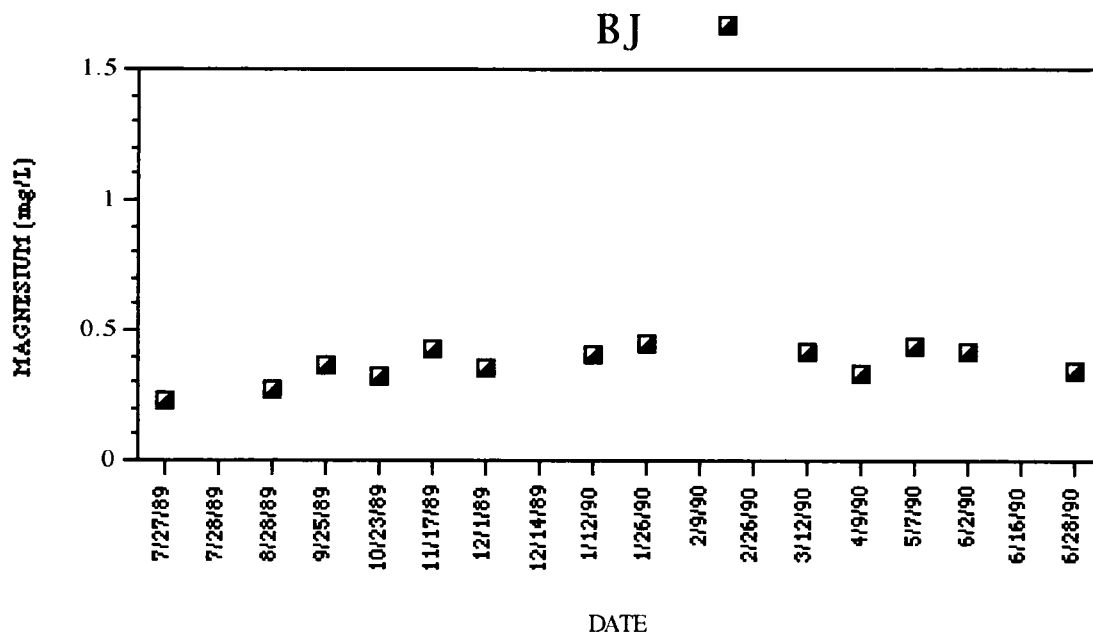


Figure A-79. Magnesium values for sampling location BJ over the duration of the sample period.

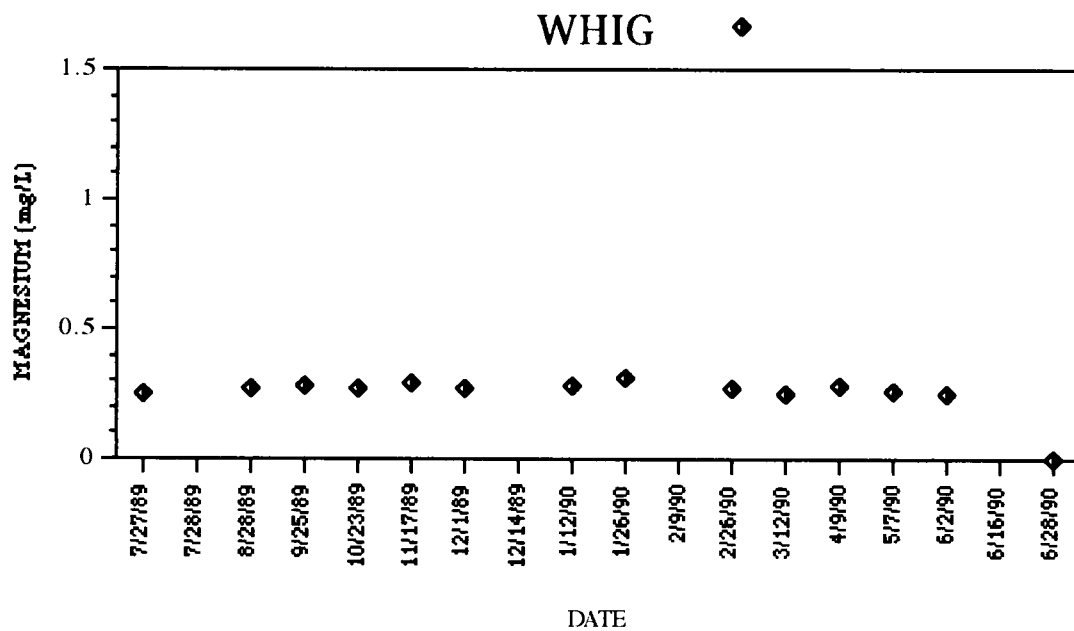


Figure A-80. Magnesium values for sampling location WHIG over the duration of the sample period.

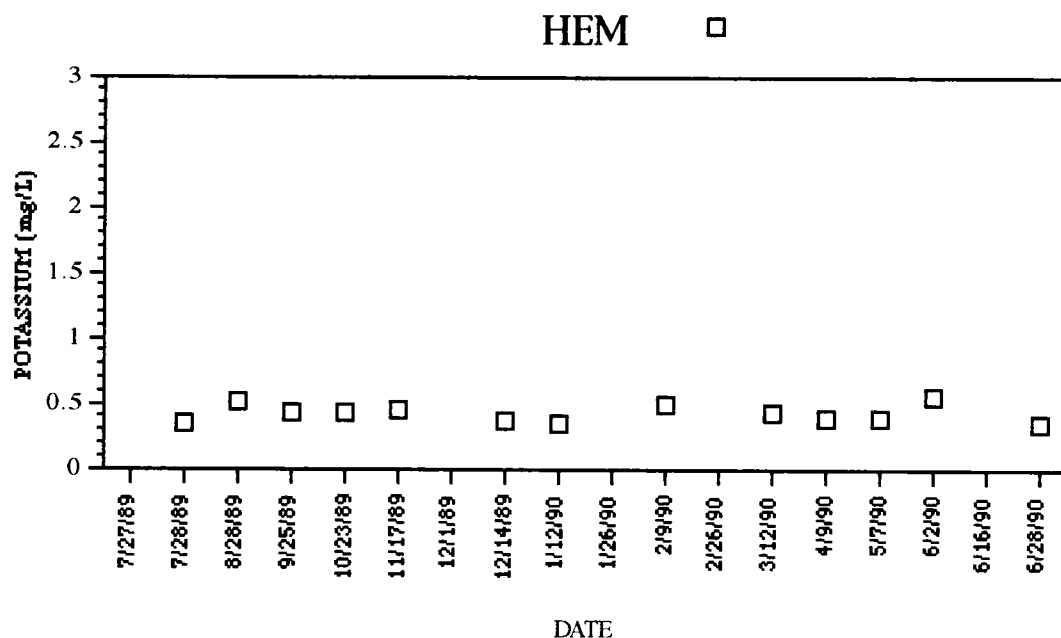


Figure A-81. Potassium values for sampling location HEM over the duration of the sample period.

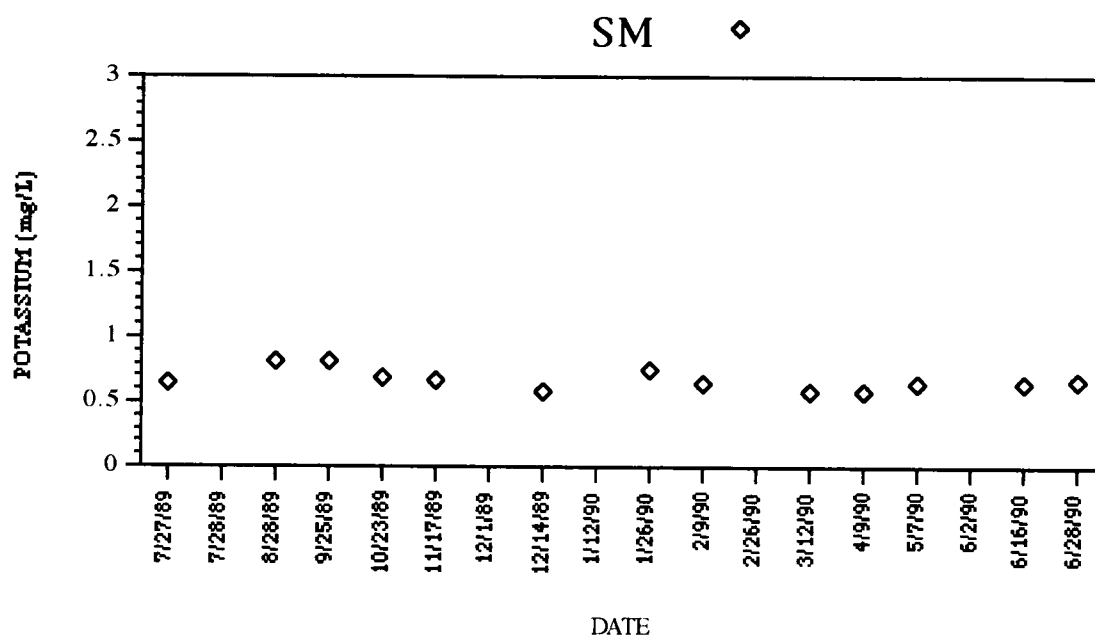


Figure A-82. Potassium values for sampling location SM over the duration of the sample period.

