8-1982

Characterization of the Saturated Zone Associated with the Contour Surface Mining Spoil in the New River Basin of Tennessee

Paul Shearin Dickens
University of Tennessee - Knoxville

Recommended Citation

Dickens, Paul Shearin, "Characterization of the Saturated Zone Associated with the Contour Surface Mining Spoil in the New River Basin of Tennessee. " Master's Thesis, University of Tennessee, 1982.
https://trace.tennessee.edu/utk_gradthes/2519

To the Graduate Council:

I am submitting herewith a thesis written by Paul Shearin Dickens entitled "Characterization of the Saturated Zone Associated with the Contour Surface Mining Spoil in the New River Basin of Tennessee." I have examined the final electronic 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 Environmental Engineering.

Roger A. Minear, Major Professor

We have read this thesis and recommend its acceptance:

Bruce Tchantz, Gregory D. Reed, R. Bruce Robinson

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Paul Shearin Dickens entitled "Characterization of the Saturated Zone Associated with the Contour Surface Mining Spoil in the New River Basin of Tennessee." 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 Environmental Engineering.

Roger A. Minear

Roger A. Minear, Major Professor

We have read this thesis
and recommend its acceptance:

R Bruce Robinson

Accepted for the Council:

L Evans Roth

Vice Chancellor
Graduate Studies and Research

CHARACTERIZATION OF THE SATURATED ZONE ASSOCIATED WITH THE CONTOUR SURFACE MINING SPOIL IN THE NEW RIVER BASIN OF TENNESSEE

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

Paul Shearin Dickens
August 1982

ACKNOWLEDGMENTS

This thesis would not have been possible without the supporting work of several graduate and undergraduate students. The author acknowledges the aid of Ms. Lisa Sullivan and Ms. Joan Giltner in cataloging the original field data, Ms. Chiang Chang-Hua for computerizing this information, and Mr. Kevin Kelly for statistical analysis and computer graphics work. Hand drawn figures in the text were prepared by Mr. Keith Harwell.

The author also wishes to acknowledge the guiding influence of Drs. Roger A. Minear and Bruce A. Tschantz and in particular the aid of doctoral candidate Raymond R. Rose under whose direction the field data for this research was obtained. The typed manuscript was prepared by Mrs. Marilyn Caponetti whose speed and editing skills were greatly appreciated as is the Federal Government's support of research activities which largely financed the author's graduate and undergraduate education.

Finally, special acknowledgment must go to the author's wife, Martha, for her understanding and support.

ABSTRACT

The spoil resulting from contour surface mining of coal in the mountainous New River Basin of Tennessee was examined to determine its extent of saturation and the water quality associated with this saturated zone. Two well study sites were established on the mining spoil in two small watersheds of the upper New River Basin. At each a set of permanent wells running in a line from the bench to the toe of the spoil was installed and periodically monitored for groundwater elevations and water quality. The extent and quality of the spoil saturated zone throughout each watershed was examined with a series of temporary, hand-driven observation wells. The spoil bank investigation covered a period of six years between 1975 and 1981 and was part of a larger comprehensive study in the New River Area examining environmental changes associated with the surface mining of coal. Principle support for this work came from the United States Department of Energy and its predecessor, the Energy Research and Development Administration.

Several large hydrologic and groundwater quality data bases were developed and are summarized with descriptive statistics. Spatial and temporal variations in the data are examined as well as chemical relationships between water quality constituents. Storage volumes and mineral constituent masses mobilized within the mining spoil are quantified. This information and surface hydrologic and water quality data from the larger comprehensive study are used to assess the impact of the surface mining spoil on low flow hydrology in the two study watersheds.

The contour surface mining spoils examined are a heterogeneous, apparently anisotropic, predominately clay material interspersed with weathering fragments of sandstone and shale of various size. They are generally saturated along their lower boundary. The size of this saturated zone, however, is known to vary as a function of surface conditions. The spoil material represents an acid soil.

Concentrations of dissolved mineral constituents found in the saturated zone are moderate compared to spoils of acid drainage areas in the East and those containing glacial deposits in the Midwest. Overall pH is acidic with a median value of 6.3. Calcium and magnesium are the major cations; bicarbonate the major anion. Acid and reducing conditions were found to be associated. Constituent concentrations show negative correlation with redox potential and positive associations with alkalinity and sulfate. An attempt was made to quantify the contribution of aluminosilicate minerals to calcium, magnesium and alkalinity found in spoil subsurface waters. The results were inconclusive; however, indirect evidence suggests this contribution is small compared to the dissolution of carbonate materials.

The contour surface mining spoil was shown to store a substantial volume of water and mobilized mineral constituent mass and to have a significant impact on the low flow hydrology of mining disturbed basins. The degree of saturation within the spoils examined was found to be increasing with time, apparently independent of short term annual trends in rainfall. This raises question as to the long-term stability of these embankments.

Constituent concentrations in the spoil subsurface water are significantly elevated above those found in the shallow, undisturbed groundwater system of the watersheds examined. However, heavy metal concentrations in the spoil drainage are low. Except for isolated point sources of acid mine drainage, this water appears suitable for livestock, irrigation, and, with conventional treatment technology, water supply purposes. No overall, long term decreasing trend in subsurface constituent concentrations, suggestive of recovery, were observed in the spoil quality data. However, short-term variations with hydrologic condition in the spoil are noted.

TABLE OF CONTENTS

CHAPTER PAGE

CHAPTER PAGE

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The surface mining of coal in the mountainous eastern coal fields has the recognized potential for adverse environmental effects. Many researchers have documented a change of hydrologic character and a deterioration of water quality in watersheds disturbed by surface mining activity. These environmental changes have proven to be long-term effects.

In 1972, research interest in the environmental impacts of coal surface mining began in the Department of Civil Engineering of The University of Tennessee, Knoxville with a study of hydrologic changes brought about by this activity in the New River Basin of East Tennessee. The work was sponsored by the National Science Foundation and found that extensive surface mining of coal had increased both flood stage and base flow at the mouth of the New River Basin (66).

As the National Science Foundation project drew to an end in 1974, it became obvious that changes seen in the New River were symptoms of the changes that occurred in subbasins of the New River directly affected by surface mining. With this understanding, a six year comprehensive study, funded primarily by the United States Department of Energy and its predecessor, the Energy Research and Development Administration, was undertaken to investigate the impact of surface mining on hydrology and water quality in six small watersheds of the New River Basin. A detailed investigation in the

New River area was considered additionally important because no studies of this type had been conducted for the coal fields of Tennessee. The New River work has examined stream hydrology and water quality. The mining spoil has been examined with studies of geochemistry, surface runoff, sediment yield, subsurface hydrology, and subsurface water quality. This thesis focuses on the last two of these studies and will attempt to characterize the saturated zone associated with the contour surface mining spoil in the New River Basin of East Tennessee.

When a contour surface mining cut is made, originally consolidated overburden material is fractured, removed, and then backfilled in a heterogeneous mixture commonly known as the mining spoil. The result is a mass of unconsolidated, permeable material overlying the intact, relatively impermeable rock structure of the floor of the mining cut and of the mountain slope below. In the humid Appalachian coalfields the spoil, initially composed of mudstones, sandstones and shale, weathers rapidly and in many cases becomes saturated along the boundary with the undisturbed strata beneath it. As a groundwater system forms in the mining spoil, leaching and weathering processes mobilize dissolved mineral constituents from the original overburden material. As a result, the quality of the water intercepted by the spoil bank may deteriorate. A typical surface mining operation in the Appalachian coal fields will produce several hundred thousand to several million cubic yards of spoil. This spoil is capable of storing a tremendous volume of water and mobilized pollutant mass which, as it moves downgradient of the spoil bank, has a potential for affecting ground and surface water quality.

Scope

The spoil bank investigation of the New River Study was initiated to determine the extent and water quality of the saturated zone associated with the contour surface mining spoil. To this end, two well study sites were established on the mining spoil in two small watersheds of the upper New River Basin. These were periodically monitored for groundwater elevations and water quality. The extent and quality of the spoil saturated zone throughout each watershed was examined with a series of temporary, hand-driven observation wells. The spoil bank investigation covered a period of six years between 1975 and 1981.

Objectives

The objectives of this thesis are threefold. First, the hydrologic and water quality data developed at the two well study sites will be characterized and examined for spatial and temporal variations. Chemical relationships between water quality constituents will also be examined. The end result will be determinations of the water volume and mobilized pollutant mass present at each well study site, hereafter to be called study spoil banks. Second, the observation well data will be examined to determine the extent and water quality of the spoil saturated zone in the two study watersheds. Observation well quality will be compared with that found at the study spoil banks. Third, the above results will be used to discuss the relation of the spoil saturated zone to low flow basin hydrology and surface water quality.

CHAPTER II

LITERATURE REVIEW

Environmental Changes Associated with the Surface Mining of Coal

The first comprehensive study of environmental changes associated with contour surface mining in small watersheds of the Appalachian coal producing region was the Beaver Creek Study in Eastern Kentucky (8,9,43). Three watersheds of less than one square mile area with moderate to steep slopes were examined; one experiencing mining disturbance, one experiencing prospecting disturbance midway through the study, and the third watershed remaining undisturbed, serving as a control. These watersheds were geographically proximate with similar topography, geology and vegetative soil cover. Coordinated by the United States Geological Survey, the research spanned an 11-year period from 1955-1966 and documents hydrologic, biological, and water quality changes that accompanied and followed surface mining disturbance.

Collier and the other Beaver Creek investigators (8,9) found that surface mining had significantly changed the chemical quality of surface and groundwaters in the disturbed watershed. The pH in affected surface water was depressed to a range of 2.5 to 4.2 from a range of 5.0 to 7.6 observed in the undisturbed watersheds. Dissolved-solids concentrations were elevated 10 to 15 times those representing undisturbed conditions. These changes occurred at the onset of mining and remained through the end of the study period. Aluminum, iron, manganese, calcium, magnesium and sulfate were found to be the principle dissolved constituents in mining disturbed waters. Principle ions found in undisturbed waters were calcium, magnesium, bicarbonate, sulfate and silicon with silicon accounting for 25 percent of the total.

Curtis (13,14), and Dyer and Curtis (17) have also examined hydrologic and chemical changes associated with surface mining in small watersheds of Eastern Kentucky. Their research involved six, adjacent, first-order watersheds of one-half square mile or less over a 9-year period between 1967 and 1975. Mining activity progressed in stages during this period, ultimately disturbing five of the six watersheds. A small amount of mining disturbance was found to significantly reduce watershed time of concentration and to increase both peak storm runoff and sediment yield. The change in these quantities was found to be proportional to the area of disturbance (14).

As in the Beaver Creek Study changes in the quality of surface waters were observed to accompany the onset of mining. However, stream pH was not depressed, but actually increased from an undisturbed watershed average of 6.8 to 7.4 in disturbed streams. The overall results indicate that the surface mining of coal may result in chemical pollution of streams even in areas where acid drainage is not a problem. Quality constituents showing greatest increase with mining were sulfate, calcium and magnesium. Bicarbonate, aluminum, iron, manganese, and zinc concentrations were also significantly elevated (13,17).

Bicarbonate, calcium and magnesium concentrations were observed to increase immediately with mining activity to levels proportional with the degree of mining disturbance. The time lag between mining and the full stream-water chemistry response of these constituents was on the order of 6 to 12 months. Sulfate concentrations continued to increase up to 2 years after mining disturbance. Whereas aluminum, iron and manganese were observed to return to undisturbed levels within about one year of the cessation of mining, bicarbonate, calcium, magnesium, and sulfate concentrations showed no evidence of recovery by the end of the study period.

In discussion of their results, Dyer and Curtis (17) note a seasonal cyclic pattern in magnesium and bicarbonate concentrations with lows occurring in winter months and peaks in early fall. Other constituents demonstrated similar patterns. With the exception of suspended solids, the highest stream constituent concentrations were found to be associated with low flows. Although mean concentrations were lower, the largest total load of dissolved constituents was associated with storm flow.

The impacts of coal surface mining on the water quality and hydrology of small mountain drainage basins in Eastern Tennessee has been examined by Rose (51), Minear and Tschantz (42), and Rose, Valentine and Minear (53). The experimental design for this research was similar to that of the Eastern Kentucky work in that small geographically proximate watersheds representing different degrees of surface mining disturbance and different reclamation practices were monitored for both flow and water quality. This work was part of a larger, comprehensive study of the environmental impacts associated with coal production in the New River Basin of East Tennessee begun in 1975 and of which this thesis is also a part.

The results parallel those of Dyer and Curtis. An increase in stream concentrations of sulfate, calcium, magnesium, alkalinity, iron, manganese and additional trace metals was found to accompany and follow surface mining disturbance. Similar seasonal and flow related variations in constituent concentrations were observed. The magnitude of stream quality changes associated with mining disturbance varied widely among the study watersheds and was found to be related not only to the area of disturbance, but also to the coal seam mined and type of reclamation practiced. As in the Kentucky studies, no improvement in disturbed water quality was indicated over the period of available quality record.

Undisturbed streams examined in the New River work were found to be poorly buffered and weakly acidic with low dissolved salt concentrations indicating very little constituent contribution to the stream from weathering of geologic materials within the undisturbed watershed. The elevated salt concentrations found in mining disturbed streams point to the unconsolidated mining spoil as the primary source of additional chemical constituents. With the exception of pH, constituent concentrations in undisturbed streams were relatively stable over time and thus largely independent of rainfall and seasonal temperature changes. The flow and seasonal variation observed for constituent concentrations in disturbed streams was related to the kinetics of weathering at the mining spoil and to the length of contact water has with this material (53).

During late summer and early fall streams in undisturbed watersheds were observed to go dry while disturbed streams of similar watershed area maintained a measurable level of flow. This was attributed to the gradual release of water stored in the mining spoil (42,53). Curtis (15), in a discussion of his early research efforts, makes note of similar observations in Eastern Kentucky. Maximum disturbed stream concentrations occur at this time and were attributed to temperatures favorable for increased chemical weathering and the lengthy time afforded groundwater in the mining spoil. The lower chemical concentrations observed during winter and spring were related to less favorable temperatures for chemical weathering and a predominance of surface runoff (51,53).

There have been other general studies of water quality associated with surface mining disturbance in the Eastern coal fields of the United States. Plass (47) has examined the surface quality of small watersheds affected by strip mining in West Virginia. Hopkins (31), and Grubb and Ryder (27) have examined effects of coal mining on the quality of surface water supplies in Western Maryland and the Tradewater River Basin of Kentucky. Gang and Langmurr (22) have examined both surface and groundwaters affected by surface mining in Northwestern Pennsylvania. This work was part of research examining geochemical controls on heavy metals. In an earlier Pennsylvania study, Emrich and Merritt (18) examined the groundwater system of a large drainage basin affected by surface mine waters.

Similar, more recent general studies have been conducted for the Western coal fields. Dettmann, Olsen, and Vinikour (16) have examined both surface water and biological quality in the Ponder River Basin of Wyoming and Montana. McWhorter, et al. (38) have examined surface and subsurface water quality in surface mined watersheds of Northwestern Colorado. The effects of coal surface mining on water quality in Alberta, Canada has been studied by Hackbarth (28).

Storage Potential of the Mining Spoil

The Beaver Creek study documented the storage of water in the contour surface mining spoil with a set of 14 monitoring wells placed in this material (8,9). Seasonal fluctuations in the amount of this storage were observed and were related to the surface storage of water in pits along the mining spoil and to precipitation. The spoil material removed during the installation of monitoring wells was found to consist predominately of clay intermixed with smaller amounts of sand, silt, coal, and shale. Spoil profiles constructed for each well site indicated the spoil bank was a heterogeneous mixture varying both vertically and laterally. Overall discharge from the mining spoil was estimated from storage depletion computations to be 265 gal/acre spoil-day (2.48 m^3/hectare spoil-day). This represented both evapotranspiration and drainage at the base of the spoil embankment. Calculations of spoil transmissibility with Darcy's equation and field values of permeability suggested flow rates of 1.0 to 16 gal/day per acre of spoil (9.35 to 150 liters/day per hectare spoil). No significant changes in spoil groundwater storage were observed during the 11-year period of the Beaver Creek Study.

Tung (66) has examined the relationship between observed changes in peak and mean daily flows and the progress of contour surface mining in the New River Basin of East Tennessee. This case study covered 32 years of stream flow record from the New River between 1943 and 1974, a period representing the onset and subsequent widespread development of surface mining. By the end of the study period 5 percent of the 382 square mile (989 sq. km) watershed had been disturbed. Associated with this disturbance was a 30 percent increase in low flow volume observed at the mouth of the basin. Tung attributed this increase to the interception and storage of surface water by the mining spoil. The stored water was gradually released as seepage, thus increasing the observed low flow during dry periods. Later New River investigators examining primary watersheds within the basin have made similar statements regarding the sustained base flows observed in disturbed streams during periods of drought (42,53).

An examination of the storage potential of area mining spoils has been made by researchers associated with the University of Indiana Water Resources Research Center in a study of the Patoka River and Busseron Creek Basins of Southwestern Indiana (1,10,65). Traux (65) and Agnew (1) introduced the idea that unconsolidated spoil, with its increased void volume, can intercept and store much more water than its undisturbed parent material. They state that this storage potential is an often overlooked water resource benefit of areal mining activity. The actual storage at the mine site is split between surface water trapped by the topography of the area and subsurface water in the spoil material. Corbett (10), when estimating storage volumes in the Patoka River Basin, attributed 70 percent to the latter. The major finding of the Indiana researchers was that extensive areal surface mining disturbance had significantly reduced storm flows and increased low flow through the direct interception and storage of precipitation (10,65). Herring (29), in a later literature review of hydrology associated with area mining in the Midwest, confirms that this storage is widespread in mining spoils of that region. He also states that this water, although high in dissolved solids, is typically not acid owing to a neutralizing capacity in the overburden greater than its capacity for acid generation.

Water Quality of the Mining Spoil

The Beaver Creek Study examined the quality of water in and on the contour surface mining spoil. In general, this water was of low pH, with dissolved solid concentrations in excess of 400 ppm. Its chemical characteristics were found to vary both laterally across the mine site and vertically within the spoil profile (8,9). A summary of the Beaver Creek data is presented in Table 1. No additional studies documenting the subsurface water quality of eastern contour surface mining spoils were found in this literature review. However, several investigations by soil scientists into the percolate quality of this material were uncovered.

Vimmerstedt and Struthers (73) report the results of a 9-year leaching/weathering study of spoil taken from Ohio coal stripmines.

Table 1. Water Quality Associated with the Contour Surface Mining Spoil, Beaver Creek Study, Eastern Kentucky (8,9)

Constituent (Total Concentrations Reported as mg/l, Except pH)	Mining Pits		Spoil Wells	
	Range	Mean	Range	Mean
pH	2.9 - 6.9	3.45	2.4 - 6.8	2.93
Alkalinity as $CaCO_3$	0 - 30	0.8	0 - 541	15.6
Acidity as $CaCO_3$	5.0 - 420	104	40 - 1450	401
Hardness as $CaCO_3$	7 - 852	157	24 - 2060	492
Sulfate	13 - 1260	251	11 - 3320	859
Fe	0.10 - 70	4.7	0.10 - 299	94.7
Mn	0.03 - 32	5.9	0.10 - 115	26.6
Al	0.0 - 42	10.5	0.0 -226	31.8

Nineteen bulk spoil samples distributed by coal seam, overburden geology, and geographic location plus one sample of agricultural soil were allowed to weather under natural climatic conditions in plastic lysimeters 1 foot in diameter and 4 feet deep (0.3 by 1.2 m). Leachate percolating through the soil columns was collected on an annual basis and analyzed for total content of soluble salts, sulfate, calcium, magnesium, iron, aluminum, and manganese. The samples had been classified at the beginning of the research as toxic, marginal, acid, and calcereous based on measurements of surface material pH and its areal distribution at the mine site. In general, the pH of toxic and marginal spoils was less than 4.0, of acid spoil between 4.0 and 7.0, and of calcereous spoil greater than 7.0. In their paper the authors examine relationships between leachate quality, rainfall, time, and the spoil classifications.