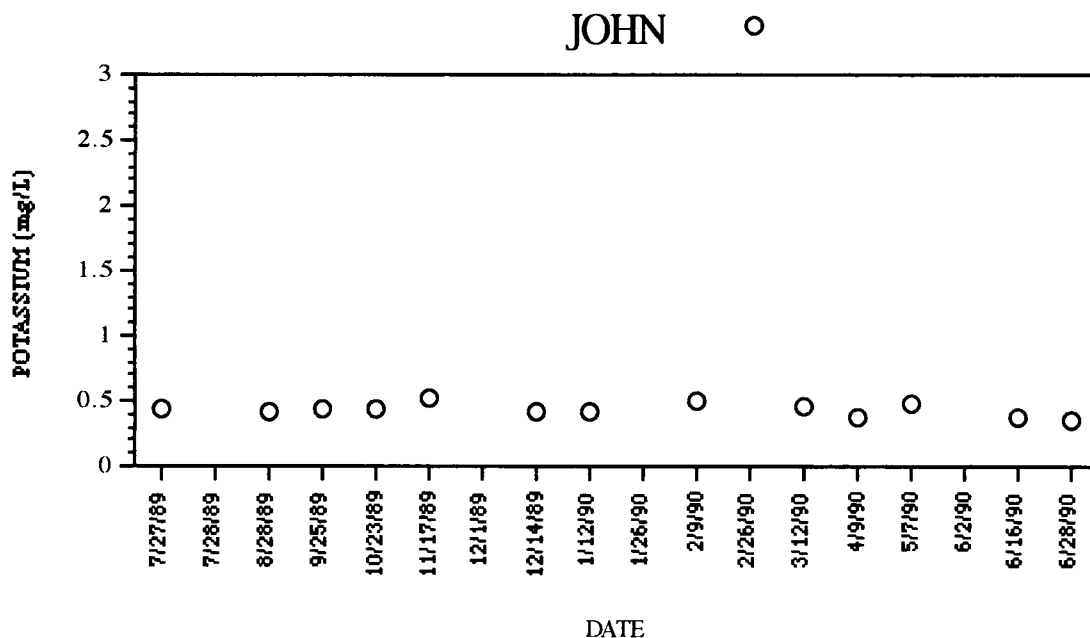


Figure A-83. Potassium values for sampling location JOHN over the duration of the sample period.

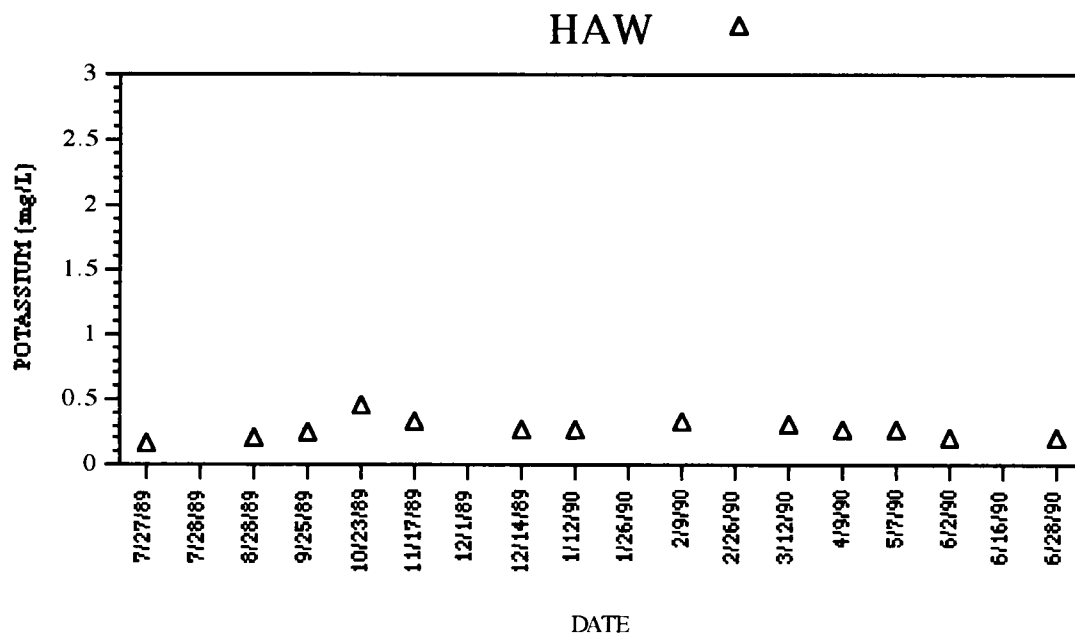


Figure A-84. Potassium values for sampling location HAW over the duration of the sample period.

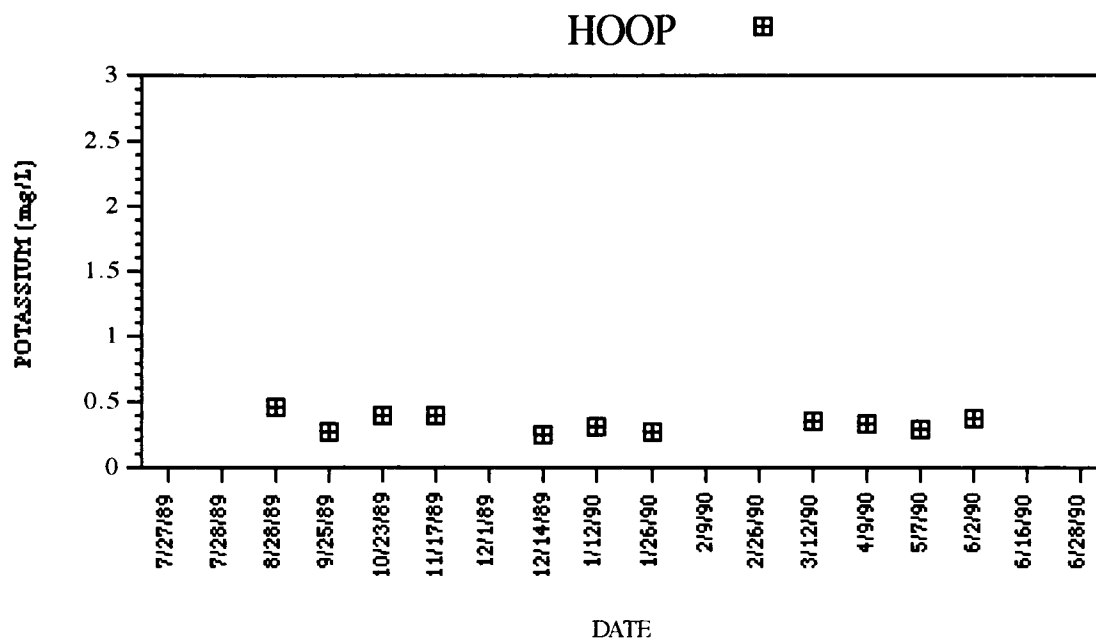


Figure A-85. Potassium values for sampling location HOOP over the duration of the sample period.

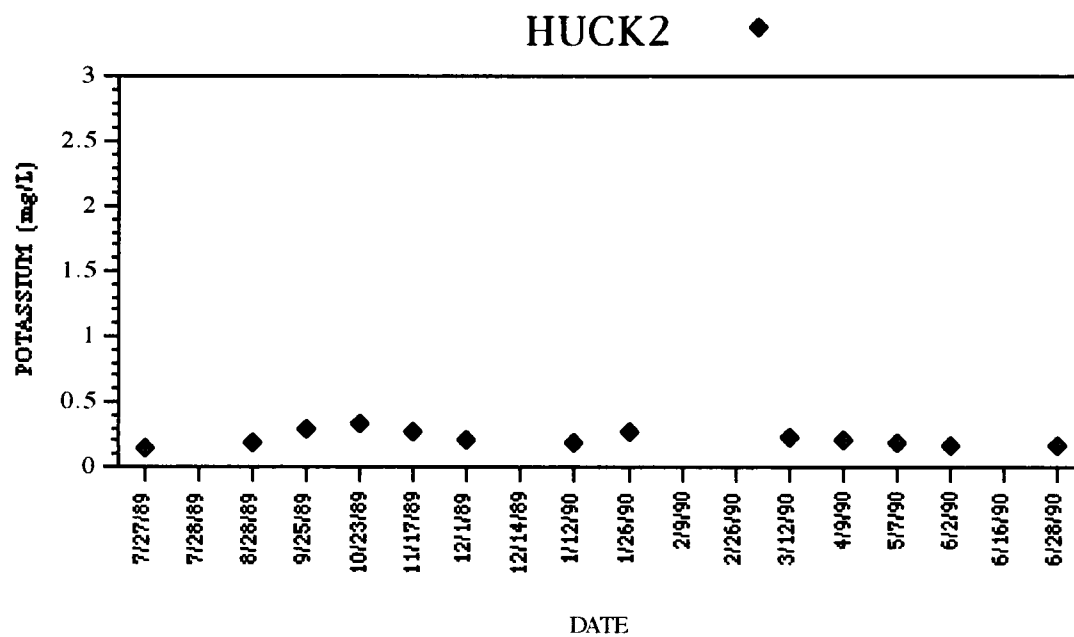


Figure A-86. Potassium values for sampling location HUCK2 over the duration of the sample period.

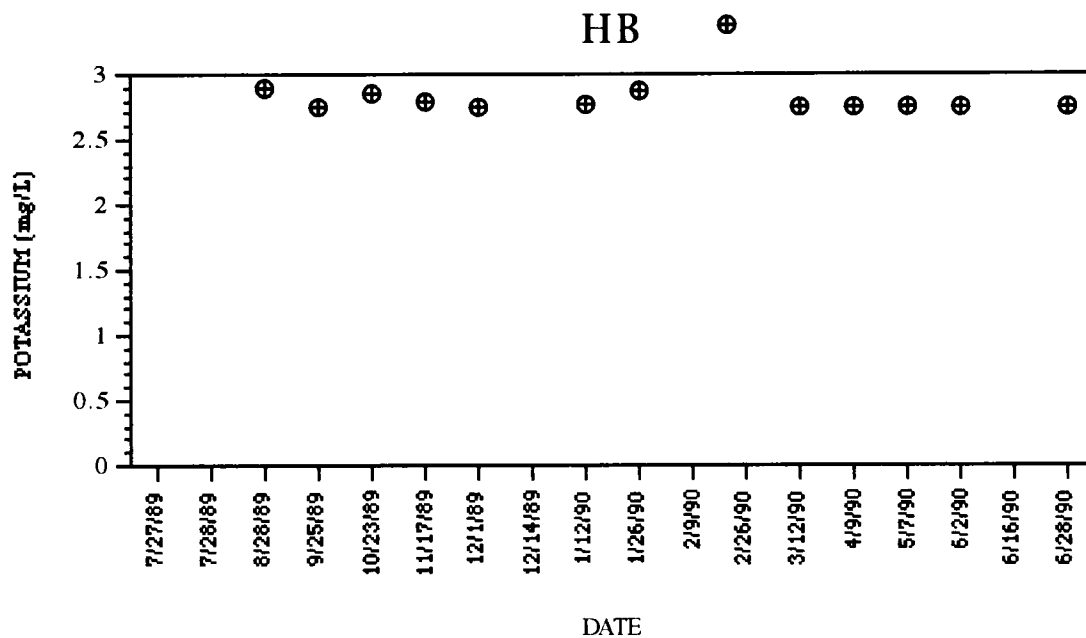


Figure A-87. Potassium values for sampling location HB over the duration of the sample period.

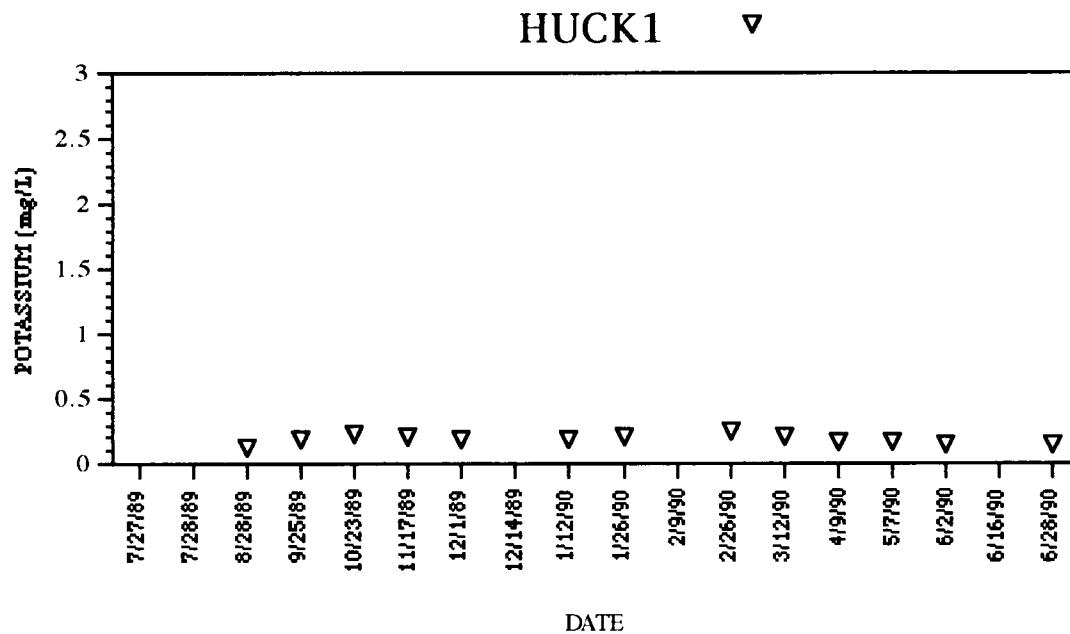


Figure A-88. Potassium values for sampling location HUCK1 over the duration of the sample period.

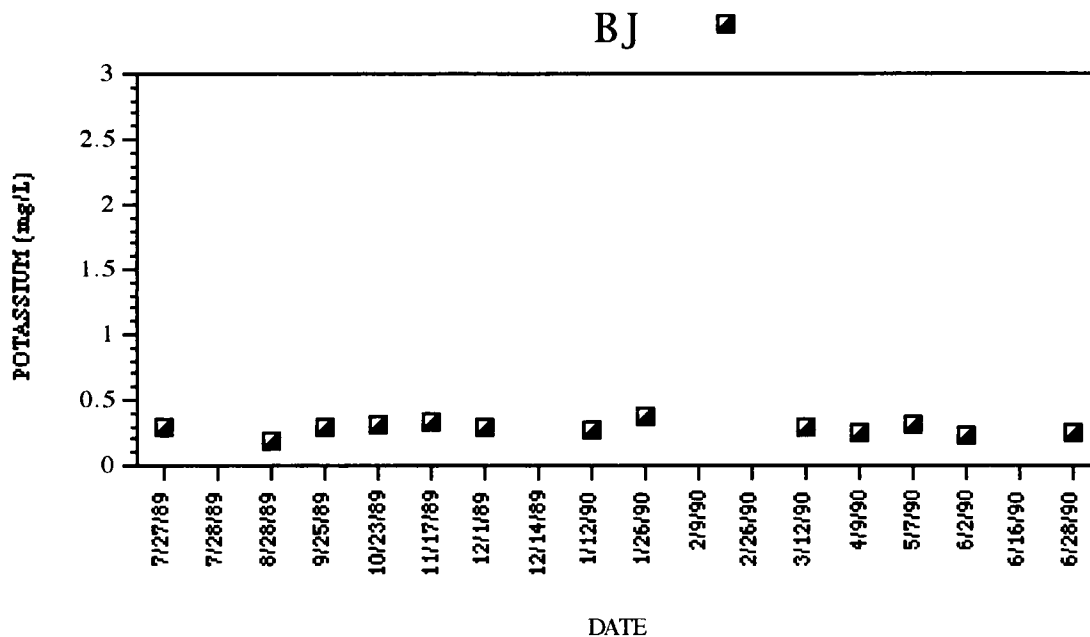


Figure A-89. Potassium values for sampling location BJ over the duration of the sample period.

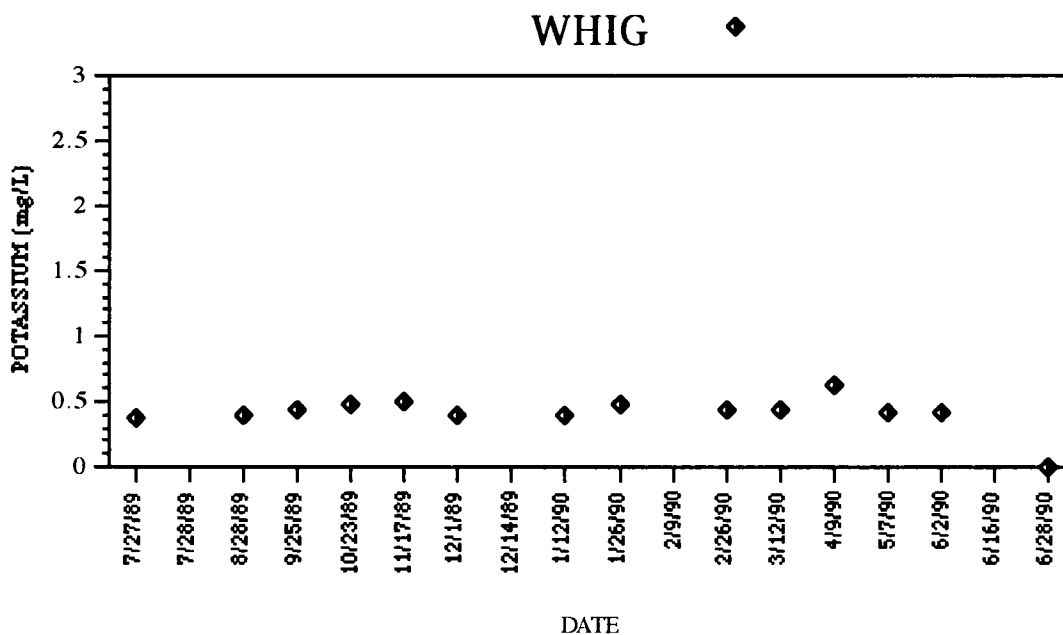


Figure A-90. Potassium values for sampling location WHIG over the duration of the sample period.