The volume of leachate and yield of soluble salts was found directly proportional to the amount of annual rainfall. Total leachate salt concentrations ranged from 2000 to 4000 mg/l. Vimmerstedt and Struthers note that in subsequent years of equal rainfall the yield of soluble salts decreased indicating pyrite oxidation and concomitant weathering of other minerals was decreasing with time. Multiple regression analysis of salt yield with time and annual precipitation confirmed this result. Constituent yields from the toxic and marginal spoils were larger than from those classified as acid or calcareous. However, these spoils exhibited a leaching half-life (i.e., time to one-half of the initial concentration) on the order of

3 to 4 years whereas that for acid and calcareous spoils was 8 years or more.

Sulfate constituted the bulk of the total salts leached from the toxic and marginal spoils (approximately 70 percent) and remained constant as a percentage or actually increased with duration of weathering. Sulfate made up a lesser percentage (50 percent) of the leachate from acid and calcareous spoils, and this percentage was found to decrease with time indicating a relative increase in bicarbonate and signaling an improvement in the quality of drainage from these spoils. The toxic and marginal spoils mobilized substantial amounts of iron, aluminum, and manganese whereas the acid and calcareous spoils did not. Calcium and magnesium yields were large for all the spoils compared to that of the agricultural soil. Again, the toxic and marginal spoils generated the greatest amounts of these constituents. Vimmerstedt and Struthers conclude from their work that the surface pH classification of spoil materials is useful for assessing the impact of surface mining on water resource quality. They also state the greater potential for water pollution of toxic spoil materials should be recognized on reclamation practice.

Massey and Barnhisel (37) examined metals released from seven samples of acid spoil material associated with surface mines in Eastern Kentucky. This "spoil material" included both roof shales taken from mining highwalls and samples of freshly completed spoil. The samples were subjected to successive pressure extractions of soil solution for 1, 4, 7, 16 and 35 week equilibration periods following moistening to a water vapor pressure of 0.10 atmosphere. After the 35 week extraction, 10 gram subsamples of the spoil material were leached with 200 ml water. Analyses for pH, nickel, copper, zinc, iron, manganese, calcium, magnesium, sodium, aluminum, and potassium were performed on each successive extraction and the final leachate.

Maximum salt concentrations were generally found to be associated with the lowest evolved solution pH in the series of extractions. This was especially true for iron and to a lesser extent for the remaining cations. Appreciable amounts of zinc, copper and nickel were mobilized indicating the potential of acid spoils for heavy metal plant toxicity and water pollution.

Massey and Barnhisel's overall results indicate the weathering of spoil bank materials can result in solubilization of an appreciable portion of the spoil mass at a rate orders of magnitude higher than normal soil weathering processes. Total mass loss by solubilization ranged from 3.8 percent of the sample weight for a minimum extraction pH of 1.0 to 0.35 percent at pH 5.2. The results also indicate the amount and nature of soluble cation production depends on the severity of acid production in the spoil. For solution pH less than 2.2 iron, the primary cation produced by pyrite oxidation, was found to dominate. Under less severe acid conditions cations produced by secondary reactions dominated, with dominance of aluminum indicating more severe conditions than dominance of calcium and magnesium.

Rogowski (49,50) and Pionke, Rogowski, and Montgomery (46) have examined water movement and percolate quality in reconstructed profiles of Pennsylvania strip mine spoil. A six meter section of spoil material was removed in layers from the field and reassembled in two large caissons. Rainwater was applied to these at uniform rates with mechanical equipment after varying incubation periods of exposure to atmospheric air and ambient temperatures. Percolate was captured in lysimeters placed within the spoil column and in a sand well at the base of each caisson. In conjunction with the caisson work, samples of each spoil layer were leached with an equal weight of water to assess its ability to affect quality in the overall profile. Analyses for pH, total acidity, sulfate, common and trace metals were made (46,49). It should be noted that Rogowski's spoil material consisted predominately of coarse fragments and sand with a clay content less than 4 percent (50).

Pionke, Rogowski, and Montgomery (46) found that water quality generally deteriorated with depth in the spoil profile. A flushing effect of total acidity was noted to accompany the start of water application. However, the chemical properties of the spoil and not hydrologic conditions were found to control the quality of percolate over the series of runs. Total acidity was found to provide a reasonable estimate of other major chemical parameters in the spoil drainage. Correlations were best with aluminum, total iron, magnesium and sulfate and less precise with calcium, ferrous iron, manganese and pH. The negative correlation of metal cations with pH shown by Massey and Barnhisel (37) was repeated. Trace metal concentrations in the spoil leachate samples agreed closely with those observed in spoil percolate. This led the authors to conclude that reduction in trace metal concentrations achieved by dilution or other processes occurs primarily after entry into the groundwater table or stream, rather than in the spoil profile. Observed concentrations of cadmium and zinc were on the same order of magnitude as Environmental Protection Agency drinking water standards for those elements. Chromium, copper, and lead were typically below these levels. Mercury was for the most part below analytical detection limits of 20 ppb.

Pietz, Peterson, and Lue-Hing (45) have examined groundwater quality associated with area mining spoils in West central Illinois. This work involved monthly chemical monitoring of wells placed in both nondisturbed and strip-mined soil profiles for a period of two years. Groundwater data from six land placed and six spoil monitoring wells were utilized for statistical analysis of water quality. The mine sites involved had been abandoned 12 to 14 years prior to the research. Both the undisturbed soil and mine spoil materials were classified as calcareous and poorly drained with textures ranging from loam to silty-clay.

A statistically significant difference was found between the chemical quality observed in the land placed and spoil monitoring wells. Both waters were hard, well buffered with near neutral pH. However, electrical conductivity, alkalinity, and concentrations of chloride, sulfate, Kjeldahl nitrogen, ammonia nitrogen, potassium, sodium, calcium, magnesium, zinc, cadmium, nickel, manganese, lead, and iron were significantly elevated (0.01 level) in the mine spoil groundwaters. The frequency of trace metal detection in spoil waters was also higher. Iron, manganese, lead and zinc concentrations were found to exceed levels described by drinking water standards in both land placed and spoil monitoring wells.

Spatial and temporal variations in the water quality data were examined and found among all the monitoring wells. However, the mine-spoil groundwaters were characterized by a greater number of significant monthly, seasonal, and well to well variations than observed in the land placed wells. The authors attributed this and the higher constituent concentrations of spoil groundwater to the altered and heterogeneous physical-chemical composition of the mining spoil. A summary of the Illinois researcher's quality results is presented in Table 2.

There have been several investigations of groundwater quality associated with the surface mining of Western coals. McWhorter, et al. (38), and McWhorter, Skogerboe, and Skogerboe (39) examined the water pollution potential of mining spoils in Colorado and New Mexico. Hounslow, et al. (32) have developed a large groundwater quality data base for the Western coal fields as a part of geochemical research relating overburden mineralogy to groundwater chemical changes associated with mining. Rahn (48) reports the results of a groundwater study examining coal strip-mine spoils in the Powder River Basin of Wyoming. As in the Illinois study of Pietz, Peterson, and Lue-Hing, a significant difference in the chemical quality of spoil

Table 2. Subsurface Water Quality Results, Pietz, Peterson, and Lue-Hing, West Central Illinois Area Mining (45)

Constituent (Total Concentrations Reported as mg/l Except pH and Conductivity)	Land Placed Wells		Mine Spoil Wells	
	Range	Mean	Range	Mean
pH	6.4 - 8.9	7.5	6.2 - 8.9	7.2
Total P	DL - 2.10	0.14	DL - 0.41	0.08
Chloride	DL - 87.0	11.9	2.0 - 44.0	17.5
Sulfate	DL - 1253	127	21.0 - 1812	609
Kjeldahl Nitrogen	DL - 6.50	1.22	DL - 730	1.65
NH_3-Nitrogen	DL - 4.80	1.04	DL - 6.90	1.25
NO_3+NO_2-N Nitrogen	DL - 30.5	0.82	DL - 0.43	0.05
Alkalinity as $CaCO_3$	110 - 700	363	100 - 1600	661
Electrical Conductivity (µmhos/cm)	200 - 1500	786	1000 - 4000	2406
K	DL - 20	1.5	2.0 - 18.7	8.3
Na	7.0 - 131	30.4	19.0 - 657	247
Ca	38.5 - 226	103	35.0 - 707	260
Mg	23 - 102	57	86 - 625	207
Zn	DL - 140	8.2	0.4 - 100	14.5
Cd	DL - 0.03	DL	DL - 0.20	0.01
Cu	DL - 0.82	0.04	DL - 0.52	0.06
Cr	DL - 0.04	DL	DL - 0.05	DL
Ni	DL - 0.30	0.02	DL - 1.10	0.08
Mn	0.21 - 279	0.86	0.39 - 9.00	2.53
Pb	DL - 0.44	0.08	DL - 0.66	0.15
Fe	DL - 78.8	18.3	2.70 - 193	52.1
Al	DL - 5.8	0.8	DL - 8.20	0.8
Hg	DL - 1.40	0.17	DL - 2.40	0.22

"DL" denotes concentrations below analytical detection limits and natural groundwaters was found; with elevated concentrations of sulfate, calcium, magnesium, and dissolved solids occurring in the mining spoil.

Geochemical Factors Associated with Surface Mine Drainage

The source of the elevated chemical constituents observed in streams draining surface mining disturbed basins is the mining spoil. Upon mining, overburden materials isolated from the surface environment for millions of years become exposed to the atmosphere and water. Fresh surfaces of the disrupted strata weather rapidly forming sediments and clay and releasing mineral constituents. Waters incident on the spoil and percolating through it mobilize these constituents and ultimately transport them from the mine site. The surface mining spoil represents a complex physical and chemical environment which is not completely understood. The quality of spoil drainage is a function of many interrelated factors including the spoil's acid producing potential and neutralizing capacity, the kinetics of these reactions, the geochemistry of the original overburden materials, the physical placement of these materials in the fill, and the hydrology of the spoil embankment (3,5,6,8,21,24).

The degraded water quality associated with the surface mining of coal is generally attributed to oxidation of iron sulfides (pyrite and marcasite) present in the overburden material (4,57,60). This oxidation releases mineral acidity which accelerates the weathering of clays and other spoil materials. Although the overall quality of drainage from the mine site will be a function of the spoil's mineral composition and acid neutralizing capacity, the amount of sulfide present in the overburden and its rate of oxidation upon exposure to the atmosphere and water will in large part determine the level of salts mobilized in the mine waters (4,6). The environmental problems presented by mine drainage has led to much research on the iron pyrites and on factors which control the ultimate quality of these waters.

The generation of acid mine drainage from the oxidation of pyritic iron (general form FeS_2) has been characterized by the following reactions (57):

$$FeS_2(s) + 7/2\ O_2 + H_2O = Fe^{2+} + 2SO_4{}^{2-} + 2H^+ \tag{2.1}$$

$$Fe^{2+} + 1/4\ O_2 + H^+ = Fe^{3+} + 1/2\ H_2O \tag{2.2}$$

$$Fe^{3+} + 3H_2O = Fe(OH)_3(s) + 3H^+ \tag{2.3}$$

$$FeS_2(s) + 14Fe^{3+} + 8H_2O = 15Fe^{2+} + 2SO_4{}^{2-} + 16H^+. \tag{2.4}$$

The oxidation of sulfide to sulfate (eq 2.1) is rapid, releasing ferrous iron and acidity. The ferrous iron subsequently undergoes oxidation to ferric iron (eq 2.2) which then hydrolyzes to form insoluble ferric hydroxide releasing additional acidity (eq 2.3). Ferric iron can react directly with pyrite (eq 2.4). Again, the sulfide is oxidized and acidity released along with ferrous iron which may re-enter the reaction cycle via equation 2.2. A schematic of pyrite oxidation is shown in Figure 1. As can be seen, the concentrations of sulfate and acidity in mine drainage are directly

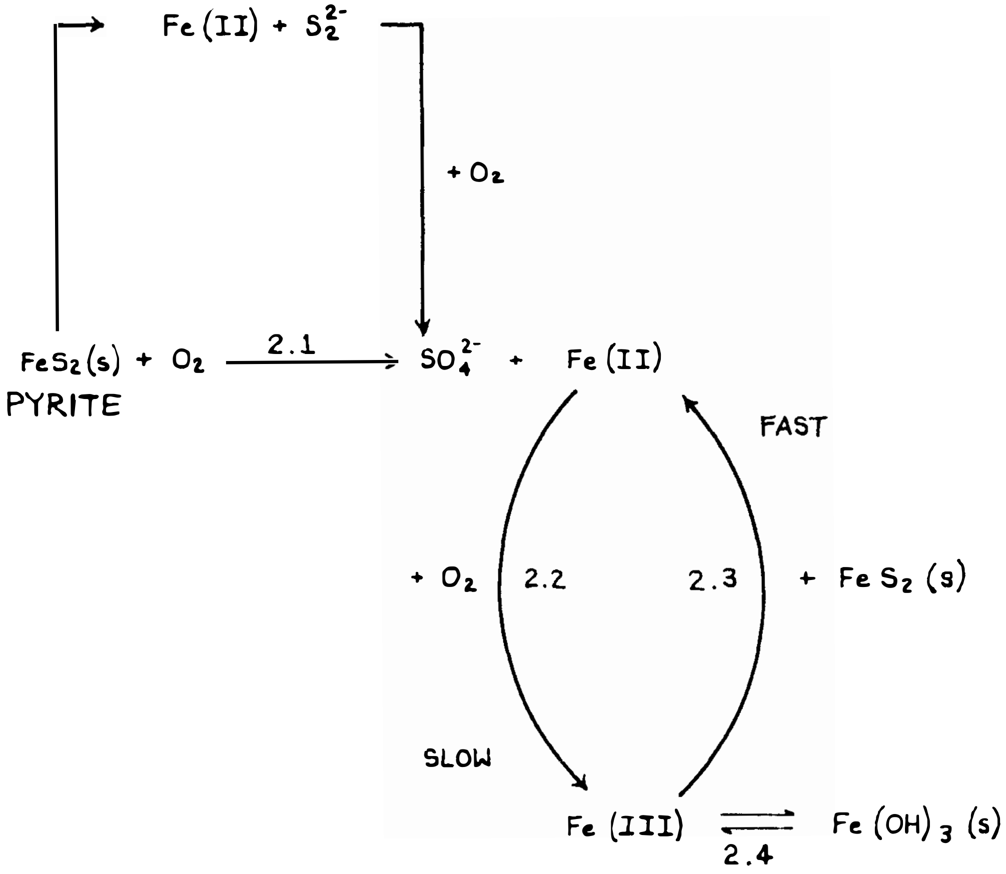


Figure 1. Pyrite Oxidation, Reactions and Kinetics (60).

correlated with the amount of pyrite oxidized. The dissolution of one mole of pyrite leads ultimately to the release of four equivalents of acidity, two equivalents from the oxidation of sulfide and two from the oxidation of ferrous iron.

Figure 1 indicates the rate of oxidation of ferrous iron is considerably slower than the oxidation of pyrite by ferric iron. As a result, ferric iron can not exist in contact with pyritic materials for it is reduced faster than it is formed. Owing also to the slow oxidation rate of ferrous iron, the ultimate acidity of mine drainage may not be expressed until far removed from the mine site. Iron bacteria, however, can catalyze this reaction significantly in acid waters (60).

From the preceding discussion acid production in the mining spoil should be proportional to the pyritic content of the mine overburden. Caruccio (3,4), however, in a study of mine drainage in Central Pennsylvania, found that acidity was a function of pyrite morphology rather than simply total pyritic content. He successfully identified fine grained (approximately 0.25 μm) or framboidal pyrite as the reactive pyrite in coal and associated strata. This sulfide is of primary origin (i.e., formed at the time of geologic deposition) and exists in gobular clusters of approximately 25 μm diameter throughout both coals and roof shales. Coarse grained pyrites of secondary origin were found to be very stable, suggesting a different crystalline structure from that of framboidal pyrite. Therefore, from Caruccio's work acid conditions are related to the occurrence of framboidal pyrite.

In addition to pyrites, the overburden may contain calcareous material which serves to neutralize the acidity produced. The ultimate pH of mine drainage depends upon the relative proportion of these in solution (6,24). While total carbonate alkalinity in solution in the spoil is fixed by calcite solubility and the partial pressure of carbon dioxide (p_{CO_2}) in filtrating waters, potential acidity from pyrite oxidation is unlimited. Thus, the pH of mine water is not only a function of the amount of carbonate and reactive pyrite, but also the amount of time pyrite is allowed to react between flushings of the spoil profile by percolation. This relationship has been demonstrated in laboratory studies by Geidel and Caruccio (24). Should the total acidity mobilized exceed the total alkalinity fixed by carbonate solubility, the drainage will be acidic. If alkalinity exceeds acidity, a neutral or basic drainage will result.

Although useful for general predictions of where acid problems will result from surface mining activity, the idea of a simple acid potential/neutralizing capacity balance is misleading and hides the complexity of reactions occurring in mining spoil (6,24). Work by Temple and Koehler (61) has shown that calcium and magnesium (presumably as carbonates) are present in stable pyrite nodules and absent in reactive ones. Washing the nodules with mild hydrochloric acid caused inert samples to become reactive suggesting that once acid conditions are formed in the spoil, pyrites may be leached of their protective carbonates and thus perpetuate acid producing reactions. A change from neutral to acid drainage with time due to this mechanism has been observed in laboratory weathering studies by Caruccio, Geidel, and Pelletier (6).

In the absence of calcareous materials, aluminum silicate minerals may control acidity by their reaction with carbon dioxide to produce alkalinity and clays. A general equation for this reaction is given (60):

$$\text{Cation Al silicate(s)} + CO_2 + H_2O = HCO_3^- + H_4SiO_4 + \text{Cation} + \text{Al silicate(s)} \qquad (2.5)$$

Note that in addition to alkalinity the incongruent weathering reaction releases cations and silicic acid. The presence of several aluminosilicate solid phases in the spoil can theoretically provide a near infinite pH buffer capacity. For example, the incongruent dissolution equilibria between anorthite and kaolinite,

$$CaAl_2Si_2O_8(s) + 2H^+ + H_2O = Al_2Si_2O_5(OH)_4\ (s) + Ca^{2+} \qquad (2.6)$$

has a buffer intensity many orders of magnitude greater than that of the carbonate system in equilibrium with atmospheric carbon dioxide at pH less than 8.0 (60). Similar, but weaker, incongruent equilibria exist for other clays such as Na-montmorillonite,

$$3Na_{0.33}\ Al_{2.33}\ Si_{3.67}O_{10}(OH)_2\ (s) + H^+ + 11\text{-}1/2\ H_2O = 3.5\ Al_2\ Si_2O_5(OH)_4\ (s) + 4H_4SiO_4 + Na^+ \qquad (2.7)$$

Ca - montmorillonite,

$$3Ca_{0.33}\ Al_{4.67}\ Si_{7.33}O_{20}(OH)_4\ (s) + 2H^+ + 23H_2O =$$

$$7Al_2Si_2O_5(OH)_4\ (s) + 8H_4SiO_4 + Ca^{2+} \qquad (2.9)$$

and illite (21,60),

$$10K_{0.6}\ Mg_{0.25}\ Al_{2.30}\ Si_{3.5}\ O_{10}(OH)_2(s) + 11H^+ + 10\text{-}1/2\ H_2O =$$

$$11\text{-}1/2\ Al_2\ Si_2\ O_5(OH)_4\ (s) + 12H_4SiO_4 + 6K^+ + 2\text{-}1/2\ Mg^+ \qquad (2.10)$$

It should be noted, however, that reaction of the solid phase silicates is slow compared to solid phase carbonate equilibria and ion exchange processes. The control of pH in the spoil is dependent upon the kinetics of these heterogeneous reactions (60). Unless the residence time of mobilized constituents is extremely long, thermodynamic equilibrium controls on pH in the mining spoil probably do not exist.

Ion exchange becomes important when the original overburden is composed of shales and mudstones. The associated clay materials can exchange interlayer and surface cations with cations, including H^+, mobilized within the spoil. This enhances the weathering of clay minerals and can neutralize mineral acidity (24). Trace metal concentrations may be greatly attenuated by cation exchange (21).