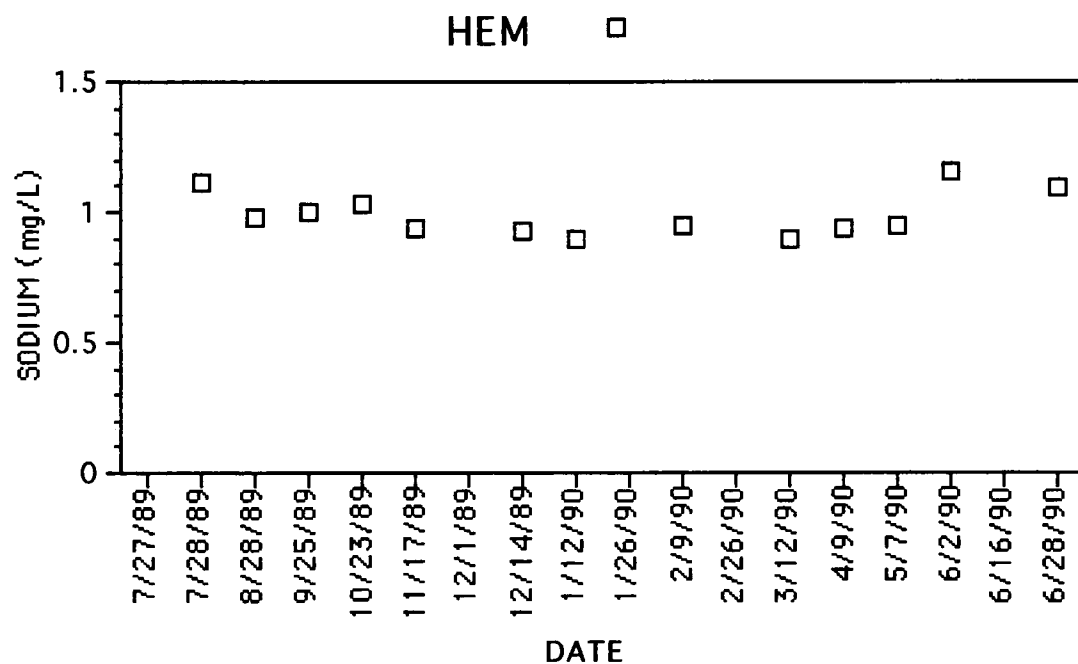


Figure A-91. Sodium values for sampling location HEM over the duration of the sample period.

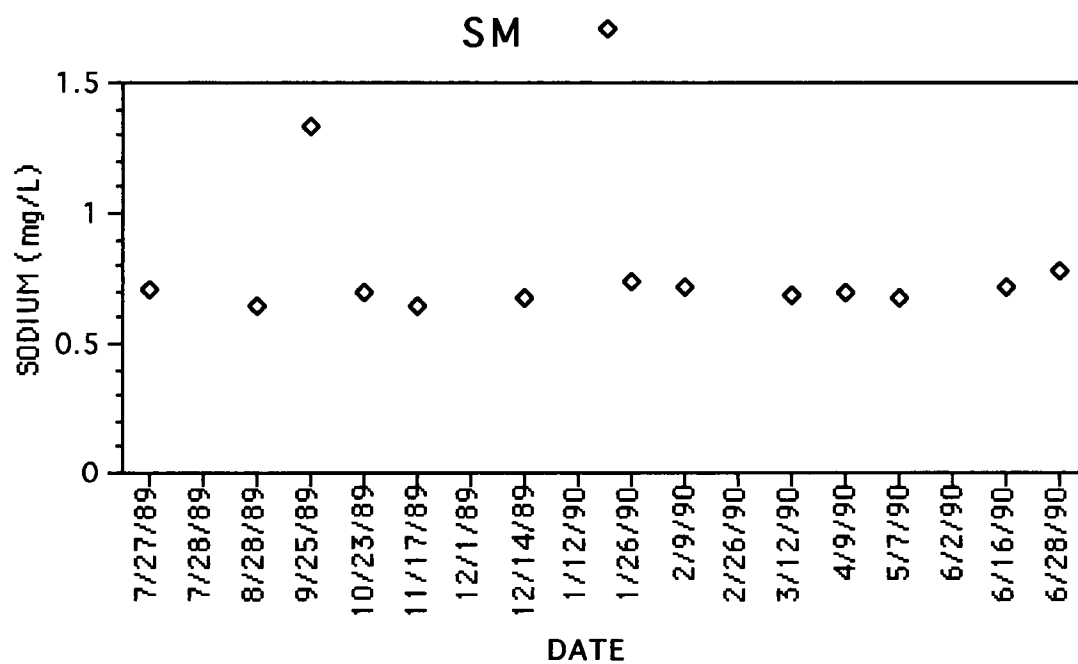


Figure A-92. Sodium values for sampling location SM over the duration of the sample period.

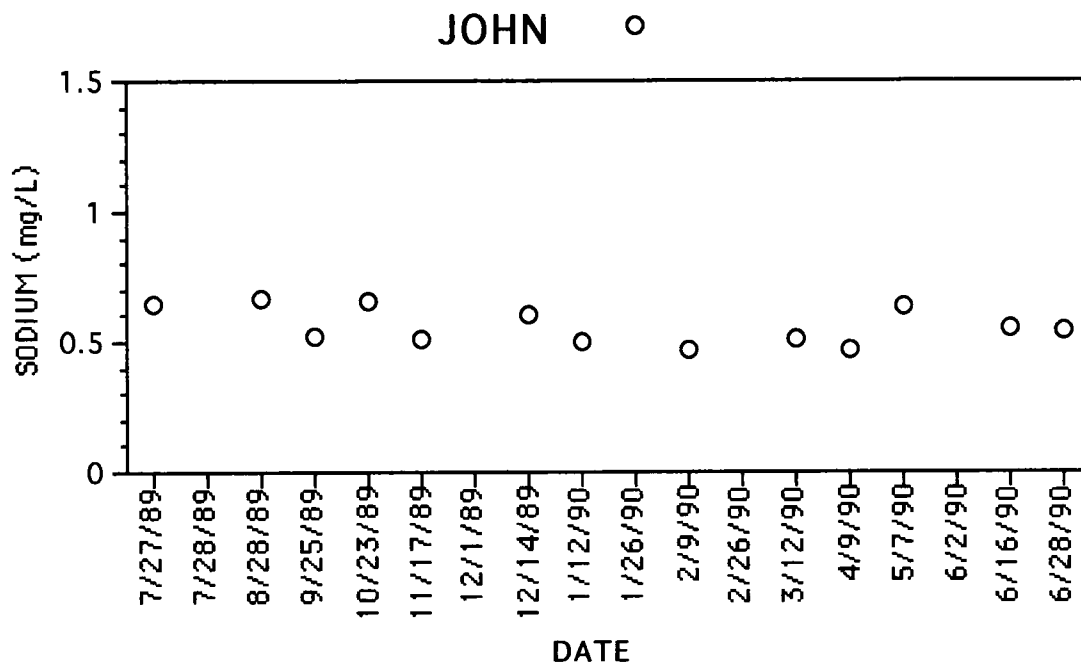


Figure A-93. Sodium values for sampling location JOHN over the duration of the sample period.

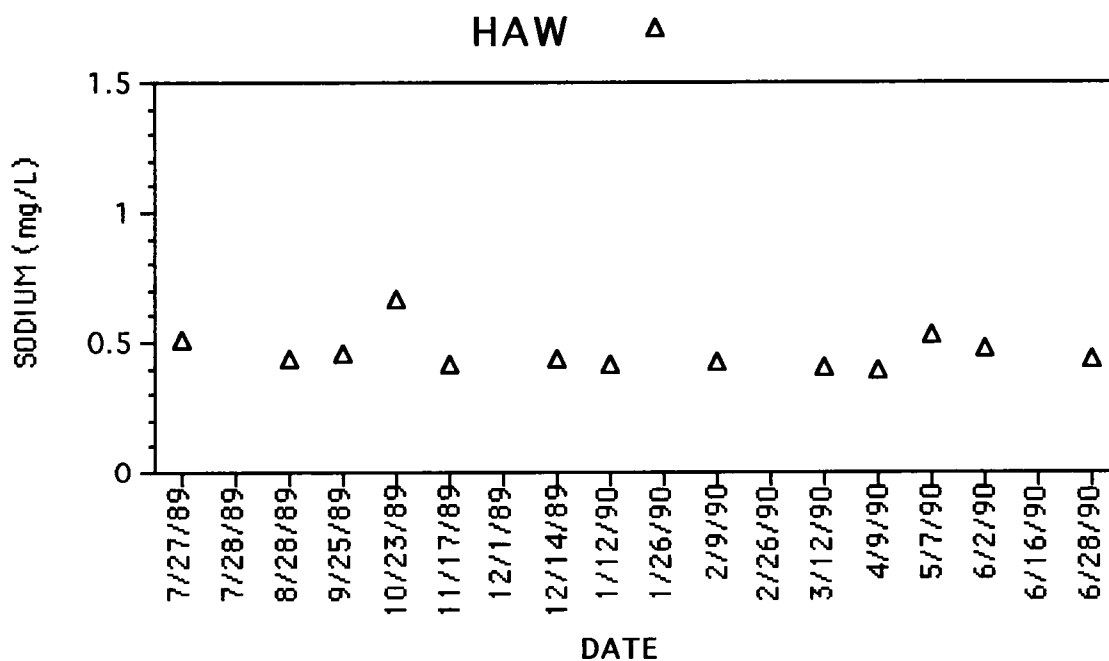


Figure A-94. Sodium values for sampling location HAW over the duration of the sample period.

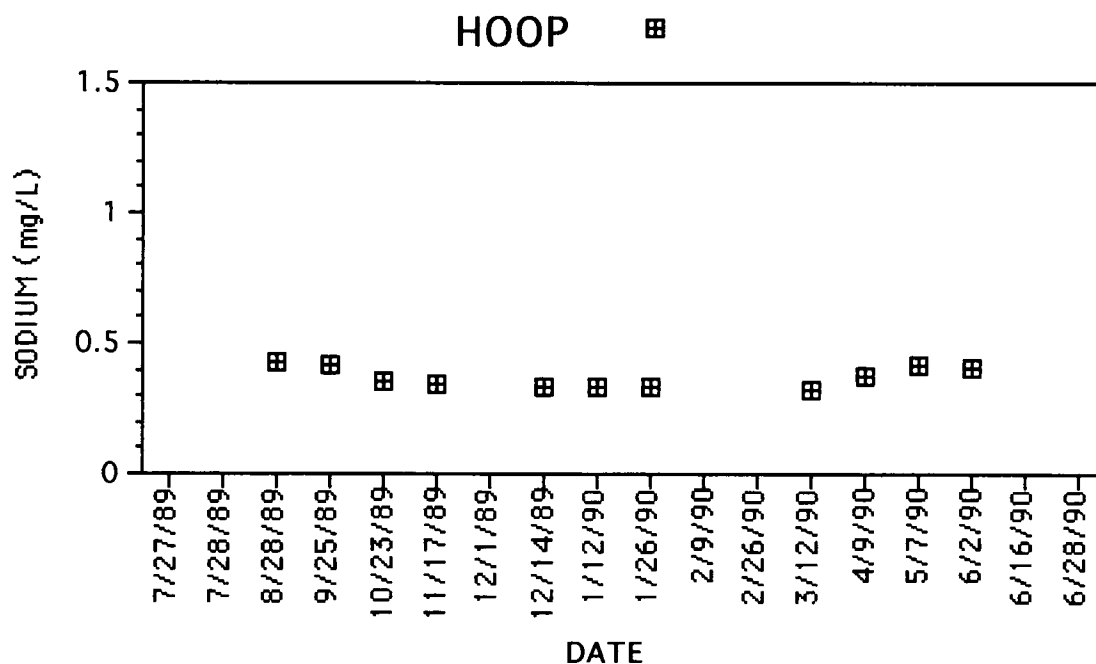


Figure A-95. Sodium values for sampling location HOOP over the duration of the sample period.

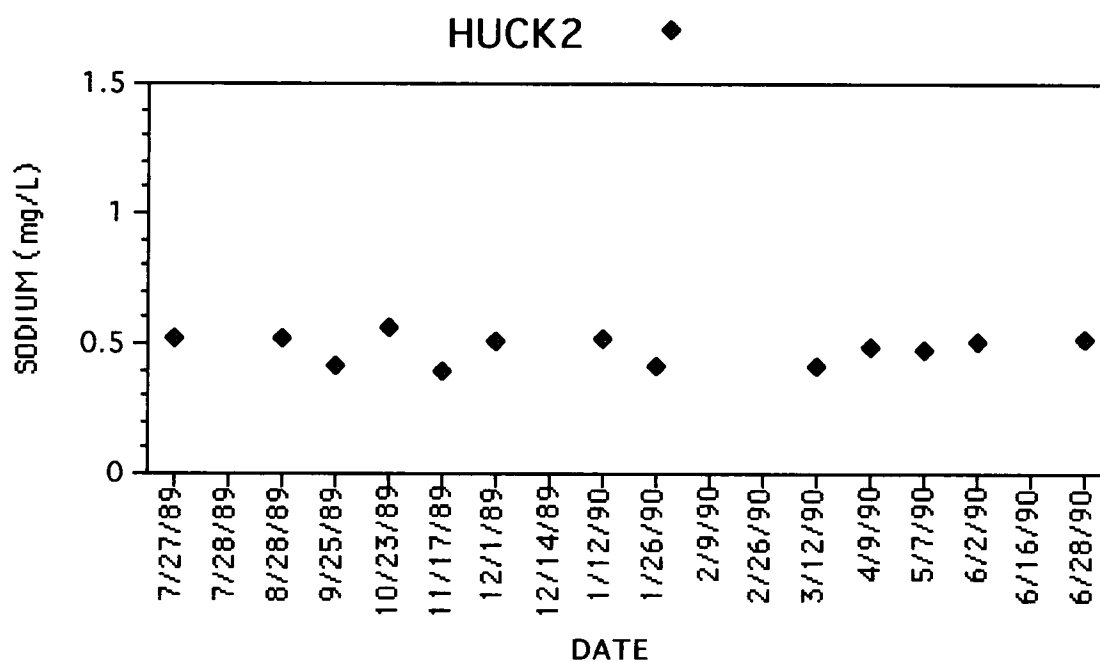


Figure A-96. Sodium values for sampling location HUCK2 over the duration of the sample period.

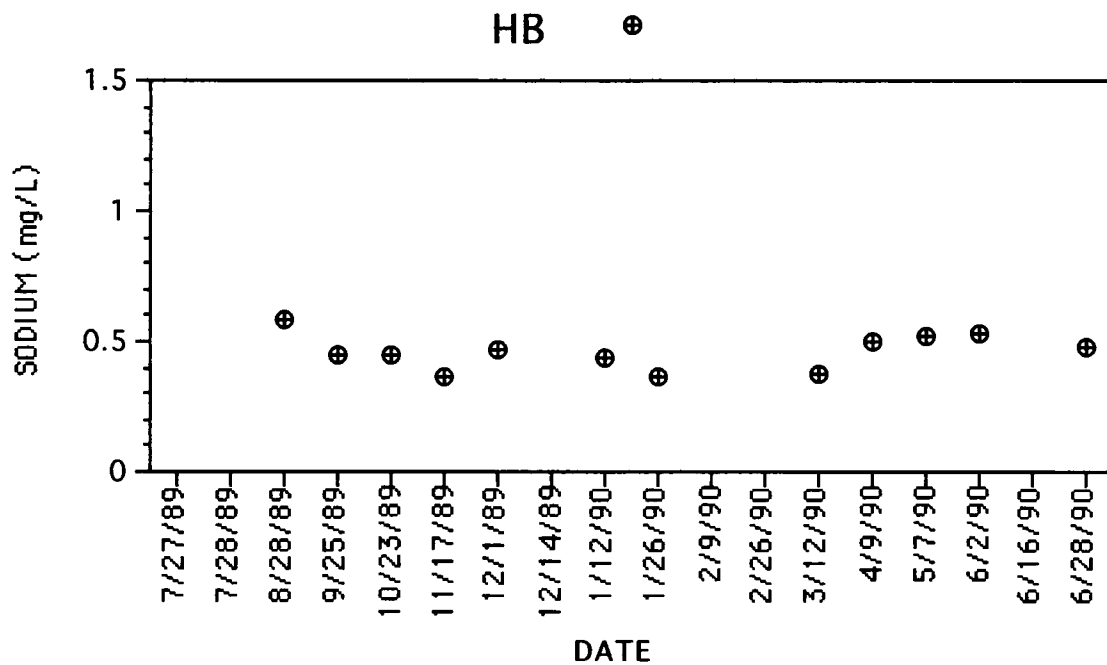


Figure A-97. Sodium values for sampling location HB over the duration of the sample period.

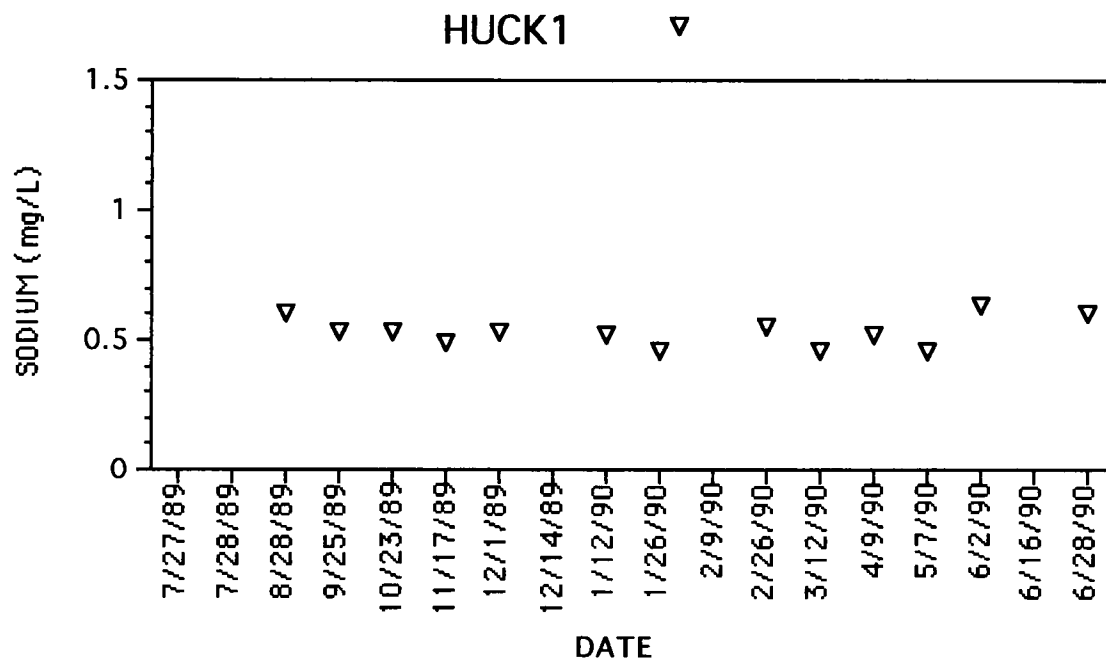


Figure A-98. Sodium values for sampling location HUCK1 over the duration of the sample period.