The type and distribution of acid producing materials and the depositional or paleoenvironment of coal seams has been correlated by researchers at the University of South Carolina. In a study of drainage quality from coal bearing strata in Eastern Kentucky, Caruccio, et al. (5), and Caruccio, Geidel, and Sewell (7) found acid mine drainage to be associated with marine and brackish water depositional environments. Neutral, highly buffered drainage was associated with fresh water coals. Although reactive pyrite was found in all the strata, the marine coals were found to contain the highest percentage. The neutral drainage of fresh water coals was attributed to an abundance of cementitious carbonate in their strata which marine shales generally lack. The drainage from transitional environments (i.e., between brackish and fresh water) was very dependent upon the amount of this calcareous material. In terms of geomorphology, lower delta plain and bay fill paleoenvironments generally produced acid forming coals. Upper delta plain and alluvial coals form neutral drainage upon mining. These relationships may serve as a rough guide for predicting drainage quality from a given coal seam if its geologic sequence is known.

CHAPTER III

BACKGROUND

Study Area Location

The study areas are part of the New River Basin, a 382 square mile (955 km^2) watershed shared by Anderson, Campbell, Morgan, and Scott Counties of East Tennessee. The community of Smokey Junction lies approximately at the center of the New River Basin and is located 19 miles (30 km) northwest of Oak Ridge, Tennessee, and 140 miles (224 km) east of Nashville.

The New River originates along the Tennessee Valley Divide in a drainage area abutting the eastern portion of the Frozen Head State Environmental Education Area. It flows northward 55 miles to its confluence with the Clear Fork River northwest of community of New River. There it forms the Big South Fork of the Cumberland River which continues north through the Big South Fork National Recreational Area into Kentucky.

Coal related research conducted by The University of Tennessee, Knoxville, has examined several subasins of the New River. The principle study areas for this thesis lie within the two smaller watersheds of Indian Fork and Bills Branch. The Indian Fork Study Basin is located in the southern portion of the New River Basin. Covering an area of 2765 acres (1119 ha), it drains east into the New River. The Bills Branch Study Basin lies 2 miles north of Indian Fork. It covers 429 acres (174 ha) and drains west into Smokey Creek which joins the New River at the community of Smokey Junction. Both Indian Fork and Bills Branch are located within the Fork Mountain Quadrangle of Tennessee, GM&MRS 129-NW. The location of the New River area within the state of Tennessee and locations of the two study basins within the larger watershed are presented in Figure 2.

Climate. The New River Basin is typical of the humid Appalachian region with moderate temperatures and a high annual rainfall. Thirty-three years of recorded temperature information (1948-1980) available from the National Oceanic and Atmospheric Administration for Oak Ridge, Tennessee, indicates a mean annual temperature of 57.6°F (14.2°C) for the area. The coldest month is usually January with a monthly mean of 37.3°F (2.9°C). However, the difference observed between the months of December, January, and February is comparatively small. July is usually the hottest month with an average temperature of 76.6°F (24.8°C). As with the winter months, June, July, and August show little difference with respect to mean monthly temperature. The record low temperature occurred in January, 1976 with -9°F (-22.8°C), and the record high was recorded in July, 1952 at 105°F (40°C). In general, temperatures below 0°F (-18°C) and above 100°F (38°C) are rare (69). While a good indicator of climatic conditions for the region, the Oak Ridge recording station is approximately 1500 ft (460 m) below the average elevation of the New River Study Area. As a result, winter and summer temperature extremes in the upper reaches of the New River Basin are more severe.

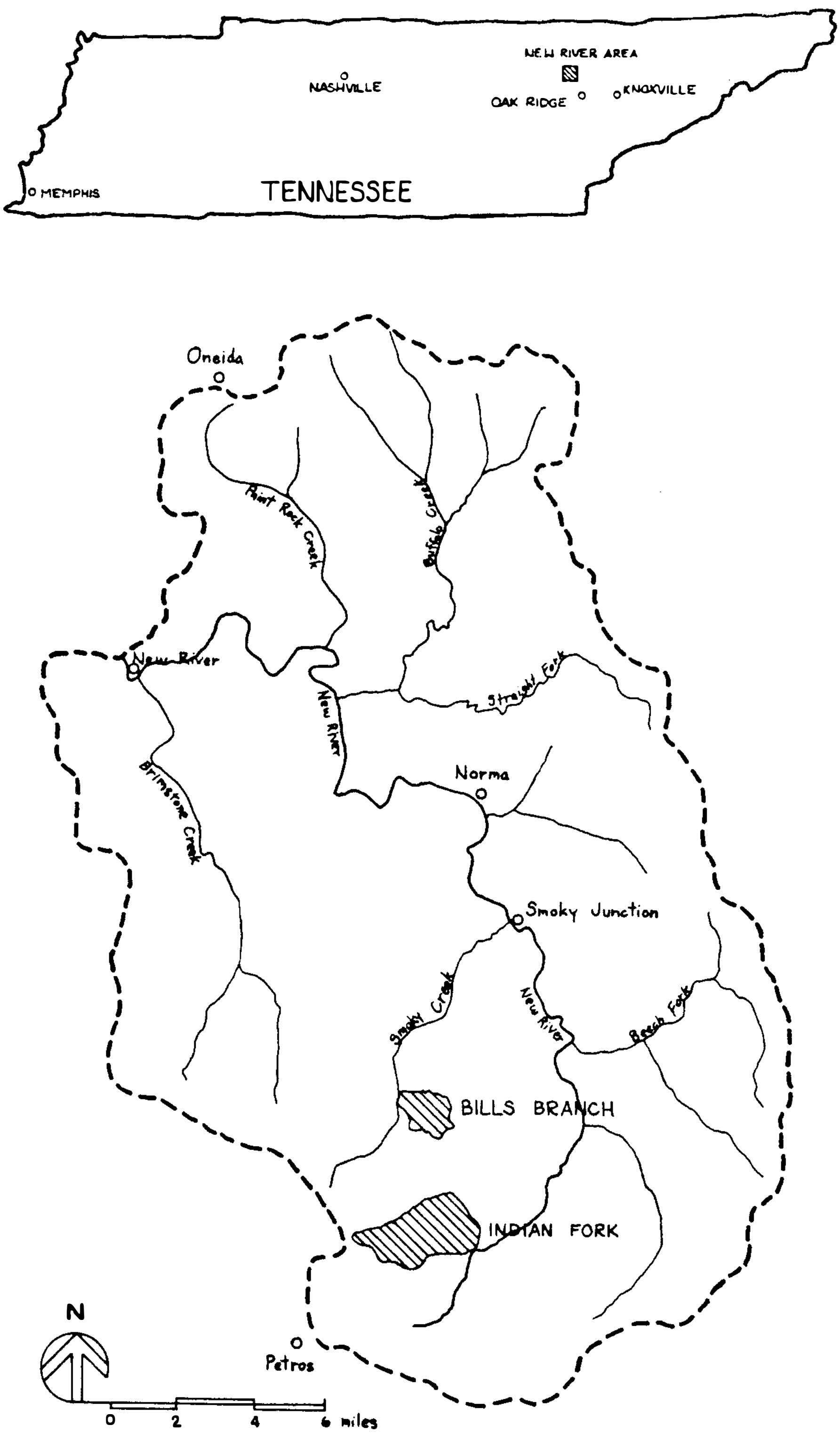


Figure 2. New River Basin, Location in Tennessee and Locations of the Bills Branch and Indian Fork Study Subbasins.

A 45-year record of rainfall (1935-1979) is available from a Tennessee Valley Authority recording station in Petros, Tennessee, which lies at the southern edge of the New River Basin. This record indicates a mean annual precipitation of 61.9 in (157 cm) with a recorded high of 87.2 in (221 cm) in 1973 and a low of 44.5 in (113 cm) in 1958 (62). Climatological data from Oak Ridge indicates winter and early spring are the seasons of heaviest precipitation with a monthly maximum occurring during the period of January to March. A secondary maximum occurs in July, due primarily to afternoon and evening thunderstorms. September and October are the driest months. However, periods of 10 days or more without measurable precipitation are reported to be rare (69). A somewhat incomplete record of daily rainfall covering the period of research activity is available for the Indian Fork and Bills Branch Study Basins. An annual summary of this information is presented in Table 3 along with comparative yearly values from Petros and Oak Ridge.

Light snowfall occurs in all months from November through March. A 10-year record of snowfall from Petros, Tennessee (1970-1979) indicates a yearly mean of 15 in (38 cm). The high year was 1978 with 29 in (74 cm), and 1976 the low year with 3 in (7.6 cm) (62). The research sites in the New River study area are approximately 1000 ft (300 m) higher than the Petros recording station and experience heavier snowfall and occasional severe icing conditions in the winter months.

The upper reaches of the New River Basin contain the highest mountains of the Cumberland Plateau. As a result, mountain tops are

Table 3. Annual Rainfall, New River Area, 1975-1979 (62,69) (values reported in inches)

Year	Recording Station			
	Indian Fork	Bills Branch	Petros	Oak Ridge
1975	65.64 (22 days-NR)	44.37 (71 days-NR)	67.50	60.68
1976	55.65 (5 days-NR)	49.63 (24 days-NR)	54.52	53.33
1977	- (138 days-NR)	- (102 days-NR)	70.15	62.77
1978	station discontinued in February 1978	40.59 (52 days-NR)	55.67	48.41
1979	-	56.26 (0 days-NR)	83.14	67.30
1980	-	- (119 days-NR)	46.72	40.12

"NR" indicates periods of "no record"

buffeted by strong westerly winds, especially during the winter months. Local weather conditions are strongly affected by topography with prevailing winds channelized along stream valleys (69).

Terrain. The New River Basin is characterized by rugged terrain with elevations from 1090 ft (332 m) to more than 3000 ft (1006 m) above mean sea level and an average slope of 13 percent. Elevation changes are more pronounced in the smaller watersheds. The Indian Fork Study Basin rises from 1400 ft (425 m) to an elevation of 3000 ft (1006 m) around its rim with an average slope of 38 percent. Bills Branch rises from 1500 ft (457 m) to 2900 ft (885 m) and also has an average slope of 38 percent.

Reflecting the humid climate and moderate temperature of the region, most of the New River Basin is heavily forested. Areas cleared by man revegetate naturally within several years where soil stability problems do not occur.

Land use. The mountainous New River Basin has always been rather sparsely populated. Settled in the early 19th century, it contains several isolated mountain communities. A depressed area, economic and social changes occurring since the 1940's have destroyed the independent identity of these communities, and the few that remain are dependent on outside areas for basic commodities and social services. The inhabitants of the basin are spread out along the valleys associated with the New River and its major tributaries. Homesteads in remote hollows have been abandoned. Most of the land in the New River Basin is owned by large land and mining companies.

Because of its rugged terrain and poor soil conditions, agriculture in the New River area has been limited to stream valleys and floodplains. Never extensive, much of the agricultural land in upper reaches of the basin has been abandoned in the past two decades. Family farms continue to operate near the mouth of the basin where the wider floodplain and gentler topography allow a greater chance for economic success. The New River Comprehensive Study, prepared for the Army Corps of Engineers and published in April, 1979, assigned 5.9 percent of the land in the New River Basin to agricultural use (68).

Historically, the economy of this section of the Cumberland Plateau has relied chiefly on its reserves of timber and coal. Aside from these, no other industries have been developed in the New River Basin. Serious efforts at oil and gas exploration have only recently begun.

Large scale timber harvesting occurred in the first three decades of this century and involved the entire New River Basin. An extensive rail system was built to support this and mining activities (25). The United States Forest Service in conjunction with the New River Comprehensive Study found that forest presently covers 88 percent of the basin's area. The predominant type is oak-hickory with small amounts of oak-pine and loblolly-shortleaf pine forest. All forested land is classified as commercial. Present logging operations are small, disturbing a relatively minor amount of the New River Basin at any one time. The Forest Service also found that due to poor management practices timber yields in the basin were only 62 percent of their potential (68).

Coal production is the primary industry in the New River Basin and has accounted for the majority of the coal produced in Tennessee (33). Large scale deep mining activity began around the turn of the century and has continued to the present (25,33). Beginning in 1944 contour strip and auger mining have become an increasingly employed method of coal production accounting for over 50 percent by 1973. Average annual production for this period was approximately 7.5 million tons (68). Surface coal production lagged during the mid-1970's due to uncertainties caused by the Federal Clean Air and Surface Mining Acts but has experienced a boom in the years since 1978 as permanent regulatory programs have come into effect and the increased price of coal has made it economical to remove greater amounts of overburden material. The Koppers Corporation, Southern Railroad and others have recently invested in improved transportation and coal handling facilities for the New River Basin. As a result, increased levels of production are expected to be maintained into the future.

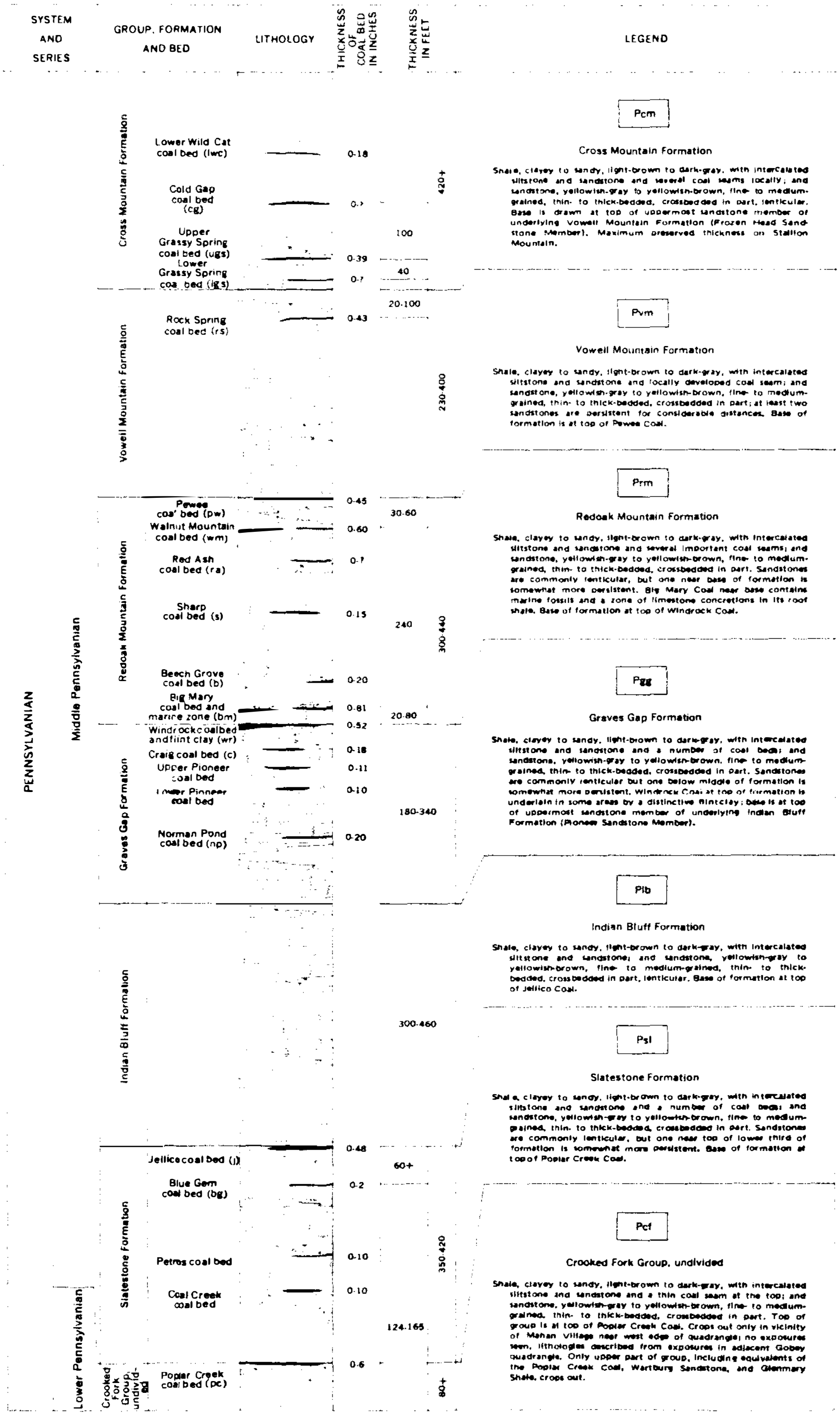
According to Tung (66), 12,000 acres or 5 percent of the total New River watershed had been affected by surface mining by the end of 1974. The 1979 New River Comprehensive Study put this figure at approximately 7 percent (68). This disturbance is expected to increase as coal production in the basin continues at its renewed pace.

Geology. The New River fluvial system drains the Northern Cumberland Plateau of East Tennessee and is contained in the Wartburg Basin, a physiographic subprovince of the plateau. The geology of this area has been described by Luther (36), Garman, Ferguson, and

Jones (23), Johnson and Luther (33), Milici (40), Milici, et al. (41), Rule and Briggs (54), and Briggs (2). The Cumberland Plateau, part of the Appalachian Mountain chain, is a broad, relatively flat-topped tableland that rises 1000 ft (300 m) or more above the Tennessee Valley on the east and the Nashville Basin on the west. It is capped with hard, resistant rocks of Pennsylvanian origin which protect the less resistant Mississippian carbonates that underline the region (33,36).

Rocks in the northern Cumberland Plateau are of middle Pennsylvanian age and have an aggregate thickness of more than 4000 ft (1400 m). The lower units of this sequence contain a predominance of thick sandstone layers with small amounts of coal. The upper units contain numerous coal seams with an increasing abundance of shale relative to the thickness of sandstone. Thin and sporadic beds of limestone are present in the overall sequence but compose a minor percentage of the whole (36). Most mining disturbance occurs in the upper Pennsylvanian units, particularly in the Redoak Mountain, Vowell Mountain, and Cross Mountain formations. Figure 3 is a cross section of the Pennsylvanian lithology exposed in the Fork Mountain Quadrangle of Tennessee (23).

Fern (19) hypothesized that Pennsylvanian sediments in the Appalachian region were deposited in a huge deltaic complex. Milici stated that the Pennsylvanian strata in Tennessee show a gradual transition upward from barrier island, tidal inlet, and lagoon deposits to channel, levee, crevasse splay, and interdistributary



Cross Mountain Formation

Shale, clayey to sandy, light-brown to dark-gray, with intercalated siltstone and sandstone and several coal seams locally; and sandstone, yellowish-gray to yellowish-brown, fine- to medium-grained, thin- to thick-bedded, crossbedded in part, lenticular. Base is drawn at top of uppermost sandstone member of underlying Vowell Mountain Formation (Frozen Head Sandstone Member). Maximum preserved thickness on Stallion Mountain.

Vowell Mountain Formation

Shale, clayey to sandy, light-brown to dark-gray, with intercalated siltstone and sandstone and locally developed coal seam; and sandstone, yellowish-gray to yellowish-brown, fine- to medium-grained, thin- to thick-bedded, crossbedded in part; at least two sandstones are persistent for considerable distances. Base of formation is at top of Pewee Coal.

Redoak Mountain Formation

Shale, clayey to sandy, light-brown to dark-gray, with intercalated siltstone and sandstone and several important coal seams; and sandstone, yellowish-gray to yellowish-brown, fine- to medium-grained, thin- to thick-bedded, crossbedded in part. Sandstones are commonly lenticular, but one near base of formation is somewhat more persistent. Big Mary Coal near base contains marine fossils and a zone of limestone concretions in its roof shale. Base of formation at top of Windrock Coal.

Graves Gap Formation

Shale, clayey to sandy, light-brown to dark-gray, with intercalated siltstone and sandstone and a number of coal beds; and sandstone, yellowish-gray to yellowish-brown, fine- to medium-grained, thin- to thick-bedded, crossbedded in part. Sandstones are commonly lenticular but one below middle of formation is somewhat more persistent. Windrock Coal at top of formation is underlain in some areas by a distinctive flintclay; base is at top of uppermost sandstone member of underlying Indian Bluff Formation (Pioneer Sandstone Member).

Indian Bluff Formation

Shale, clayey to sandy, light-brown to dark-gray, with intercalated siltstone and sandstone; and sandstone, yellowish-gray to yellowish-brown, fine- to medium-grained, thin- to thick-bedded, crossbedded in part, lenticular. Base of formation at top of Jellico Coal.

Slatestone Formation

Shale, clayey to sandy, light-brown to dark-gray, with intercalated siltstone and sandstone and a number of coal beds; and sandstone, yellowish-gray to yellowish-brown, fine- to medium-grained, thin- to thick-bedded, crossbedded in part. Sandstones are commonly lenticular, but one near top of lower third of formation is somewhat more persistent. Base of formation at top of Poplar Creek Coal.

Crooked Fork Group, undivided

Shale, clayey to sandy, light-brown to dark-gray, with intercalated siltstone and sandstone and a thin coal seam at the top; and sandstone, yellowish-gray to yellowish-brown, fine- to medium-grained, thin- to thick-bedded, crossbedded in part. Top of group is at top of Poplar Creek Coal. Crops out only in vicinity of Mahan Village near west edge of quadrangle; no exposures seen, lithologies described from exposures in adjacent Gobey quadrangle. Only upper part of group, including equivalents of the Poplar Creek Coal, Wartburg Sandstone, and Glenmary Shale, crops out.

Figure 3. Geologic Cross Section for the Fork Mountain Quadrangle, Tennessee GM 129-NW (23).

deposits indicative of an advancing shoreline and delta (40). Rule and Briggs, and Briggs have examined the depositional history of a 1000 ft (300 m) sequence of middle Pennsylvanian strata that includes the Redoak, Vowell, and Cross Mountain formations. This work involved the geologic mapping of highwalls exposed by mining operations in the Indian Fork and Bills Branch subbasins of the New River. The resulting columnar section is shown in Figure 4 (41). Their work supports the characterizations of Fern and Milici and cites the origin of the sedimentary strata within the New River Basin as the depositional environment of an ancient prograding river delta (2,41,54).

The sequence examined by Rule and Briggs, and Briggs records at least seven major cycles of delta growth and destruction. The overall sequence shows the transition from a lower delta plain to an upper delta plain depositional environment. Each cycle commonly begins as a dark gray marine shale resulting from the incursion of marine waters into the delta and grades upward into coarser sediments that include levee, splay and channel deposits characteristic of delta expansion toward the sea. Capping each cycle is a coal deposit whose swamp origin identifies the conclusion of delta growth and the imminence of another marine incursion. In the upper delta plain environment the incursion would be the formation of a freshwater lake or sea (2,54).

Within the examined sequence are a dozen or more minable coal seams. The major seams of economic interest in the region for mining are the Big Mary and Pewee coals at approximately 2250 ft (686 m) and 2650 ft (808 m), respectively. Also mined to a lesser extent are

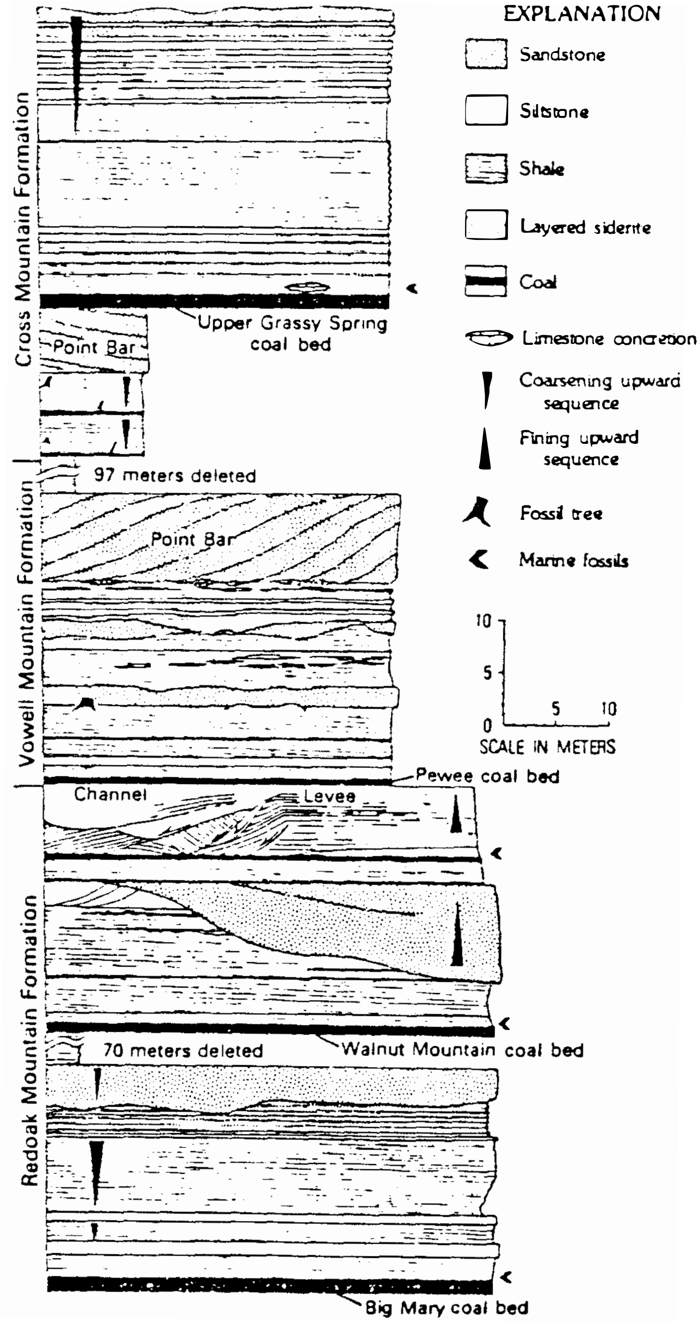


Figure 4. Columnar Section Resulting from Highwall Mapping in the Bills Branch and Indian Fork Study Basins (2).

the Walnut Mountain and Grassy Springs coals at approximately 2570 ft (784 m) and 3000 ft (915 m). However, these coals, and to a greater extent the remaining seams in the sequence, are often discontinuous and vary more in thickness than the Big Mary and Pewee coals (2).

Luther estimated in 1959 that there were 101,274,000 short tons of recoverable reserves in the Big Mary coal (36). The seam varies in thickness from 1-8.5 ft (0.30-2.59 m), including splits by shale partings and beds that generally range from 0.17-4 ft (0.95-1.2 m) (41). The seam has been extensively surface mined, augured and deep mined throughout the region. The mined product is considered a low-grade steam coal because of its relatively high sulfur and ash content (33,36,41).

The Pewee coal lies approximately 380-400 ft (116-122 m) above the Big Mary. Luther estimated recoverable reserves of Pewee coal at 32,934,000 short tons in 1959 (36). Seam thickness ranges from (1-7 ft) (0.3-2.1 m) including partings of 0.17-2.5 ft (5-76 cm) (41). Like the Big Mary coal, the Pewee bed has been extensively surface mined, augured and deep mined in Tennessee. The Pewee is a high-grade steam coal with a low to moderate sulfur content (33,36, 41).

The rock units above the Big Mary coal are fairly homogeneous both vertically and laterally. Overlying the coal is 10-15 ft (3.0-4.6 m) of medium to dark gray, carbonaceous, marine shales. This and the broad areal extent of the Big Mary coal within the Wartburg Basin testify to the abandonment and wide-spread inundation of an ancient delta plain. Within the marine unit and immediately above the coal is a 3-4 in (10-15 cm) layer of calcareous mudstone characterized by a concentration of pyritized fossil material. Commonly referred to as "roof shale" this unit is highly reduced and friable. Above the roof shale are gray, chunky mudstones whose fossil content decreases upward as the silt content increases. Thin, persistent layers of siderite ($FeCO_3$) are found throughout the unit alternating between layers of the gray, silty shales (2,20,34,72).

Above the lower 10-15 ft (3.0-4.6 m) fossil remains virtually disappear, and siderite layers begin to segment into disk-shaped nodules as the sequence in which they are enclosed coarsens and becomes less marine. At 20-30 ft (6.1-9.2 m) above the coal horizon are sometimes found large, dense, lens-shaped concretions of siderite and limestone. Known to miners as "flying saucers" these have been found up to 8.0 ft (2.5 m) in diameter and 3 ft (1 m) in width. Also present within this sequence are tabular, clayey siltstone beds interpreted as representing advancing delta deposits (2,20,41,72).

At about 70 ft (21 m) a thin zone of dark gray, carbonaceous shale is found, representative of a transition in depositional environments. A major sandstone body overlies this shale, beginning with the deposition of the fine-grained sands of overbank channels and grading into coarser materials marking the reestablishment of deltaic conditions (20,72).

The Walnut Mountain coal seam and its overlying units are from an interdistributary bay area. Some marine fossils are found and channels are quite common. Siderite beds are also present (72).

The Pewee and Walnut Mountain seams were not mined in the Bills Branch basin. At Indian Fork the coal is split into two beds roughly 30 ft (9 m) apart and identified as the lower Pewee and upper Pewee coals. The lower Pewee coal is enclosed by rooted mudstones. A carbonaceous unit immediately overlies the coal and is composed of fine-grained, brackish and terrigeneous clastics deposited in the reducing environment of an ancient swamp. Mudstones generally enclose the upper Pewee coal as well, except in areas where a sandstone cap was deposited (20,72).

The sequence overlying the Pewee coals is not as uniform as that above the Big Mary seam. Contained in the lithology are sandstones, siltstone, rooted mudstones, shaley mudstones, shale, conglomerates, several small coal seams, and siderite nodules. These change abruptly in both the horizontal and vertical planes as a function of changing depositional environments (20,72). Within this interval is an abundance of fossilized trees preserved in the growth position on levees and in interdistributary areas (41). This is interpreted as evidence of a fresh water swamp and a middle to upper delta plain depositional environment (2).

Surface Mining Practice and Reclamation

Contour strip mining is the prevalent surface mining practice in the mountainous New River Basin. The method consists of removing overburden above the coal seam in successive cuts along the mineral outcrop perpendicular to the slope of the mountainside. The mining cut appears as a contour line, thus, the name. Originally, the overburden material, or spoil, was simply cast down the mountainside below the mining cut. Diagrams of cast overburden mining practice are shown in Figures 5 and 6.

Modern mining practice involves engineered placement of the spoil back along the shelf, or bench, created by the mining cut after removal of the coal. The depth of the cut into the mountainside is a function of slope, overburden thickness, the physical properties of the overburden, and economic value of the recovered coal. Where coal beds are horizontal or negative to the slope of the mountain, overburden thickness increases rapidly with each successive cut (26). On the steep mountain slopes of the New River Basin, bench widths seldom exceed 500 ft (150 m) and the practical limit on overburden removal ranges 100-200 ft (30-60 m). Contour mining disturbance on a given coal seam may extend unbroken for miles.

The old mining practice of cast overburden caused massive erosional and landslide problems. These have led to improved mining practice and stricter legal requirements for the surface mining industry. Most of these changes occurred in the past decade culminating with the Federal Surface Mining Control and Reclamation Act of 1977. A historical outline of Federal and state laws and regulations governing surface mining in the New River Basin is given in Table 4.

Reclamation refers primarily to the final configuration of the spoil after mining. Reestablishment of vegetation, sediment control, and slope stability are other components. Legal requirements for reclamation have in large part dictated mining techniques employed in

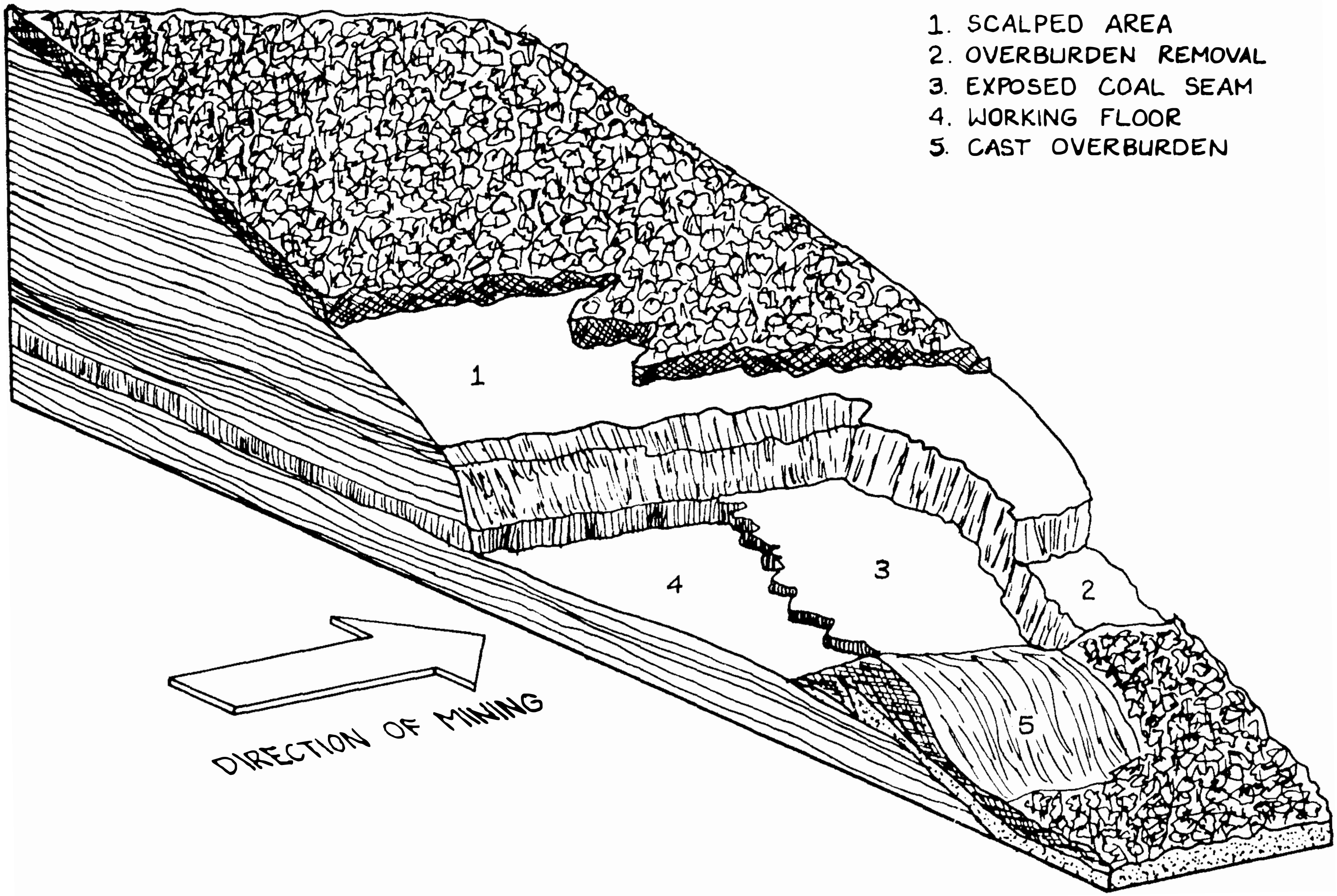


Figure 5. Contour Surface Mining with Cast Overburden.

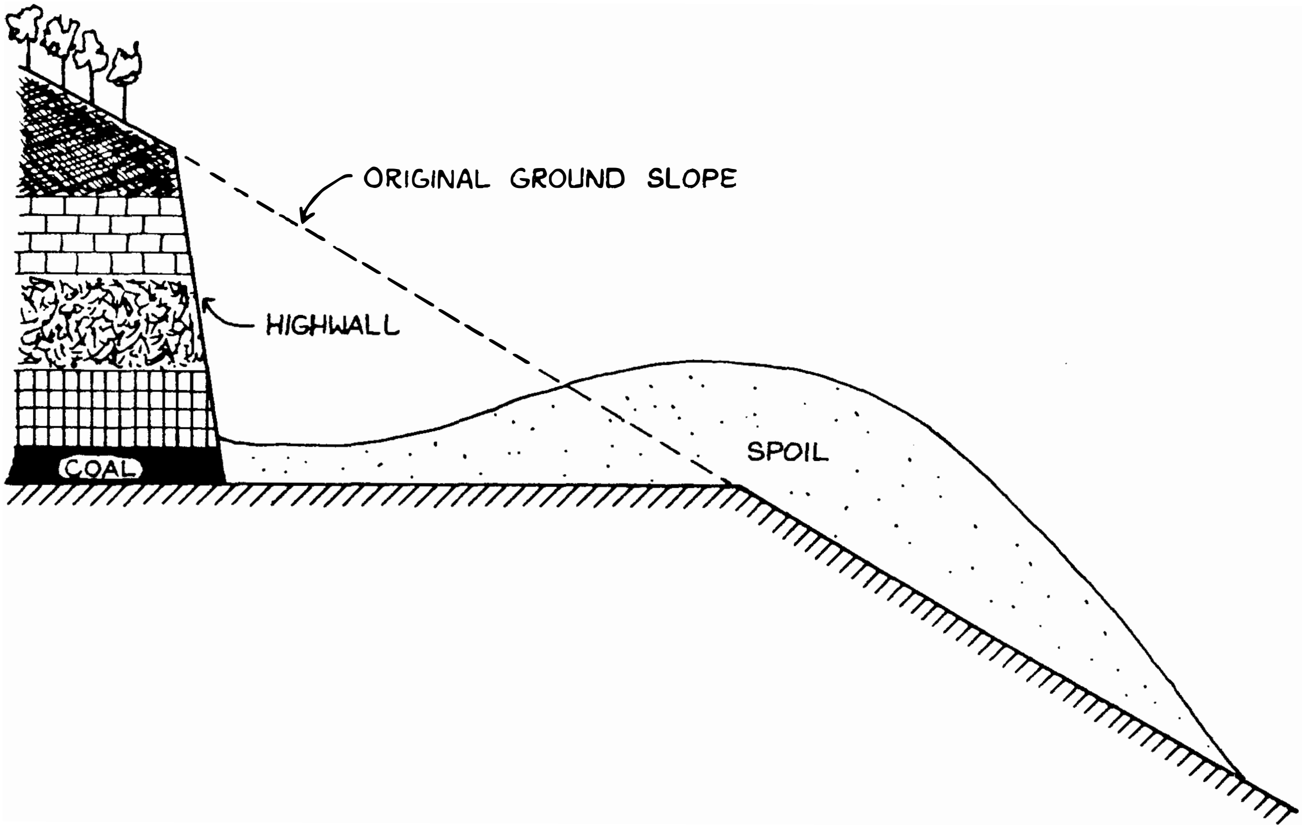


Figure 6. Cast Overburden, Profile.

Table 4. Historical Outline of Federal and State Laws and Regulations Governing Surface Mining in the New River Basin

Law	Regulation Major Impacts and Clauses
No law prior to Sept., 1967.	No State or Federal strip mine control prior to September, 1967.
September, 1967 - Tennessee Strip Mine Law of 1967. First State provision for strip mine regulation and control, permits, reclamation, enforcement.[1]	September, 1967, Regulations Pertaining to Surface Mining; General regulation of complete backfill cover against highwall: placement and grading of spoil banks and overburden to to favor revegetation; drainage ditches; erosion and sediment control structures; revegetation program; broad time-period constraints; $400/acre bond required.
March, 1972 - The Tennessee Surface Mining Law, Amendments to 1967 Law, established the Division of Surface Mining within the Dept of Conservation	March, 1973, Regulations Pertaining to Surface Mining; More specific regulation criteria; water quality discharge permit application required; major mining constraint on >28° slopes; drainage ditch and culvert criteria; toxic materials segregation; maximum solid bench width/slope below coal outcrop criteria 35° maximum spoilbank slope; 30 foot maximum highwall exposure; 10 foot minimum fill above coal seam; grasses and trees revegetation required; general limitation on head-of-hollow mining; $600/acre bond requirement; enforcement and civil penalty provisions.
March, 1972 - Federal Water Pollution Control Act and Ammendments, increased the scope and authority of the Federal Government over pollutant discharges.	May, 1973, National Pollutant Discharge Elimination System: Rules and Regulations; NPDES permits required for all point sources discharging into navigable waters; established funding for mine water pollution control demonstration projects thorugh the Appalachian Regional Commission May, 1976 - EPA, Coal Mining Effluing Guidelines and Standards. Established Federal effluent limitations standards for coal handling, storage, and mining operations.