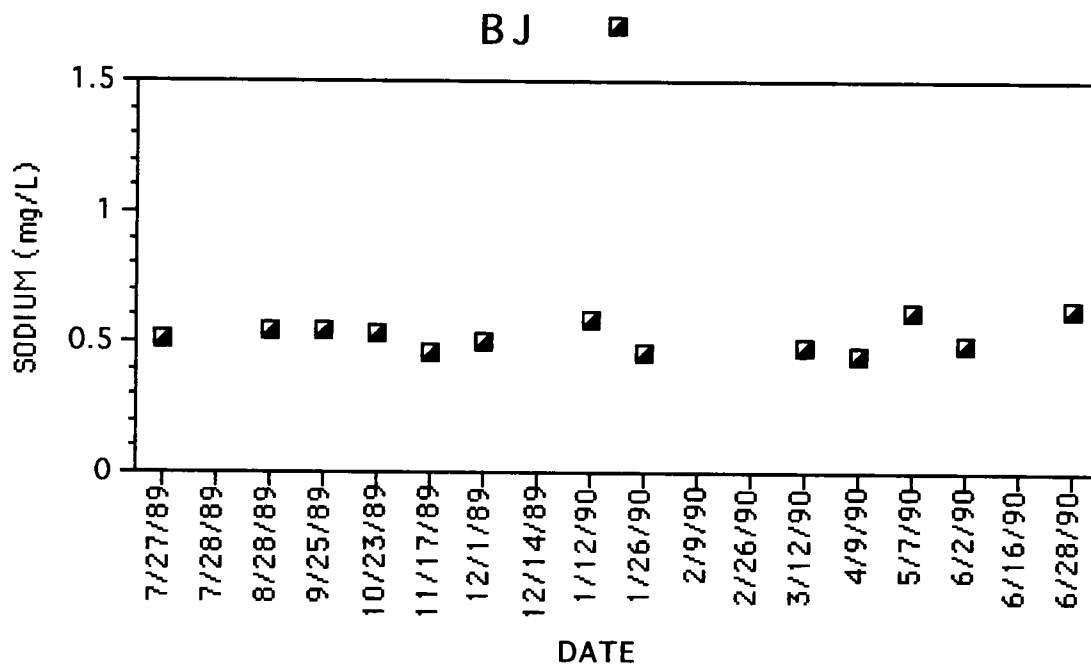


Figure A-99. Sodium values for sampling location BJ over the duration of the sample period.

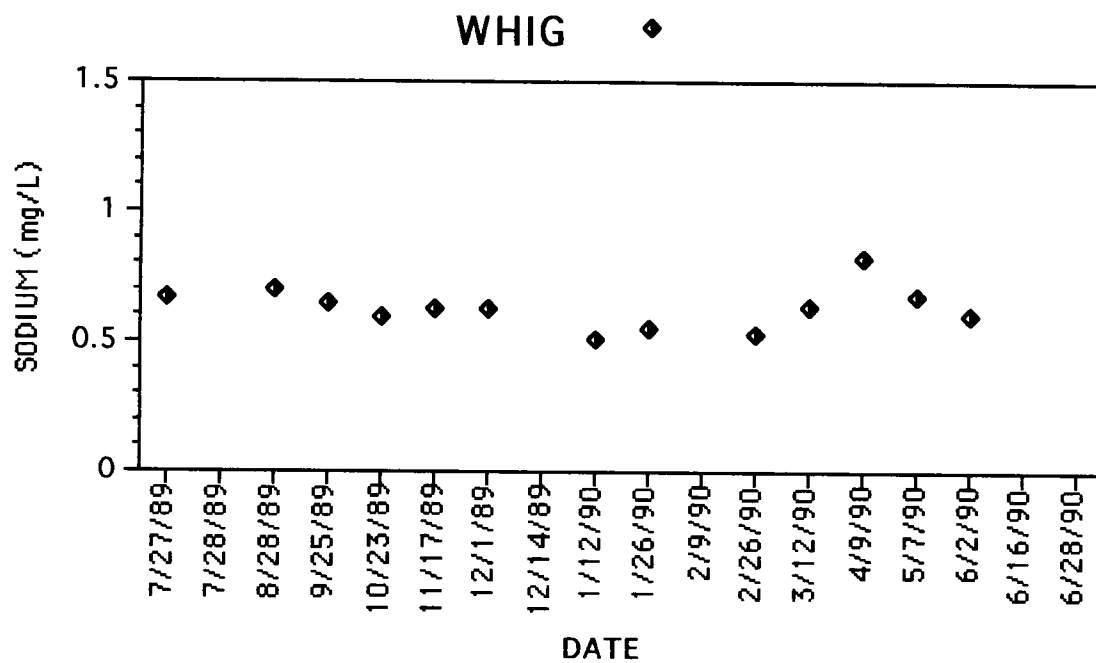


Figure A-100. Sodium values for sampling location WHIG over the duration of the sample period.

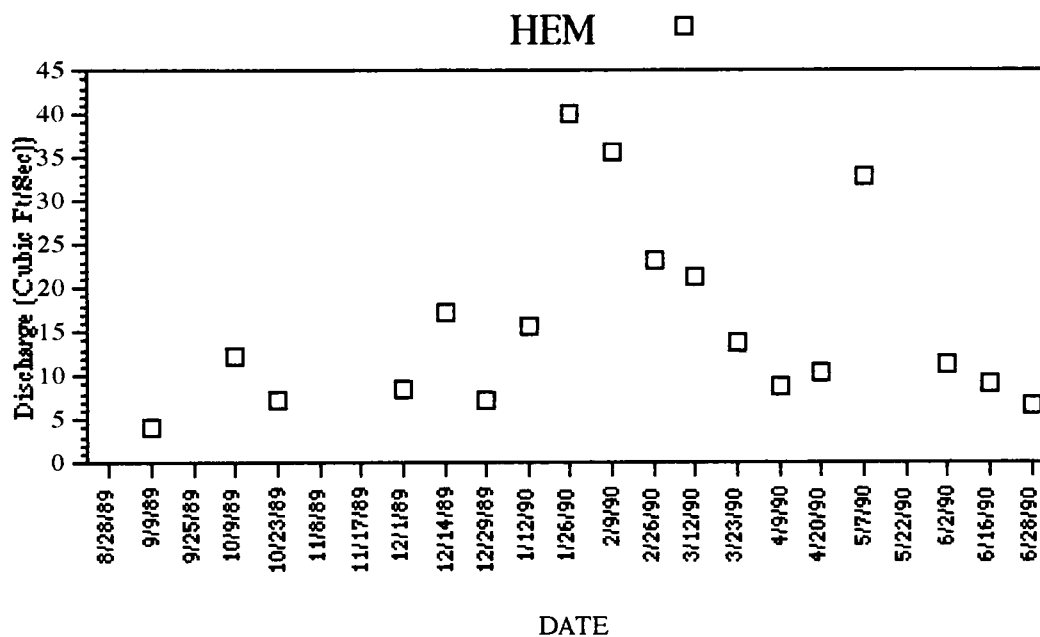


Figure A-101. Discharge estimates for sampling location HEM over the duration of the sample period.

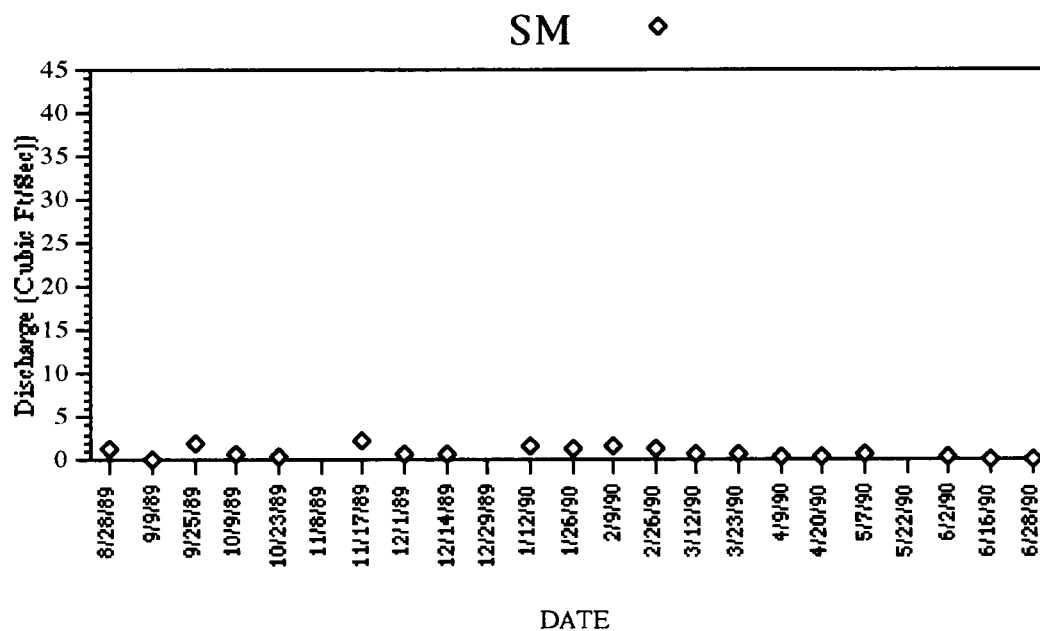


Figure A-102. Discharge estimates for sampling location SM over the duration of the sample period.