Table 4. (Continued)

Law	Regulation Major Impacts and Clauses
March, 1974 - The Tennessee Surface Mining Law, Amendments providing for more specific regulation and control to minimize injurious environmental surface mining effects.	June, 1974, Regulations Pertaining to Surface Mining; More specific regulation criteria and rules; newspaper notice of permit application required; water quality discharge permit required prior to mining application; prospecting permit required; specific rules on access roads plans; 28° slope limitation on mining; 125-foot downslope spoil limit below cropline for slopes <28°; 20-foot maximum highwall exposure before July 1, 1975 - no highwall after July 1, 1975 on new cuts; landslide prevention rules; no mining within 25 feet of wet weather drainage centerlines; no mining within 100 feet of flowing stream centerlines; $1000/acre bond requirement; enforcement and civil penalty provisions.
	December, 1975, Addendum to Regulations Pertaining to Surface Mining; Adoption of drainage control handbook for controlling mine and haul road water runoff and sediment; major revegetation changes, including agricultural lime rates, mulch requirements, and seeding rates.
	July, 1976, Addendum to Regulations Pertaining to Surface Mining; 50-foot downslope spoil limit for slopes <28°; brush clearance area disturbance and barrier below spoil--not to exceed 125-foot downslope from cropline; 30° maximum spoil bank slope, 100-foot distance limitation.
August, 1977 - Federal Surface Mining Controll and Reclamation Act of 1977, established a nationwide regulatory program and set of performance standards to control the environ mental impacts of surface	December, 1977. Interim Regulatory Program, Surface Mining Reclamation and Enforcement Provisions; General regulation requiring back-to-approximate-original contour placement of spoil; special steep slope performance standards requiring complete elimination of highwalls, backfill to approximate-original contour, and prohibiting downslope placement of spoil; requirements for the segregation of toxic materials, storage of

Table 4. (Continued)

Law	Regulation Major Impacts and Clauses
and deep mining; created the Federal Office of Surface Mining within the Department of the Interior; provides for state primacy when state laws and regulations parallel the provisions in the federal Act.[2]	top soil, drainage structures, erosion and sediment control structures; requirement for public notice of permit applications; detailed mining and reclamation plans required prior to permitting; special requirements on post mining land use; special provisions for prime farmlands, background and compliance water quality monitoring; mining prohibited within 100 feet of stream beds, roads and public facilities; special blasting rules; revegetation provisions requiring native species; performance standards for the surface effects of deep mining; provisions for enforcement, administration review and civil penalties.
	March, 1979, Permanent Regulatory Program, Office of Surface Mining Reclamation and Enforcement; Permanently established provisions of the interium program; clarifies variances to performance standards based on post mining land use; more detailed permitting requirements including hydrologic impact studies and core sampling logs.
May, 1980, Tennessee Coal Surface Mining Law of 1980. State law parallel with the Federal Surface Mining Control and Reclamation Act of 1977 in order to achieve state primancy over surface mining activities; applied to all operations removing greater than 25 tons and any disturbance for the purpose of coal exploration.	August, 1981, Proposed Regulations Pertaining to Surface Mining; Modification of previous regulations to parallel Federal requirements; $1500/acre performance bond with a minimum required bond of $10,000; enforcement and civil penalty provisions

Table 4. (Continued)

NOTES:

1. Due to a lack of adequate funds, enforcement of the 1967 Tennessee Strip Mining Law was minimal.

2. Although the Federal Surface Mining Act went into effect in February, 1978, the State of Tennessee continued to operate under its 1974 law. The State Division of Surface Mining, under cooperative agreements with the Federal Office of Surface Mining, has shared responsibility for enforcing provisions of the Federal law, including inspections, since 1978. The 1980 Tennessee Surface Mining Law established the legal framework for state to resume full enforcement responsibility, and upon approval of the 1981 Proposed Regulations by the Office of Surface Mining, Tennessee will receive primacy for the regulation of surface mining.

the New River Basin. Four reclamation practices are pertinent to this thesis.

Figure 7 illustrates swale backfill. This type of spoil placement was developed by the mining industry in the early 1970's to reduce peak storm runoff by diverting and storing water along the mining bench. Excess spoil is graded on the downslope to reduce erosion. Trees and boulders are placed at the toe in a windrow to provide stability and capture sediment. A small blossom of undisturbed rock is left on the outside edge of the mining cut to also improve stability. This detail, however, was often omitted in New River mining practice. Diverted runoff is channeled along the bench to stabilized outlet structures which conduct it down the spoil below the mining disturbance. The entire spoil is revegetated after backfill and grading (26,66).

Beginning in 1974, height limitations on the exposed highwall were enforced in Tennessee, and a reclamation practice locally known as pasture backfill became employed. In this practice, spoil placed back in the mining pit is graded into a gentle incline across the bench to the highwall. The downslope discharge of spoil below the bench was to be limited to 125 ft (38 m). A diagram of typical pasture backfill is shown in Figure 8.

After July, 1975 complete elimination of the highwall was required in Tennessee. A terraced backfill similar to the previous pasture backfill was employed with spoil placed completely against the highwall on the back of the bench. The Federal Surface Mining Control and Reclamation Act of 1977 presently requires back-to-

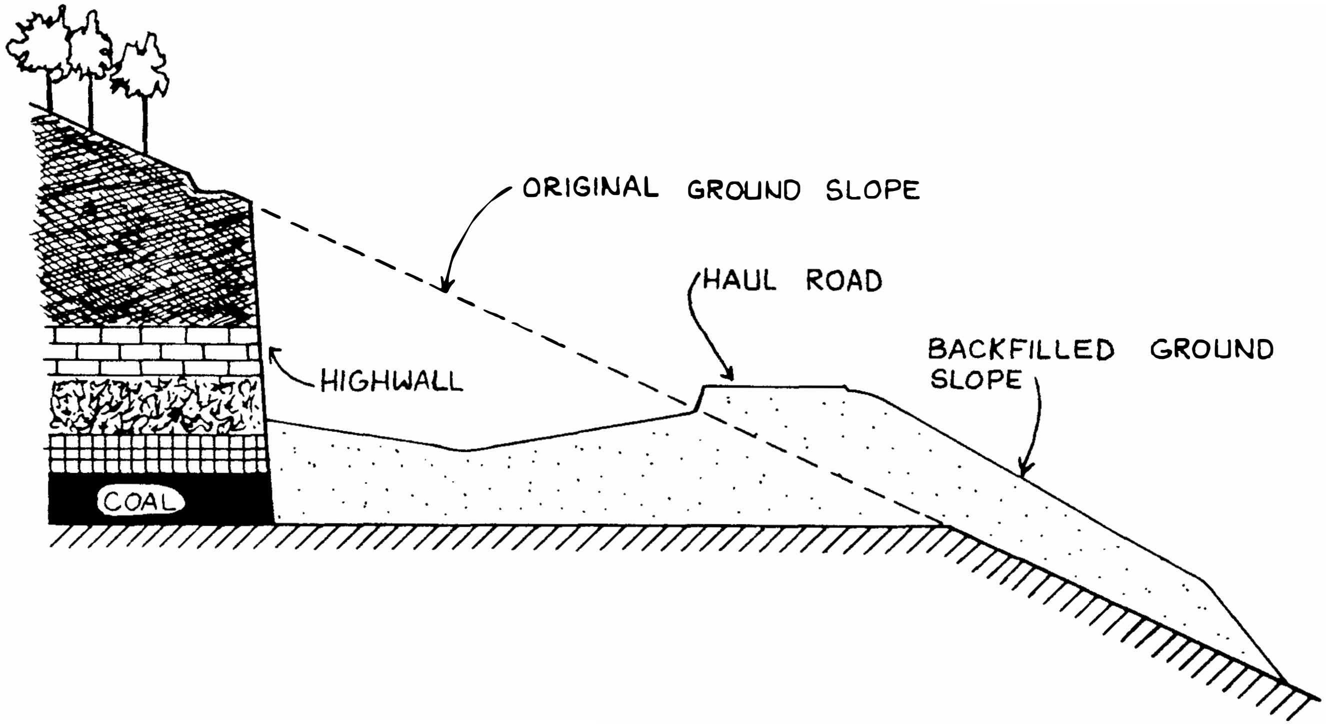


Figure 7. Swale Backfill as Practiced in the New River Basin, Circa 1970-1974.

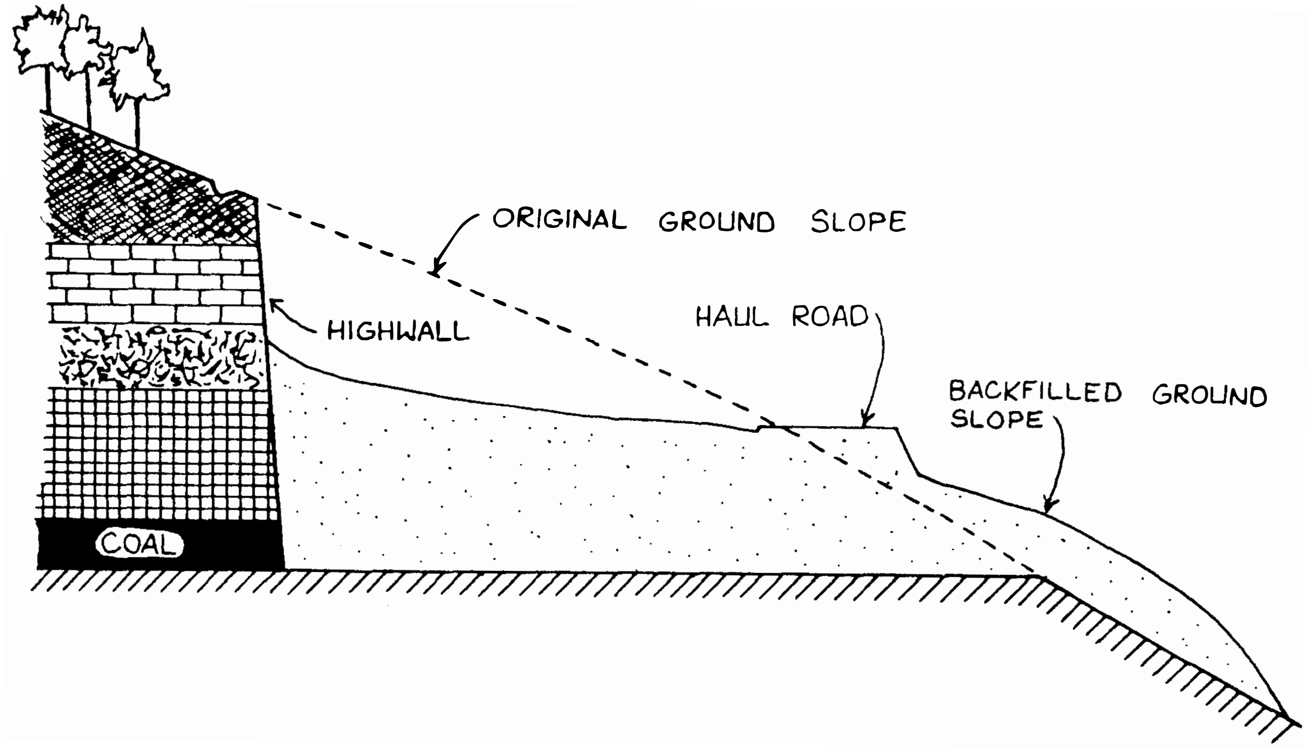


Figure 8. Pasture Backfill as Practiced Under 1974 Tennessee Surface Mining Regulation.

approximate-original-contour placement of the spoil and prohibits downslope discharge of material below the mining cut. Back-to-approximate-original-contour fill as practiced in steep slope mining is shown in Figure 9. Excess spoil is placed in an engineered head of hollow fill.

The spoil banks examined in this thesis represent swale, pasture, and to a small extent terraced backfill. Since the study sites to be introduced in the next chapter were established in the mid-1970's, before the Federal Surface Mining Act, the present reclamation practice of back-to-approximate-original-contour was not directly examined.

Previous New River Work

As noted in the introduction, investigation of the mining spoil is part of a larger project examining the environmental aspects of surface mining in the New River Basin of Tennessee. Several of the investigations already completed are related to this thesis. Most important are the hydrologic modeling of the spoil bank by Turnmire (67), and Crosby, Overton, and Minear (12); the geochemical characterizations of the highwall by Franks (20), Thompson (63), and Thompson and Rule (64); and the examination of stream sediments by Upham (72), Ketelle (34), and Rule and Briggs (54). In addition to these was a small investigation of spoil bank mineralogy by Rose (52).

Turnmire examined the subsurface flow regime of the ponded spoil bank. His work involved the development of a two-dimensional mathematical model to describe this flow and predict variations in the

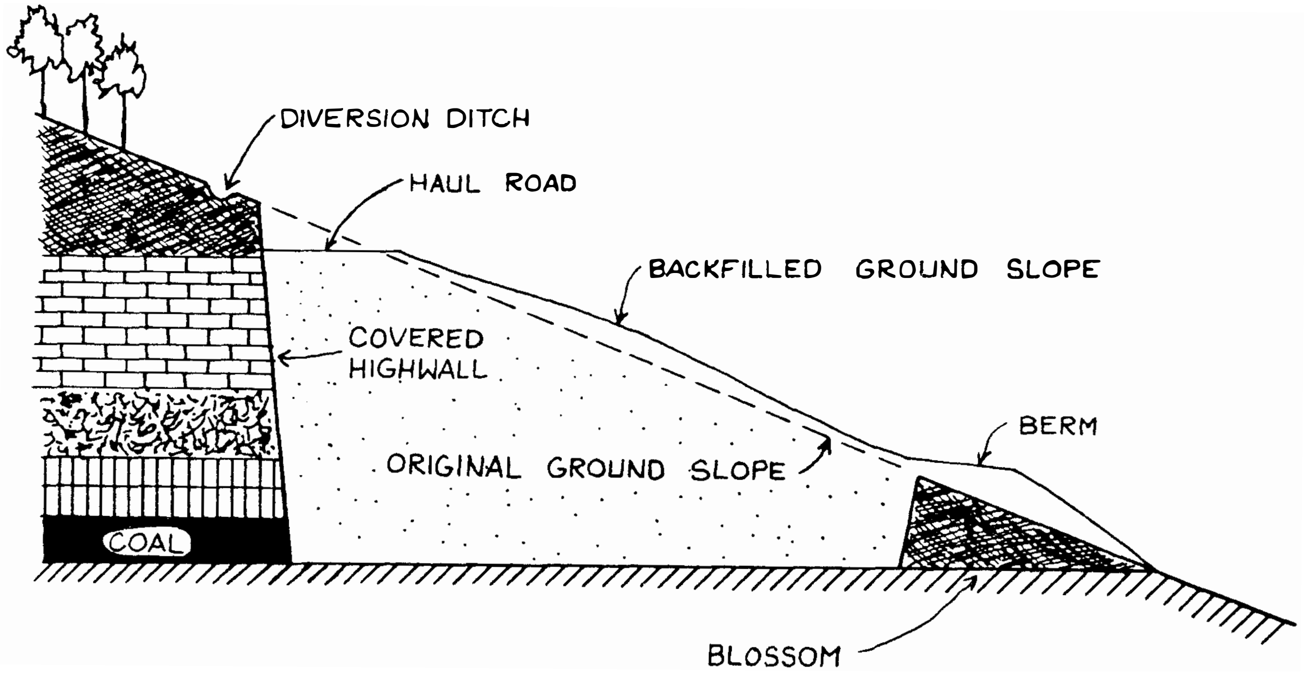


Figure 9. Back-to-Approximate-Original-Contour Backfill as Required by the 1977 Federal Surface Mining Control and Reclamation Act.

phreatic surface with respect to time and non-uniform recharge. The model also provided a calculation of discharge from the spoil groundwater system based on the predicted free surface. Turnmire tested his model against field data taken from a set of galvanized wells at the Indian Fork Study Spoil Bank (see Field Sites, Chapter IV). An approximate fit was obtained between the predicted phreatic surface and observed well elevations (67).

Crosby, Overton, and Minear examined a mathematical simulation of the ponded Indian Fork Study Spoil Bank. Their hydrologic model was conceptually deterministic with theoretical coefficients calculated from assumed baseline conditions observed in the system of wells. Verification of the model against other than baseline conditions was not performed. The simulation model divided the spoil into a saturated zone overlying an impermeable layer and an unsaturated zone above the phreatic surface. Flow perpendicular to the slope was not considered. The spoil material was considered to be homogeneous and isotropic with a porosity of 0.35 (12). Major conclusions drawn from this work were as follows:

1. Recharge to the saturated zone is primarily attributable to the pond.
2. Travel time through the saturated zone from the pond to the toe of the spoil bank is approximately two years.
3. Travel time of infiltrated water (percolation) through the unsaturated zone to the saturated zone is approximately six years at field capacity, assuming vertical percolation.

Crosby, Overton, and Minear applied the results from the simulation of the ponded spoil to the non-ponded spoil bank. Citing steepness and bareness of the spoil (which produces a high runoff potential and little infiltration), a high potential for evapotranspiration, and an apparently long time for percolation, it was considered unlikely that a saturated zone would form in the spoil bank from percolation in the absence of a recharge pond. Thus, surface runoff was concluded to be the primary transport mechanism for pollutants from the non-ponded spoil bank (12).

Associated with the geologic mapping of Rule and Briggs (54), and Briggs (2) described earlier were studies conducted by Franks, Thompson, and Thompson and Rule to characterize the heavy metal content of strata overlying the Big Mary and Pewee coals. The metals Ag, Ca, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were examined. Attempts to associate particular trace metals to distinct overburden layers and thus to depositional environment were ultimately inconclusive. However, a general correlation between metal concentrations and grain size was found. Roof shales consisting of small grained mudstones immediately overlying the coals contain the highest metal concentrations. Metal content was found to decrease as grain size increased in the depositional sequence, i.e., roof shales, shales and mudstones, silty-shales, siltstones and sandstone. Manganese was an exception as its concentration increased with grain size (20,63,64). Table 5 was derived from Frank's data and presents average metal concentrations found in strata associated with the major coal seams of the New River Basin.

Thompson's work included static leaching tests of samples from coal, roof shales, shales, silty shales, siltstones, and sandstones.

Table 5. Summary of Frank's Data of Heavy Metal Content in Strata Associated with the Big Mary and Pewee Coals (20)

	Fe % total	Mn ppm	As ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm
<u>Lower Delta Plain</u>										
Big Mary Coal	0.4	46	7.2	<0.5	4.0	78	12	172	17	10
Mudstones & Shales	3.7	563	50	3.3	40	242	28	86	36	121
Sandstones & Siltstones	2.0	1094	16	2.2	14	104	7.3	46	12	154
<u>Upper Delta Plain</u>										
Walnut Mountain Coal	0.2	10	3.6	1.3	8.8	140	16	375	28	21
Lower Pewee Coal	0.2	80	3.9	3.2	11	106	25	223	50	66
Upper Pewee Coal	0.1	6.1	5.2	1.4	8.2	52	16	128	22	11
Mudstones & Shales	2.6	366	43	3.1	36	218	2.6	111	39	140
Sandstones & Siltstones	1.5	522	18	1.8	11	9.4	42	25	25	59

As with Franks' work, these samples were taken from highwalls exposed in the Indian Fork and Bills Branch Study Basins. Coals and roof shales were reported to generate the lowest pH values (3.1-4.9) and to release the highest percentage of their total metals, of which iron, manganese, and calcium were predominant. While lechate concentrations were highest in iron, a relatively low percentage of the total iron in the rock was released. Thompson used this as evidence to conclude reactive framboidal pyrite is a small percentage of total pyrite and other iron compounds in the mine overburden. The larger-grained shales, silty-shales, siltstones, and sandstones generated near neutral pH's and released only calcium and manganese in measurable amounts (63,64). Since the coals and roof shales compose a small percentage of the highwall exposed by surface mining, Thompson and Rule concluded their acidity will be neutralized when placed with the overburden in the spoil bank (64). Thompson noted that many of the shales and siltstones fiz when contacted with acid solution and cited this as evidence of $CaCO_3$ cementation (63). However, no direct evidence of a substantial carbonate presence other than siderite was found in geochemical characterizations of the highwall (20,63,64).