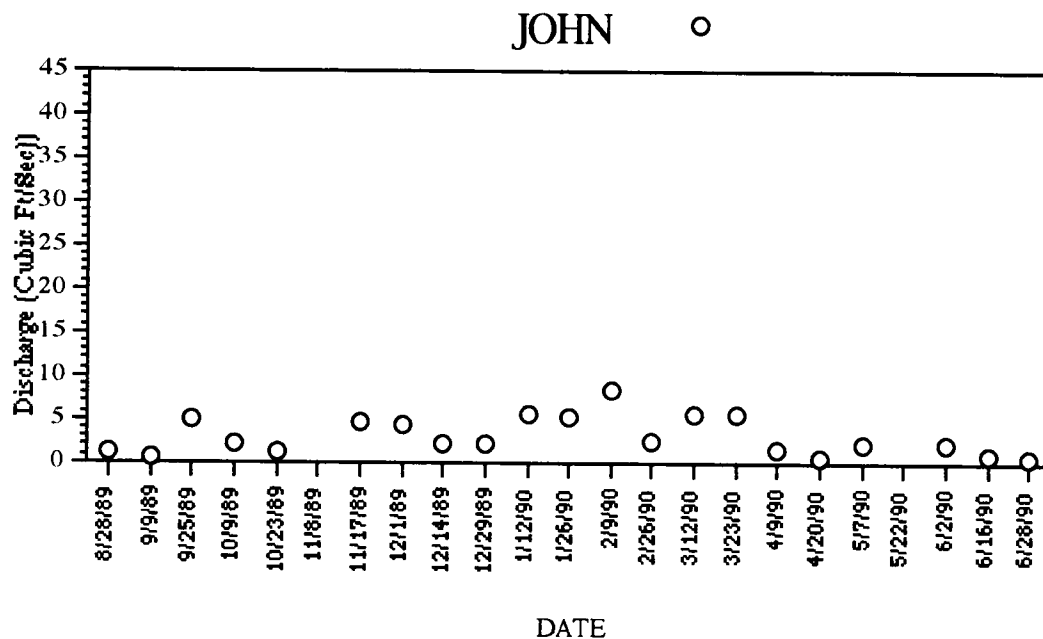


Figure A-103. Discharge estimates for sampling location JOHN over the duration of the sample period.

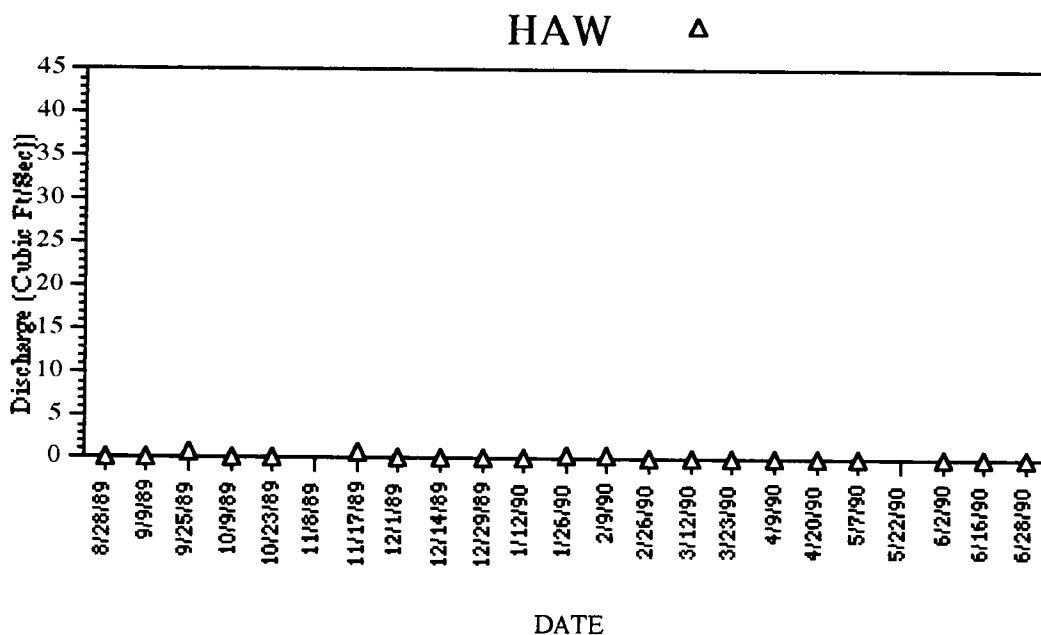


Figure A-104. Discharge estimates for sampling location HAW over the duration of the sample period.

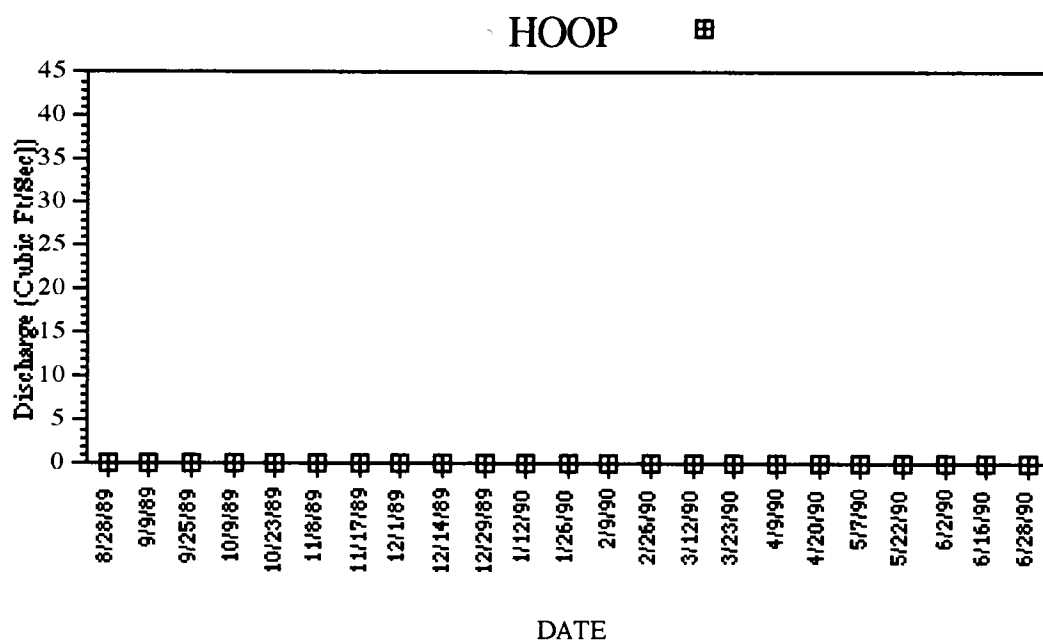


Figure A-105. Discharge estimates for sampling location HOOP over the duration of the sample period.

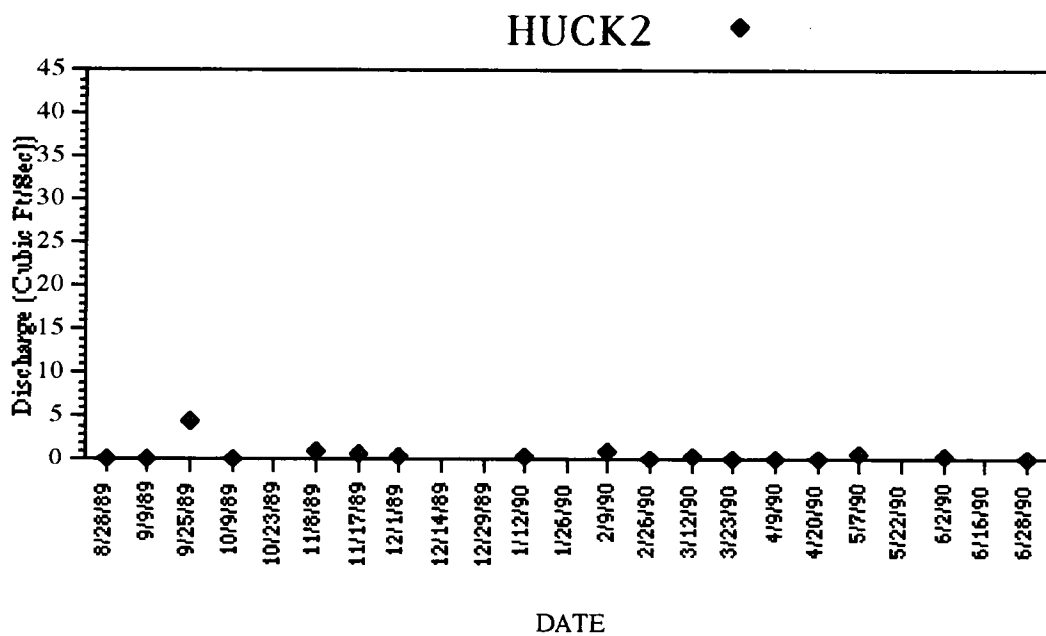


Figure A-106. Discharge estimates for sampling location HUCK2 over the duration of the sample period.