Upham and Ketelle investigated trace metals in sediments transported from the mining site in Indian Fork, Bills Branch and two other basins. They found trends similar to that of Franks, Thompson, and Thompson and Rule. With the exception of manganese, trace metal content was found to decrease with increasing particle size (34,54,72). Ketelle's work included an examination of extractable metal oxides and found that hydrous oxide forms comprised a significant volume of the sediment load (34). Mineral analysis with X-ray diffraction was also performed on the sediments. Quartz, illite, kaolinite, and vermiculite were identified with quartz dominating the larger size fractions (greater than 5 microns) and the clays dominating the smaller fractions. Minor amounts of geothite, chlorite, anglesite, and montmorillonite were identified in the small sediment particles. No significant variation in crystalline mineral content was found in streams draining areas of different mining and reclamation histories (34,54).

The investigations of the highwall and of disturbed stream sediment suggest that the fine-grained rock types concentrate heavy metals by sorption into their clay mineral matrix. Larger grained rocks hold metals within precipitated layers of hydrous Fe and Mn oxides on the surface of the grains. The greater exposed surface area of the small grained minerals provides a large potential for concentrating metals as indicated by the high metal concentrations found in the roof shales (34,54,64).

Rose has conducted a small investigation of spoil bank mineralogy as part of research examining chemical equilibrium in the mine spoil. The purpose of this work was to verify the existence of secondarily precipitated mineral solids predicted by chemical modeling. To this end, solids were extracted from wells at the Indian Fork and Bills Branch Study Spoil Banks (see Field Sites, Chapter IV) and subjected to analysis by X-ray diffraction. The results were inconclusive but do provide qualitative information on the mineral composition of the spoil at both banks. Crystalline solids identified were primarily quartz, kaolinite, and illites. Examination for the carbonates of iron, manganese, calcium and magnesium revealed possible evidence only of siderite, the iron carbonate (52).

The previous New River work outlined above provides a useful perspective for the work that is to follow. From their hydrologic modeling, Crosby, Overton, and Minear (12) conclude the percolation of infiltrated waters through the spoil is slow and that a saturated zone is unlikely to form in a non-ponded spoil bank. Frank's results indicate the overburden associated with the Big Mary coal has a higher iron and manganese content than that of the upper delta plain Walnut Mountain and Pewee seams (20). Other trace metal concentrations in the strata were found to be similar. These relationships may be repeated in the subsurface water quality found at the two study spoil banks. The geologic mapping of Rule and Briggs (54), and Briggs (2) assigned a lower delta plain, marine depositional environment to the Big Mary coal. This suggests its drainage should be acidic. However, the leaching studies of Thompson (63), and Thompson and Rule (64) indicate drainage from mining on both the Big Mary and Pewee coals will be of neutral pH. Failure to positively identify carbonates other than siderite in the highwall strata suggest alkalinity in the spoil may be generated from other sources such as the aluminosilicate minerals. The X-ray diffraction work by Uphman (72), Ketelle (34), and Rose (52) characterize the spoil material as a mixture of sand (quartz) and clays (predominately illite and kaolinite), the presence of the latter insuring a complex weathering chemistry.

CHAPTER IV

EXPERIMENTAL DESIGN

Field Sites

Two study sites were chosen for the spoil bank investigation, a ponded site on the upper bench and northern side of the Indian Fork Study Basin and a non-ponded site on the southwestern edge of the Bills Branch Study Basin. These basins and the location of the study spoil banks are presented in Figures 10 and 11. Areas of mining disturbance are outlined, and the location of stream gaging stations, observation wells, undisturbed seepage sampling points, and permanent bench ponds noted. These additional items will be discussed later in the text.

The two study spoil banks represent different reclamation practices and mining on different coal seams. At each bank, a set of wells running in a line from the bench to the toe was installed and subsequently monitored for groundwater elevations and water quality.

The Indian Fork Study Spoil Bank was contour stripped to mine the upper and lower Pewee coal. Mining along the seam was completed by 1972. The spoil material was placed in a swale backfill configuration with the excess discharged down slope. The remaining highwall is approximately 50 feet (15 m). Reclamation was minimal and the spoil remained barren until 1974 when disturbance in the entire Indian Fork basin was hydro-seeded with a mixture of fescue, sericea lespedeza, and black locust. This vegetation became firmly established within a

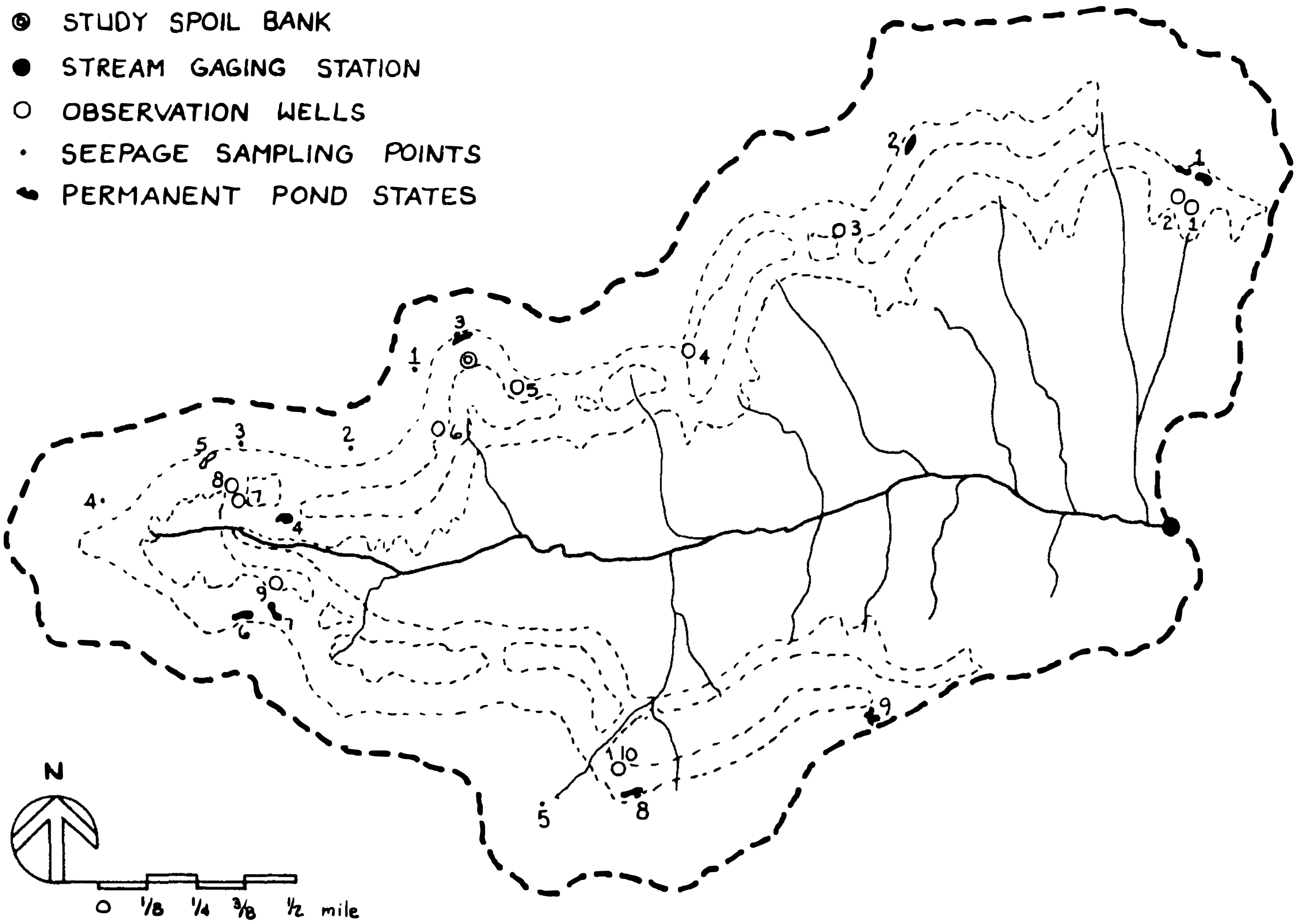


Figure 10. Indian Fork Study Basin with Mining Disturbance and Locations of Study Spoil Bank, Stream Gaging Station, Observation Wells, Permanent Bench Ponds, and Seepage Sampling Points.

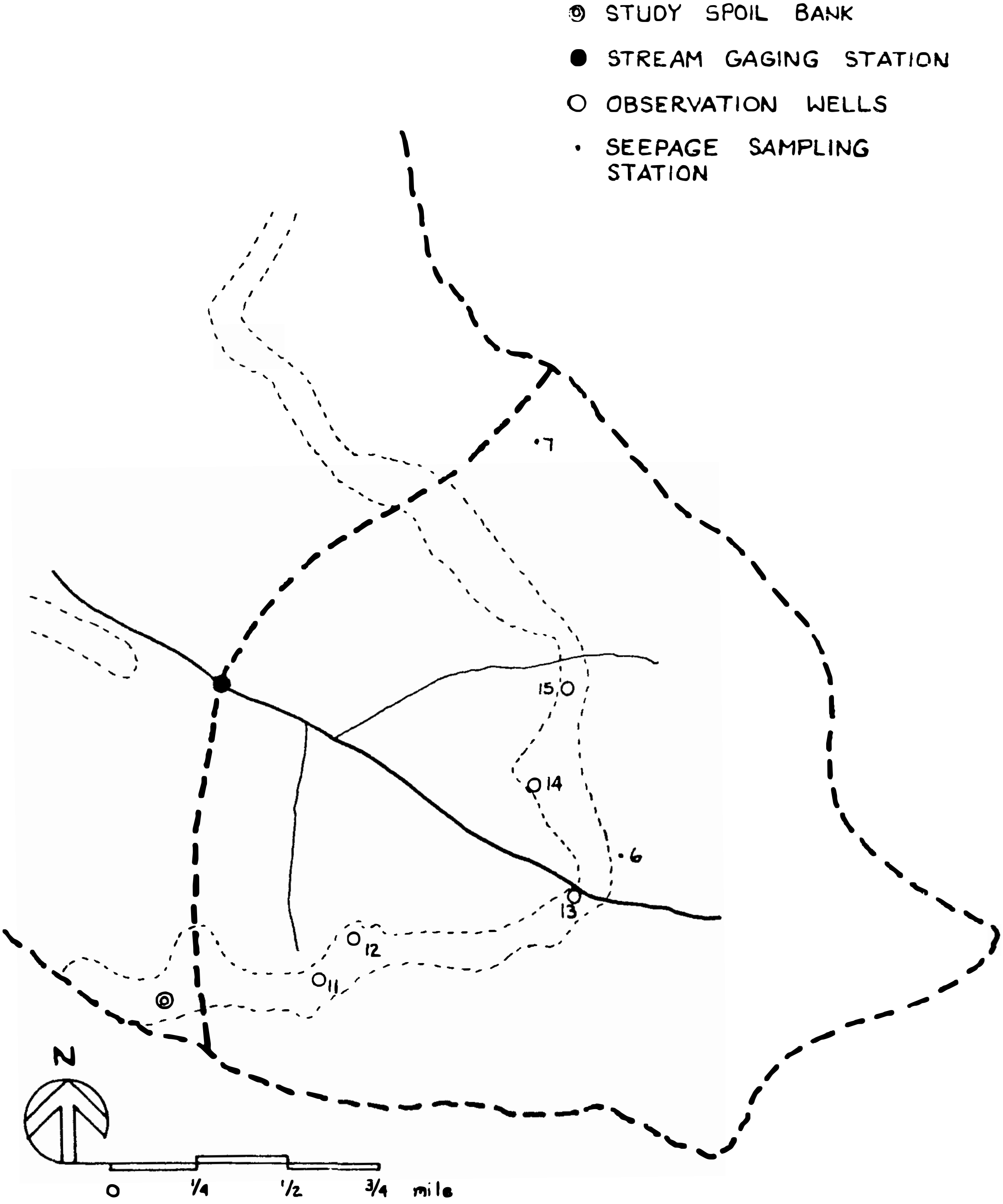


Figure 11. Bills Branch Study Basin with Mining Disturbance and Locations of Study Spoil Bank, Stream Gaging Station, Observation Wells, and Seepage Sampling Points.

year. A surface water fed pond exists on the bench in a depression along the highwall. It covers an area of approximately 1/4 acre (0.10 ha) and drains through a culvert placed in the haul road which traverses the mining bench. The discharge is channeled down the spoil bank and into an existing watercourse.

In the fall of 1973 a series of 3/4 inch (2 cm) galvanized steel wells was installed at the Indian Fork Study Spoil Bank as a part of research examining the storage and movement of groundwater in the mining spoil (67). A subsurface saturated zone was found, and in November, 1974 and January, 1975 a set of four, 2 inch (5 cm) diameter polyvinylchloride (PVC) wells was installed to fully access the spoil groundwater system. Several smaller, stainless steel wells were installed to access water at the toe of the spoil in August, 1977. All wells had 1/4 inch (0.6 cm) holes drilled along their length to provide entry of subsurface water. Table 6 introduces the well sites at the Indian Fork Study Spoil Bank, summarizes their history, and outlines the periods for which groundwater elevation and water quality data exist.

When a contour strip mine cut is made, originally consolidated overburden material is fractured, removed, and then backfilled in a heterogenous mixture commonly known as the mining spoil. The result is a mass of unconsolidated, permeable material overlying the intact, relatively impermeable rock structure of the floor of the mining cut and of the mountain slope below. Four surveys were conducted at the Indian Fork Study Spoil Bank over the course of the research. This, information from the well driller's log, and a knowledge of the mining

Table 6. Indian Fork Study Spoil Bank, Well Histories

Well	Date Installed	Material	Depth (feet)	Period of Hydrologic Record	Period of Chemical Sampling	Comments
F1	13 Nov 74	Drilled & Cased, 2 Inch ID - PVC pipe	30	8 Apr 75 - 25 Aug 79	21 Mar 75 - 28 Jun 80	Well in pond on bench of spoil; chemical sampling from pond; hydrologic measurements made at well.
F2	10 Jan 75	Drilled & Cased, 2 inch ID - PVC pipe	35	4 Apr 75 - 25 Aug 79	21 Mar 75 - 4 Oct 76	Well on outer edge of bench; destroyed by vandalism in November 1976; hydrologic record continued using adjacent G1 well.
F3	8 Jan 75	Drilled & Cased, 2 inch ID - PVC pipe	21	4 Apr 75 - 25 Aug 79	21 Mar 75 - 19 Dec 79	Well in upper-middle portion of spoil slope; blockage occurred in April 1976 from apparent shifting of spoil material; saturated zone re-accessed with 3/4 inch, stainless steel pipe driven down into broken casing; well destroyed by vandalism in June, 1980.
F4	8 Jan 75	Drilled & Cased, 2 inch ID - PVC pipe	23	4 Apr 75 - 25 Aug 79	21 Mar 75 - 28 Jun 80	Well in lower-middle portion of spoil slope.

Table 6. (Continued)

Well	Date Installed	Material	Depth (feet)	Period of Hydrologic Record	Period of Chemical Sampling	Comments
F5					10 Jul 75 - 14 Jul 79	Breakout, or seepage, in toe region of the spoil along edge of channel cut by surface discharge from pond.
F6	4 Aug 77	Hand-driven, 3/4 inch ID -stainless steel pipe	11	10 Aug 77 - 25 Aug 79	10 Aug 77 - 28 Jun 80	Well at base of spoil just above the toe.
F7	4 Aug 77	Hand-driven, 3/4 inch ID - stainless steel pipe	7	26 Sep 78 - 4 Jan 79	10 Aug 77 - 14 Jul 79	Well in middle portion of toe; problems with mud plugging and the interception of surface water place hydrologic and chemical sampling results in question.
F8	23 Aug 77	Hand-driven, 3/4 inch ID - stainless steel pipe	5	24 Aug 77 - 25 Aug 79	1 Sep 77 - 28 Jun 80	Well at extreme edge of the toe.
G1 G2 G3 G4 G5 G6 G7	Fall, 1973	Hand-driven, 3/4 inch ID - galvanized steel pipe	8 to 20			Wells installed at the Indian Fork Study Spoil Bank as a part of an earlier study of spoil groundwater movement; no chemical samples were taken from galvanized wells.

operation was used to construct a configuration for the spoil bank and impermeable layer beneath it. The survey results are presented in Table 7. Figures 12 and 13 show, to scale, a profile and plan of the Indian Fork Study Spoil Bank system of wells.

Contour stripping of the Big Mary coal began in the Bills Branch Study Basin in late 1974 and was completed by September, 1975. As required by Tennessee state law at that time, the spoil material was backfilled into a pasture configuration leaving a gently sloping bench and an exposed highwall of 30 feet (9 m). The 125 foot limit on downslope discharge of spoil was exceeded. The mining disturbance was revegetated with a fescue, sericea lespedeza, and black locust mixture shortly after backfilling was complete. The configuration of the spoil at the Bills Branch Study Spoil Bank does not promote ponding.

A set of five, 2 inch (5 cm) diameter PVC wells was installed at the Bills Branch Study Spoil Bank in November, 1975. Shortly after installation a section of haul road embankment built along the edge of the bench became saturated and started to creep down the spoil slope. The resulting movement destroyed the C2 well, eventually dropping the ground surface 13 feet (4 m). Fortunately, this soil movement was localized and did not damage the remaining wells. Additional stainless steel wells were driven in May, 1976 and October, 1977 to access groundwater at the toe. Table 8 introduces the Bills Branch Study Spoil Bank well sites, summarizes their history, and outlines the periods for which groundwater elevation and water quality data exist. Several surveys were conducted at the study bank, and these were used along with the

Table 7. Indian Fork Study Spoil Bank, Survey Results

Well	Station Along Horizontal Line Perpendicular to the Highwall (feet)	Well Top Elevation (feet)	Ground Surface Elevation (feet)	Estimated Elevation of the Mining Cut or Original Ground Surface (feet)	Well Bottom Elevation (feet)	Estimated Elevation of the Impermeable Layer (feet)	Comments
	0-29.0		212.94				Slope Above Spoil Bank
	0-14.0		205.50				
	0+00.0		198.00			115.99	Top of Highwall
	0+06.0		149.74			115.99	Base of Highwall
F1	0+56.0	145.99		117.99	115.99	115.99	Original well top broken; corrected elevation 145.40
G1	1+35.5	149.58	147.40		127.43	115.99	
G2	1+37.0	149.92	147.88		131.47	115.99	Bench Mark
F2		148.90			113.90	113.90	Well Destroyed by Vandalism
G3	1+57.0	136.98	134.08		125.00	110.00	
F3	1+97.0	114.92	112.66	94.66	91.16	91.16	Original PVC well top elevation 116.15

Table 7. (Continued)

Well	Station Along Horizontal Line Perpendicular to the Highwall (feet)	Well Top Elevation (feet)	Ground Surface Elevation (feet)	Estimated Elevation of the Mining Cut or Original Ground Surface (feet)	Well Bottom Elevation (feet)	Estimated Elevation of the Impermeable Layer (feet)	Comments
G4	2+07.0	110.50	107.60		94.50	86.00	
F4	2+54.0	92.40	91.64		64.41	64.41	
G5	2+58.0	85.60	82.23		73.60	63.00	
G6	2+78.0	73.38	70.92		57.38	54.00	
G7	2+81.5	72.70	72.26		52.70	52.70	
F5	2+29.5		58.24				Breakout
F6	3+04.0	59.46	58.90		47.46	46.00	
F7	3+24.0	47.44	46.20		39.44	39.44	
F8	3+49.5	34.13	33.22		28.13	28.13	
	3+66.0		29.44				Slope Below Spoil Bank
	4+02.0		21.52				
	4+24.0		15.26				

Information compiled from surveys:
January 4, 1974
April 22, 1975
September 9, 1977
February 24, 1980

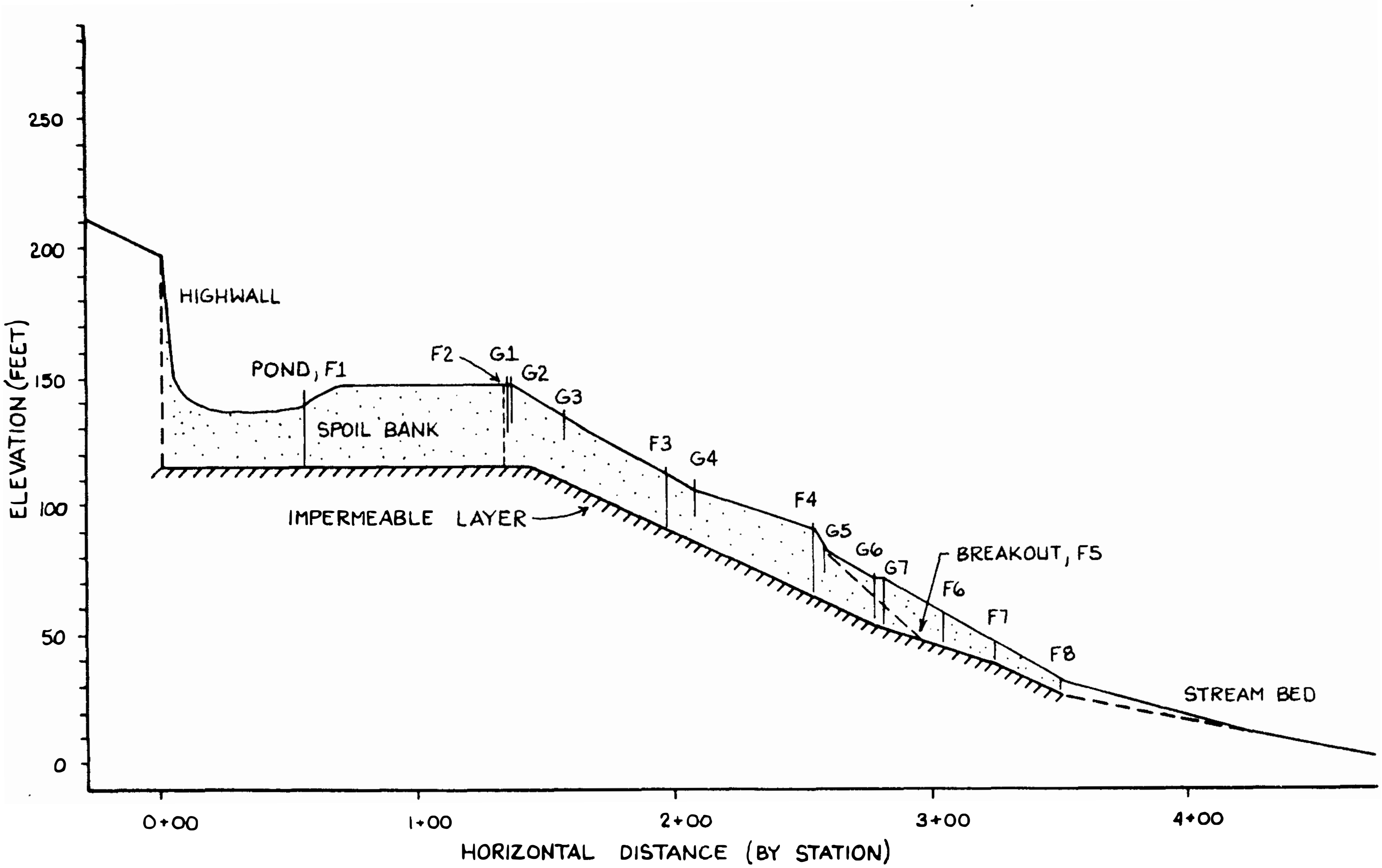


Figure 12. Profile, Indian Fork Study Spoil Bank.

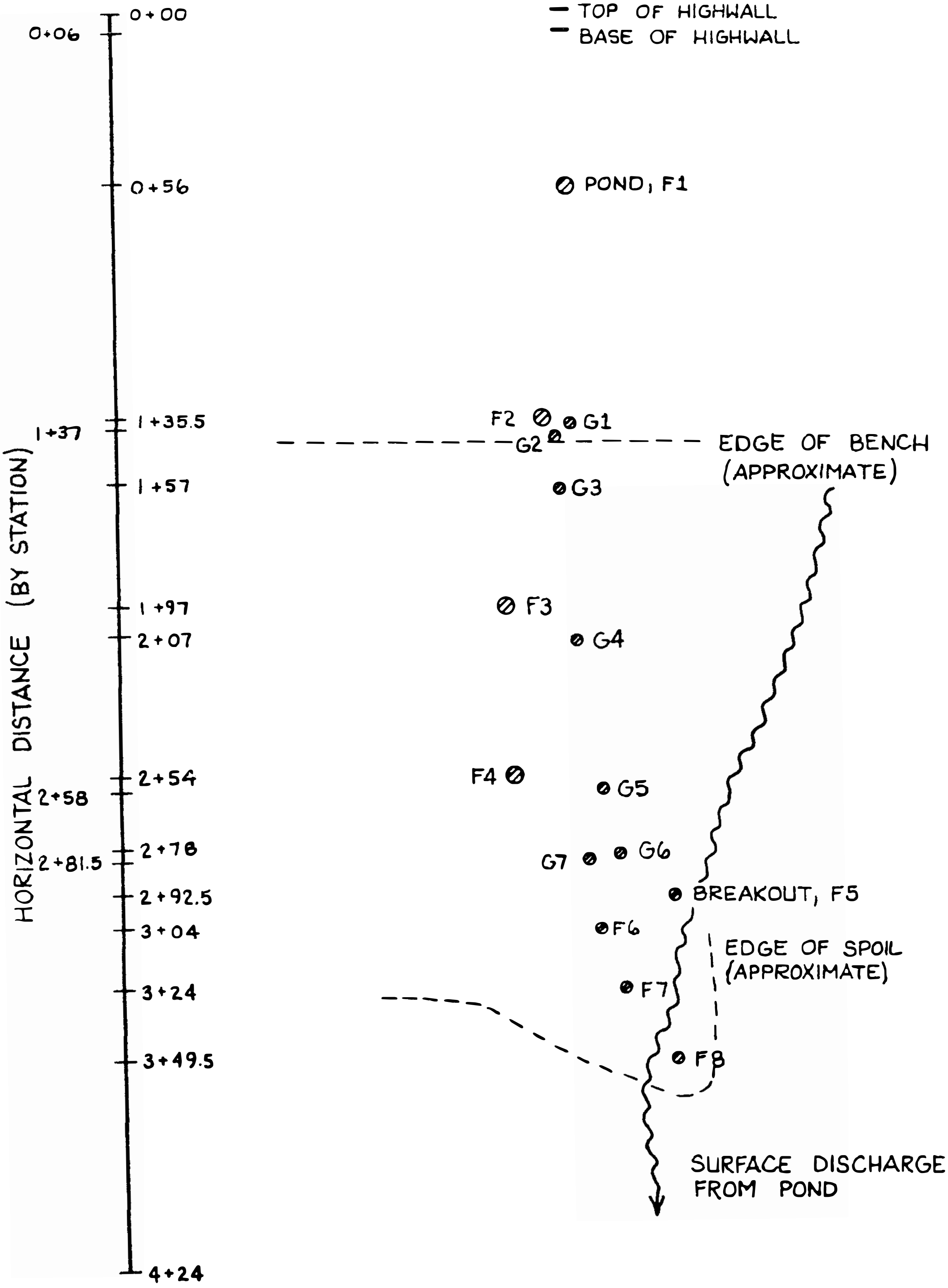


Figure 13. Plan, Indian Fork Study Spoil Bank.

Table 8. Bills Branch Study Spoil Bank, Well Histories

Well	Date Installed	Material	Depth (feet)	Period of Hydrologic Record	Period of Chemical Sampling	Comments
C1	24 Nov 75	Drilled & Cased, 2 inch ID - PVC pipe	20	22 Jan 76 - 25 Aug 79		Well on bench near highwall offset from the line of remaining wells: well driller's log and survey results indicate well does not extend to the depth of the mining cut; no chemical samples.
B1	24 Nov 75	Drilled & Cased, 2 inch ID - PVC pipe	29	22 Jan 76 - 25 Aug 79	22 Apr 76 - 13 Jun 78	Well on bench near highwall; well driller's log and survey results indicate well does not extend to the depth of the mining cut; frequently contained insufficient volume for chemical sampling.
B2	24 Nov 75	Drilled & Cased 2 inch ID - PVC pipe	32	22 Jan 76 - 25 Aug 79	21 Apr 76 - 19 Dec 79	Well on outer portion of the bench.
C2	24 Nov 75	Drilled & Cased, 2 inch ID - PVC pipe	57			Well on outer edge of the bench; blockage occurred in January, 1976 from shifting of the spoil material.

Table 8. (Continued)

Well	Date Installed	Material	Depth (feet)	Period of Hydrologic Record	Period of Chemical Sampling	Comments
B3	24 Nov 75	Drilled & Cased, 2 inch ID - PVC pipe	57	22 Jan 76 - 25 Aug 79	21 Apr 76 - 28 Jun 80	Well in middle portion of the spoil slope; initially dry, water observed in April, 1976 following shift and blockage at the C2 well site.
B4	28 Oct 77	Hand-driven, 3/4 inch ID - stainless steel pipe	14.5		3 Dec 77 - 13 Jun 78	Well on lower portion of the spoil slope: was not tied into vertical serveys conducted at the study spoil bank.
B5	19 May 76	Hand-driven, 3/4 inch ID - stainless steel pipe	10 (11)	8 Jul 76 - 20 Jul 78	19 May 76 - 30 Nov 78	Well at base of spoil just above the toe; became plugged with mud 9.5 ft below top; removed and replaced in August 1978; became plugged again.
B6					21 Apr 76 - 8 Mar 77	Breakout, or seepage, at the toe where spoil converges with the original ground surface; flow generally insufficient for sampling.

well driller's logs and mining information to construct a configuration for the Bills Branch Study Spoil Bank and impermeable layer beneath it. The survey results are presented in Table 9. A profile and plan of the study spoil bank are presented in Figures 14 and 15.

Monitoring activities at both study banks ended in June, 1980 and maintenance of the research sites was curtailed two months later.

Application of results from the Indian Fork and Bills Branch Study Spoil Banks to adjacent sections of the spoil and to the spoil bank in general will require evidence that a saturated zone exists elsewhere and that the ground water quality found at the study banks is not anomalous. With this in mind, a portion of the spoil bank investigation has been directed at determining the extent of saturation and the associated ground water quality of the spoil throughout the two study basins. This investigation involved extensive reconnaissance of the spoil and a series of special observation wells. Figures 10 and 11 present the locations of this work.

Reconnaissance of the spoil in the two study basins was conducted to identify sites where spoil saturation was advanced. Subsurface water can be identified by surface features such as seepage, creeping or sliding soil, cat-tails, and willow trees on the spoil slope. Seeping highwalls and trapped surface water on the mining bench can serve as sources of recharge for the spoil groundwater system. The occurrence of these features was noted and mapped in each of the study basins.

The reconnaissance results were used to select sites where a saturated zone should exist. At each site, the postulated zone was

Table 9. Bills Branch Study Spoil Bank, Survey Results

Well	Station Along Horizontal Line Perpendicular to the Highwall (feet)	Well Top Elevation (feet)	Ground Surface Elevation (feet)	Estimated Elevation of the Mining Cut or Original Ground Surface (feet)	Well Bottom Elevation (feet)	Estimated Elevation of the Impermeable Layer (feet)	Comments
	0+00.0		181.20			91.74	Top of Highwall
	0+10.0		135.00			91.74	Approx. Base of Highwall
C1	0+27.6	139.94	137.98		119.95	91.74	
B1	0+27.6	131.89	130.71		106.70	91.74	
B2	0+98.5	126.06	123.06	91.74	91.74	91.74	Bench Mark
C2	1+59.5	127	123.38		66.38	66.38	Well destroyed by slide, final ground elevation, 110.44
B3	2+19.4	97.05	93.63	60.63	43.28	43.28	
B4	2+80						Well not tied into vertical control
B5	3+11.0	50.00	46.86		34.00	22.00	
	3+28.5		45.72				Top of Steep Embankment at Base of Spoil

Table 9. (Continued)

Well	Station Along Horizontal Line Perpendicular to the Highwall (feet)	Well Top Elevation (feet)	Ground Surface Elevation (feet)	Estimated Elevation of the Mining Cut or Original Ground Surface (feet)	Well Bottom Elevation (feet)	Estimated Elevation of the Impermeable Layer (feet)	Comments
B6	3+48.0		22.00				Approx. Upper Limit of Saturation at Toe
	3+55.5		11.00			11.00	Base of Toe Embankment
	3+72.0		4.50				Slope Below Spoil Bank

Information compiled from surveys: October 2, 1975
February 12, 1976
July 26, 1977
February 24, 1980

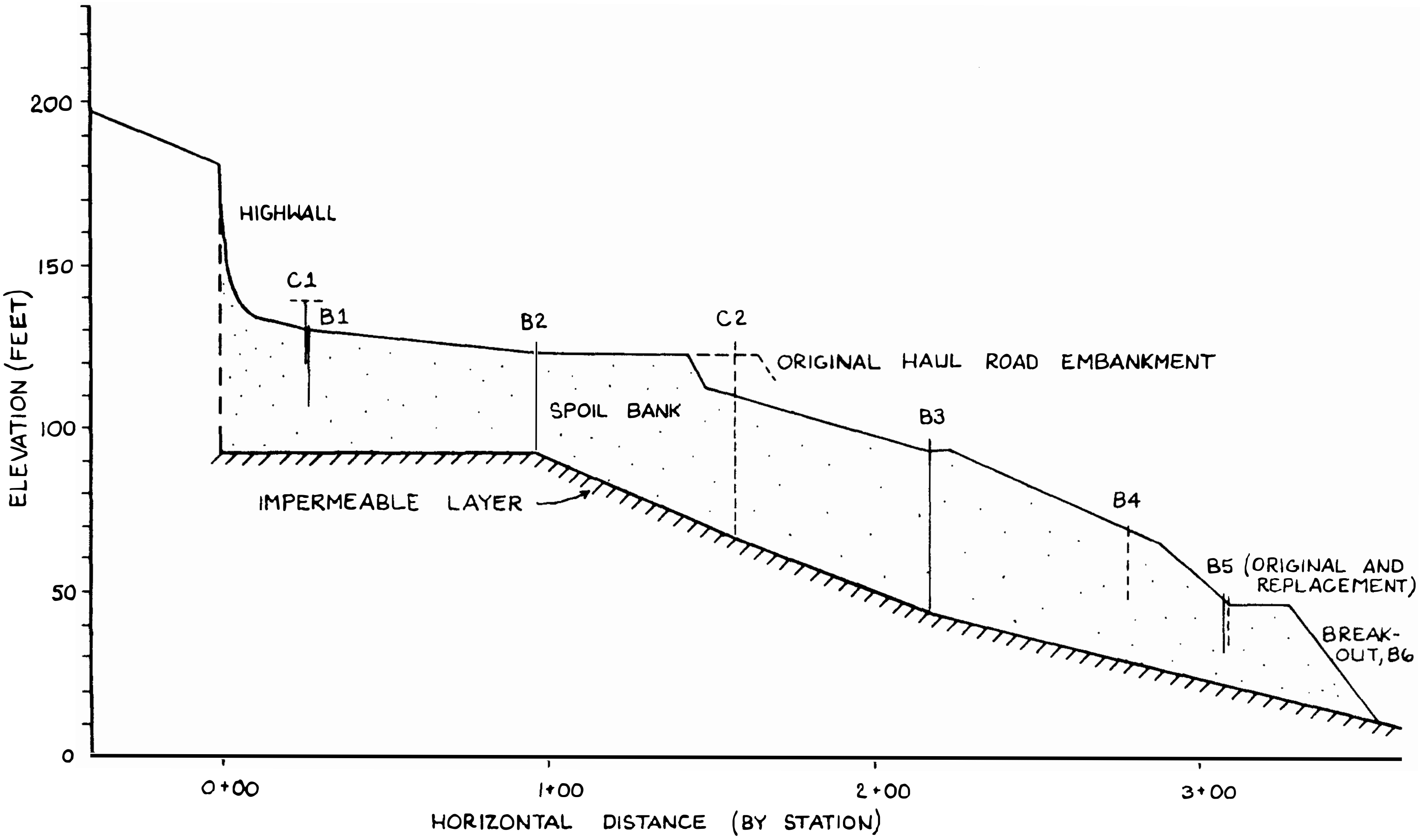


Figure 14. Profile, Bills Branch Study Spoil Bank.

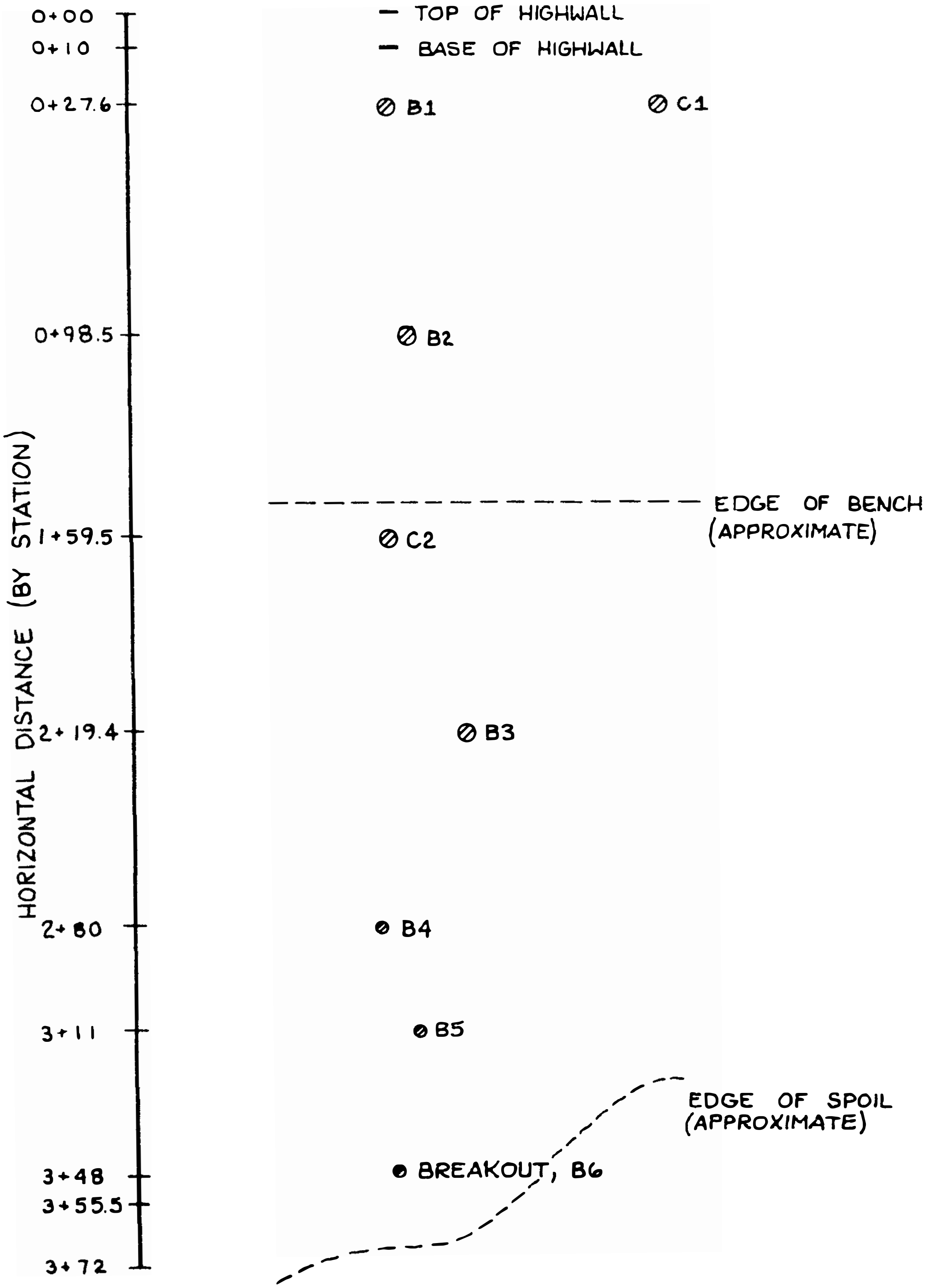


Figure 15. Plan, Bills Branch Study Spoil Bank.

accessed with a hand-driven, 3/4 inch (2 cm) ID stainless steel observation well installed near the toe where the reduced thickness of the spoil would allow complete penetration of the fill. These wells were driven in 4 foot sections with a maximum attainable depth between 10 and 20 feet (3 and 6 m). All were carefully sealed at ground level to prevent the intrusion of surface water. The intersection and collection of water in these observation wells would serve as verification of the suspected saturated zone. The quality of this water would then be compared to that found at the study spoil banks.