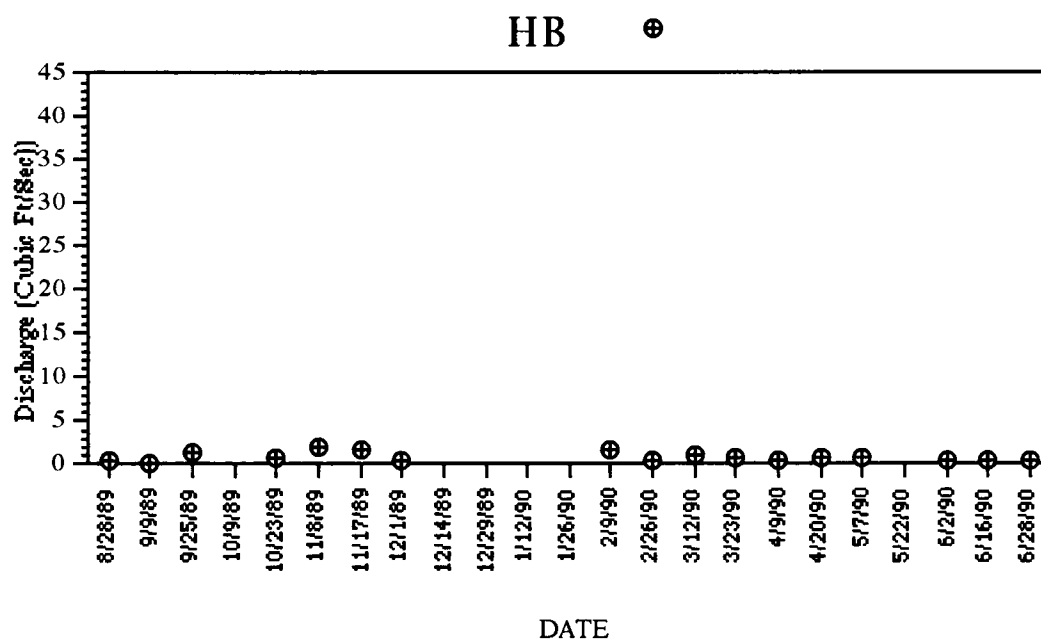


Figure A-107. Discharge estimates for sampling location HB over the duration of the sample period.

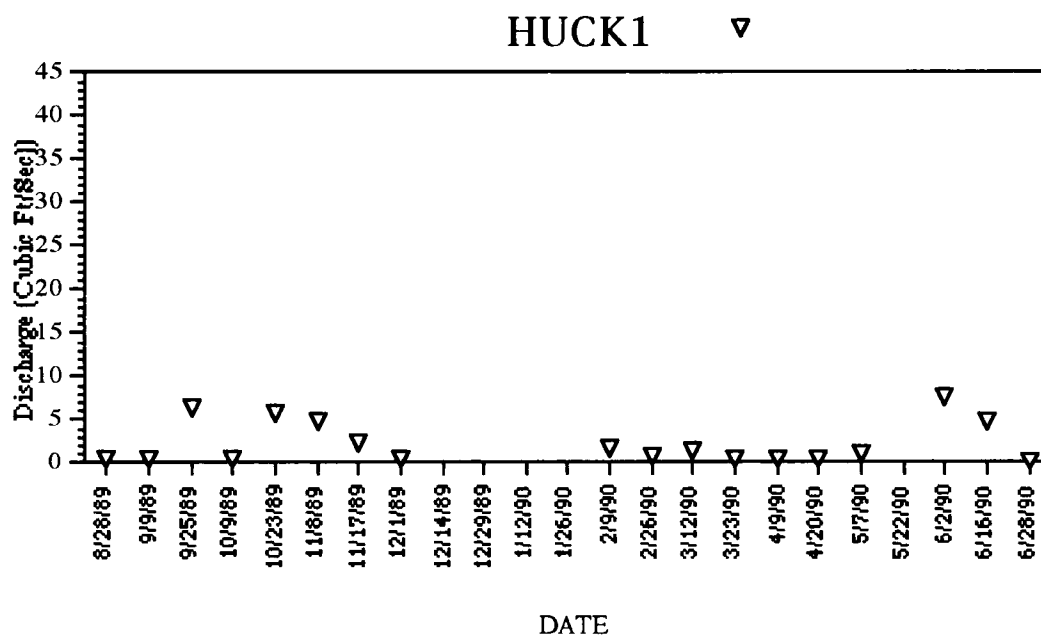


Figure A-108. Discharge estimates for sampling location HUCK1 over the duration of the sample period.

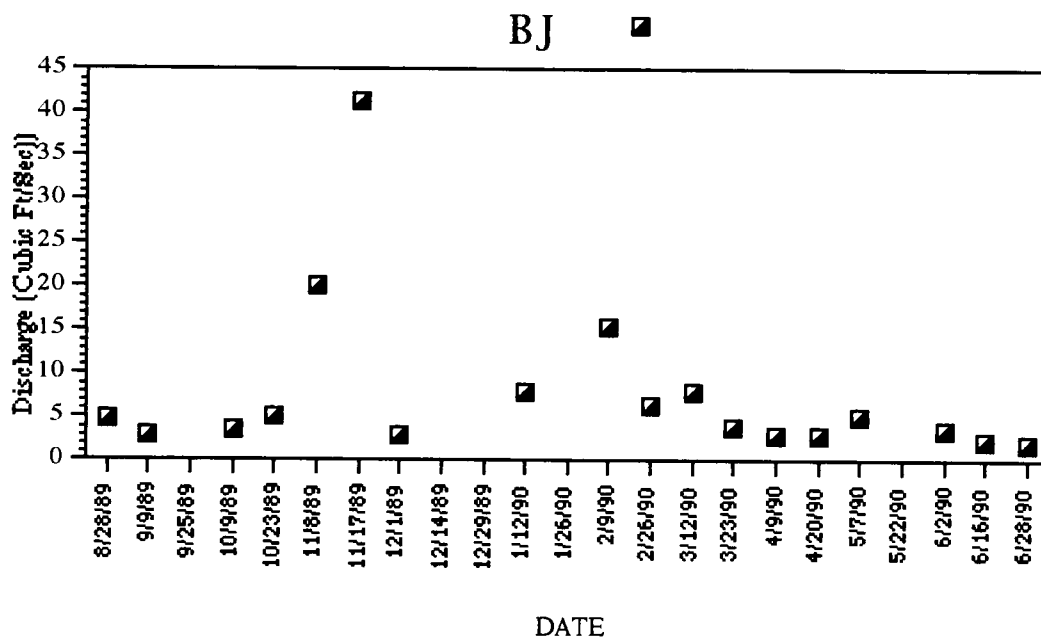


Figure A-109. Discharge estimates for sampling location BJ over the duration of the sample period.

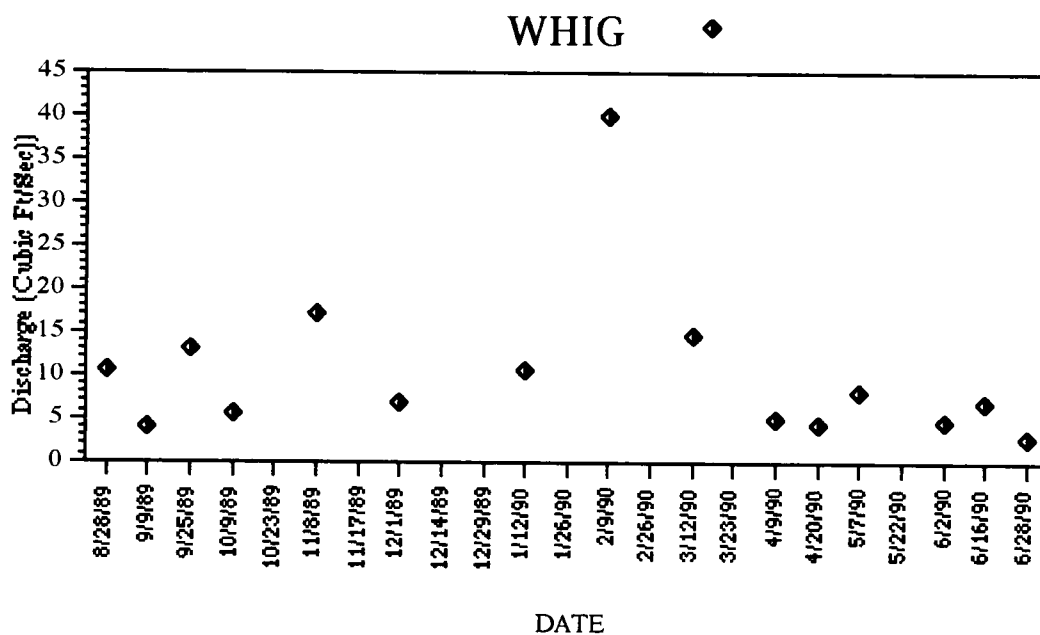


Figure A-110. Discharge estimates for sampling location WHIG over the duration of the sample period.

VITA

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Mr. Tingle is currently employed as a hydrogeologist with Analysas Corporation in Oak Ridge, Tennessee. He is a member of the Hazardous Waste Control Resources Institute, the Association of Engineering Geologists, and the Geological Society of America.