A total of 15 observation wells were installed in the two study basins, 10 in Indian Fork and 5 in Bills Branch. These are introduced along with their histories and site characteristics in Table 10. After sampling, each observation well was removed, cleaned, and reinstalled at another site.

Monitoring, Sampling and Analytical Methods

Hydrologic monitoring of groundwater elevations began in April, 1975 at the Indian Fork Study Spoil Bank and in January, 1976 at the Bills Branch Study Spoil Bank. It ended for both banks in August, 1979. This work involved periodic field measurements of the depth from the top of each study well to the groundwater surface. The water surface was detected with an electrical resistance probe. This information was later combined with field survey results to yield groundwater elevation and saturated zone thickness data for each well. Saturated zone thickness is defined as the height of the water column above the impermeable layer constructed for each study spoil bank.

Table 10. Observation Well Histories and Site Characteristics

Basin & Well	Date Installed	Depth (feet)	Date Sampled	Accessed Water	Comments/Site Characteristics
<u>Indian Fork</u>					
Obs #1	17 Aug 78	15	7 Dec 78	yes	- well driven to refusal - ponding on bench at entrance to abandoned deep mine - breakouts on spoil slope
Obs #2	17 Aug 78	5	7 Dec 78	yes	- ponding on bench at entrance to abandoned deep mine - breakouts on spoil slope
Obs #3	21 Jun 80	9	28 Jun 80	no	- well driven to refusal - wet highwall - breakouts on spoil slope
Obs #4	21 Jun 80	7.5	28 Jun 80	yes	- well driven to refusal - seasonal ponding on bench - breakouts on spoil slope
Obs #5	14 Dec 78	10	6 Jan 79	no	- well driven to refusal - seasonal ponding on bench - wet highwall
Obs #6	15 Dec 78	13.5	6 Jan 79	yes	- well driven to refusal - dry bench
Obs #7	21 Jun 80	5.5	28 Jun 80	yes	- well driven to refusal - seasonal ponding on bench

Table 10. (Continued)

Basin & Well	Date Installed	Depth (feet)	Date Sampled	Accessed Water	Comments/Site Characteristics
Indian Fork					
Obs #7 Cont'd					- creeping spoil - breakouts at toe of spoil
Obs #8	21 Jun 80	6	28 Jun 80	yes	- well driven to refusal - seasonal ponding on bench - creeping spoil - breakouts at toe of spoil
Obs #9	17 Aug 78	11.5	7 Dec 78	yes	- well driven to refusal - permanent pond on bench (pond #6) - breakouts on spoil slope
Obs #10	19 Aug 78	11.5	7 Dec 78	yes	- well driven to refusal - permanent pond on bench (pond #8) - breakouts on spoil slope
Bills Branch					
Obs #11	21 Jun 80	9	28 Jun 80	no	- well driven to refusal - dry bench
Obs #12	14 Dec 78	9.5	6 Jan 79	yes	- creeping spoil - seepage on spoil slope
Obs #13	14 Dec 78	12.5	6 Jan 79	yes	- well driven to refusal

Table 10. (Continued)

Basin & Well	Date Installed	Depth (feet)	Date Sampled	Accessed Water	Comments/Site Characteristics
Bills Branch					
Obs #13 Cont'd					- dry bench
Obs #14	21 Jun 80	7.5	28 Jun 80	yes	- dry brench - creeping spoil - marshes and breakouts on spoil slope
Obs #15	21 Jun 80	13	28 Jun 80	yes	- well driven to refusal - dry bench - marsh on spoil slope

Water quality monitoring of the spoil saturated zone began in March, 1975 at the Indian Fork Study Spoil Bank. Monitoring of the Bills Branch Bank began in April, 1976. On each sampling date, all wells with sufficient water at a study bank were sampled. Routine water quality determinations involved field measurement of pH and Eh (redox potential) and laboratory analysis of wet chemical, metal, and trace metal constituents. During the research, special sample sets were taken for organic carbon, ferrous iron, sulfides, nitrates, and phosphates.

The wells at the Indian Fork Study Spoil Bank and the observation wells installed throughout the two study basins were fitted with 1/4 inch (0.6 cm), Tygon S-50-HL tubing and sampled from the bottom with the aid of a portable peristaltic pump. Initially, on-line monitoring of pH and Eh were conducted as a well was pumped down. Several small volume samples would be taken for chemical analysis. During the latter half of the research, composite samples of one liter or more were taken in an attempt to better represent the column of well water and avoid stratification. The pH and Eh were determined on the composite sample.

Sampling of the deeper wells at the Bills Branch Study Bank required the use of a plexiglass bailer which was lowered into them and allowed to sink. The pH and Eh were measured immediately after water was removed from a well. As at Indian Fork, initial samples were taken in small volumes, with several samples representing a well on each sampling date. Later samples represent a single composite volume removed from the well.

In addition to the measurement of pH and Eh, the field sampling procedure included preparation of samples for laboratory analysis. Total and dissolved constituent samples were acidified to pH <2.0 with ultra-pure nitric acid. All dissolved constituent samples were filtered through 0.45 micron Millipore filters in a plastic field filtering apparatus prior to acidification. This equipment was acid rinsed between samples to eliminate carry-over contamination of metals. Total samples were not altered other than acidification. Along with the metals samples, an unacidified total sample was taken for wet chemical analysis. Distilled/de-ionized water was used to rinse all sampling equipment between wells. New Nalge polyethylene bottles were used to transport and store field samples. Samples for special analyses were prepared in the field as was required to preserve them.

The water quality variables monitored and the analytical methods employed are outlined in Table 11. Analytical detection limits for these methods are presented in Appendix A. During the six years of research, improved analytical techniques became available in the water quality laboratory, especially for the determination of metals. However, in order to maintain consistency in the spoil bank data, the methods employed remained the same as those originally developed. Advanced techniques such as lanthanum addition, alkali addition, and matrix modification were not practiced in the analysis of metals by atomic absorption spectroscopy.

In December, 1981 and January, 1982 in-situ soil samples were taken at the two study spoil banks. This work was undertaken to

Table 11. Water Quality Variables and Analytical Methods

Variable	Method	Comments
Wet Chemistry		
pH	Potentiometric Standard Methods, 15th edition, Method 423; U.S. EPA Method 150.1	Field measurements using portable meter (Orion Research Ionalyzer/Model 407A), standardized and temperature adjusted.
Eh (Redox Potential)	Selective ion electrode	Field measurement using portable meter and platinum Redox electrode (Orion Research Combination Redox Electrode/Model 96-78).
Alkalinity	Potentiometric Titration (pH 4.5) Standard Methods, 15th edition, Method 403; U.S. EPA Method 310.1	Laboratory analysis performed on filtered sample; titration end point at pH 4.5.
Sulfate	Turbidimetric Standard Methods, 15th edition, Method 426C; U.S. EPA Method 375.4	Laboratory analysis performed on filtered sample; turbidimetric response of samples checked against sulfate standards.
Metals	Atomic Adsorption Spectrophotometry Standard Methods, 15th edition, Methods 303 and 304; specific U.S. EPA Method listed for each metal	Laboratory analysis using a Perkin Elmer Model 403 Atomic Absorption Spectrophometer additionally equipped with a HGA 2100 graphite furnace. Metals analyses were performed on both total (nonfiltered) and dissolved (filtered) samples. Filtration was perfomred in the field using 0.45 um Millipore filters. Metals samples were field acidified to pH<2.0 for storage prior to analysis.
Fe	Standard Methods # 303A; U.S. EPA Methods 243.1 and .2	Low level analyses on graphite furnace.

Table 11. (Continued)

Variable	Method	Comments
Metals (Cont)		
Mn	Standard Methods # 303A; U.S. EPA Methods 243.1 and .2	Low level analyses on graphite furnace.
Ca	Standard Methods # 303A; U.S. EPA Method 215.1	No lanthanum addition.
Mg	Standard Methods # 303A; U.S. EPA Method 242.1	No lanthanum addition.
Trace Metals	Atomic Adsorption Spectrophotometry as above	Laboratory analyses of selected metals samples for trace and minor constituents. No special sample modifications prior to analysis. See Appendix for analytical detection limits.
Cd	Standard Methods # 303A and 304; U.S. EPA Methods 213.1 and .2	
Co	Standard Methods # 303A and 304; U.S. EPA Methods 219.1 and .2	
Cr	Standard Methods # 303A and 304; U.S. EPA Methods 218.1 and .2	
Cu	Standard Methods # 303A and 304; U.S. EPA Methods 220.1 and .2	
Ni	Standard Methods # 303A and 304; U.S. EPA Methods 249. 1 and .2	
Pb	Standard Methods # 303A and 304; U.S. EPA Methods 239.1 and .2	

Table 11. (Continued)

Variable	Method	Comments
Trace Metals (Cont)		
Al	Standard Methods # 303C and 304; U.S. EPA Methods 202.1 and .2	
K	Standard Methods # 303A; U.S. EPA Method 258.1	
Na	Standard Methods # 303A; U.S. EPA Method 273.1	
Si	Standard Methods # 303C	
Zn	Standard Methods # 303A and 304; U.S. EPA Methods 289.1 and .2	
Special Analyses		
Organic Carbon	Combustion-Infrared Standard Methods, 15th edition, Method 505; U.S. EPA Method 415.1	Total and dissolved samples prepared in the field for laboratory analysis. Samples acidified to pH<2.0 with HCL and stripped to remove CO_2. Analyses performed on a Beckman Model 915 Total Organic Carbon Analyzer.
Ferrous Iron	Phenanthroline Method Standard Methods, 15th edition, Method 315B	Dissolved samples prepared in the field and acidified to pH<2.0. Sample was not reduced. Laboratory spectrophotometric determination at 510nm against ferrous iron standards.
Sulfide	Selective ion electrode	Dissolved samples prepared in the field and preserved with a special anti-oxidant, ionic strength buffer. Laboratory analyses against known sulfide standards

Table 11. (Continued)

Variable	Method	Comments
Sulfide (Cont)		using a silver/sulfide selective ion electrode, double junction reference electrode system (Orion Research Models 94-16A and 90-02-00).
Nitrate	Selective ion electrode <u>Standard Methods</u>, 15th edition, Method 418B	Total samples prepared in the field. Laboratory analysis against known nitrate standards using a nitrate selective ion electrode, double junction reference electrode system (Orion Research Models 93-07-01 and 90-02-00). Ionic strength adjustment was applied to both samples and standards.
Phosphate	Absorbic Acid Method with persulfate digestion <u>Standard Methods</u>, 15th edition, Methods 424C and F; U.S. EPA Method 365.3	Dissolved samples prepared in the field and acidified to pH<2.0. Laboratory analysis with persulfate digestion and spectrophotometric determination of total dissolved phosphate against known standards.
Acidity	Potentiometric Titration (pH 8.3) <u>Standard Methods</u>, 15th edition, Method 402; U.S. EPA Method 305.1	Laboratory analysis determined for specific special samples. Sample was filtered; titration end point 8.3.

define the physical properties of the spoil material. The unsaturated and saturated zones were accessed at the toe of each bank. Small, 2.8 by 4.0 inch (7.0 by 10.0 cm) push tubes were used to take the in-situ samples. Field density, porosity and void ratio were determined on these. Additional samples for moisture content, grain size analysis, and Atterburg limits were obtained. All soil samples were taken from a depth of at least 3 feet. Table 12 outlines the laboratory determinations and standard methods associated with the spoil soil sampling effort.

Statistical Methods

The large data bases assembled in this research suggest the use of descriptive statistics in order to summarize the results. The use of statistics to characterize the spoil saturated zone, however, must not proceed blindly. Evaluations of normality and spatial and temporal variations should accompany the statistical summaries. This approach will be used in the Results and Discussion Chapters to follow.

The computerized Statistical Analysis System (SAS), copyrighted by the SAS Institute, Incorporated of Raleigh, North Carolina, was used for statistical handling of the data (55). The SAS UNIVARIATE procedure was used to compute descriptive statistics. These include the number of observations, the mean and median of the sample, the range, the standard deviation, and values of skewness and kurtosis. The standard deviation represents the second moment about the mean and describes the spread of the data distribution. Skewness and kurtosis represent the third and fourth moments about the mean. These

Table 12. Spoil Soil Sampling, Laboratory Determinations and Methods

Laboratory Determination	Standard Method	Comments
Water Content	ASTM D2216-71	Drying temperature 110°C
Grain Size Analysis	AASHTO T87-70 & T88-70 ASTM D421-58 & D422-63	
Mechanical Method		Fines removed prior to analysis by washing through U.S. Standard # 200 sieve.
Hydrometer Method		Hydrometer samples prepared separately from those for mechanical analysis.
Specific Gravity	AASHTO T100-70 ASTM D854-58	Samples deaired with vacuum for 4 hours.
Atterberg Limits	AASHTO T89-68 & T90-70 ASTM 423-66 & D424-59	Liquid and plastic limits determined on samples prepared for hydrometer gram size analysis.

statistics describe the symmetry of the data distribution. Kurtosis is useful for identifying bi-modality when it occurs.

Skewness and kurtosis as well as the closeness of the median to the mean were used as indicators of the normality of the sample data. In a normal distribution both are zero. A negative value of skewness indicates the distribution tails asymmetrically to the left. A positive value indicates skewness to the right. Kurtosis is a measure of "peakedness." A negative value indicates a platykurtic distribution. The platykurtic distribution has fewer observations at the mean and at the tails than the normal distribution but has more observations in intermediate regions. A bi-modal distribution is an extreme platykurtic distribution. A positive kurtosis indicates a leptokurtic distribution which has more items near the mean and at the tails with fewer items in the intermediate regions than a normal distribution with the same mean and variance (58).

Normality testing is important for a normally distributed population tends towards a central value described by the mean. In this case, specification of sample means and standard deviation adequately characterizes the expected system response. Sample populations that fail to meet tests of normality suggest underlying spatial, temporal, and other variation. The UNIVARIATE procedure includes two tests for normality, the Shapiro-Wilk W-test for sets of up to 50 observations and a modified version of the Kolmogorov-Smirnov D-statistic for larger data sets. The null hypothesis for both is that the input data values are a random sample taken from a normal distribution. The tests are regression techniques in which the sample data are ordered and compared to expected values generated for the hypothesized normal population using descriptive statistics computed from the sample. A close fit about the expected values suggests the hypothesized distribution is correct. A value of the test statistic falling outside the critical region indicates a poor fit of the sample data about the expected values and that the null hypothesis (normality) should be rejected (35,55,56).

The null hypothesis is rejected for small values of the Shapiro-Wilk W-statistic and for large values of the Kolmogorov-Smirnov D-statistic (35,56). The Kolmogorov-Smirnov D-test used by UNIVARIATE includes an algorithm to calculate the approximate level of significance. Significance levels for the W-test are from a table look-up procedure (55). Since the distribution function about which the sample data are tested is defined by descriptive statistics computed from the same data, the inherent type II error is greater than for other statistical tests. Bi-modal and other distributions that are balanced about the mean can produce erroneous results. Thus, a conservative level of significance should be applied to these tests (59). The Shapiro-Wilk W-test, the modified Kolmogorov-Smirnov D-test, and cumulative distribution plots produced by the UNIVARIATE procedure were the primary tools used to evaluate the normality of the spoil bank data and the transformations applied to it. Histograms of selected data were also used in this effort.

Several statistical models for analysis of the spoil bank data are presented in the Discussion chapter. These were evaluated using the CORR, TTEST, General Linear Models (GLM), and DUNCAN procedures of SAS. The CORR procedure performs a correlation analysis between inputted variables. The purpose of correlation is to measure the degree of association between pairs of variables and to test whether it is greater than what would be expected by chance alone. In this test a correlation coefficient (R) is computed whose magnitude represents the degree of association and whose sign represents the apparent slope. R is an estimate of Rho, the descriptor of the bivariate normal frequency distribution. When Rho equals zero, there is no correlation between two variables. A Rho value of ± 1.00 indicates a perfect correlation. In correlation analysis the null hypothesis of no significant association between the inputted variables is tested. A value of R outside the critical region indicates a significant correlation exists (55,58).

The TTEST procedure tests the equality of two population means with information computed from samples of the populations. The underlying assumptions are that the populations are normally distributed and that their variances are equal. When the population variances are unequal, a modified value of the degrees of freedom for the test statistic is calculated from the observed variance of the samples (30,55,74). Transformations were performed on the sample data when necessary to insure normality.

The GLM procedures were used to perform analysis of variance and linear regression on the spoil bank data. One-way analysis of variance was employed using the fixed effects model to examine the equality of treatment effects hypothesized in the Discussion. The assumptions underlying analysis of variance are that the sample populations are normal, the random error within each treatment is normally distributed with a mean of zero, and the variance of the error is constant for all treatment effects (30,55,58,74). The power of analysis of variance is maximized when the experimental design is balanced (i.e., equal number of observations under each treatment effect). The test statistic is also relatively insensitive to small departures from the assumption of equality of variances. This is not the case in an unbalanced design, and the probability of type II error is increased (74). Spoil bank data for each water quality parameter were transformed into a normal form before analysis of variance procedures were applied. The GLM regression procedures were used to supplement correlations performed on the spoil bank data. The validity of simple first order models was checked and magnitudes for the apparent slope obtained.

The DUNCAN procedure applies the Duncan multiple range test to groups of samples to determine if their mean values are significantly different. The null hypothesis states that there is no significant difference. The mean values are ordered and the differences between all possible pairs are compared to significant ranges based on sample size and degrees freedom of error. A difference greater than the corresponding least significant range provides the grounds to reject the null hypothesis for the pair of means in question. The Duncan test avoids the large probability of a type I error that is associated with a series of t-tests examining all possible pairs of sample means from a group of samples. The test entails the same assumptions as analysis of variance. For a given level of significance, the DUNCAN procedure segregates the samples into groups that are not significantly different. It can be applied to the output of analysis of variance using GLM to evaluate treatment effects hypothesized in the statistical design. The Duncan multiple range test was originated for balanced samples (30,74). The SAS DUNCAN procedure allows the use of unbalanced sample data with a reduced power for the test (55).

CHAPTER V

RESULTS

As outlined in the Introduction and Experimental Design, the spoil saturated zone has been examined to determine its size, extent and water quality. Several hydrologic and water quality data bases were developed and are summarized in this chapter. Also presented are results from soil sampling at the two study spoil banks. Much of this information was collected in the field and analyzed in the laboratory by the author while an undergraduate.

Hydrologic Data

Groundwater elevations monitored at the Indian Fork and Bills Branch Study Spoil Banks are tabulated in Appendix B along with corresponding tabulations of saturated zone thickness. This information, as saturated zone thickness, is summarized in Tables 13 and 14 for the two study banks. The number of observations at each well is indicated along with descriptive statistics. The value of saturated zone thickness corresponding to the bottom of each well is provided as a reference to the elevation of the impermeable layer. As defined in the experimental design, saturated zone thickness is the height of the water surface above the impermeable layer constructed for each study spoil bank. An examination of the tables indicates the Indian Fork, F6 and the Bills Branch, C1, B1 and B5 wells do not fully penetrate the spoil to the impermeable layer. As a result, water

Table 13. Summary of Saturated Zone Thickness Data for the Indian Fork Study Spoil Bank (values in feet)

	F1	F2	F3	F4	F6	F8
Number	128	127	128	129	42	39
Mean	27.12	14.29	9.61	11.02	9.52	2.53
Std. Dev.	1.2779	2.8153	4.1324	5.7227	1.6598	1.2036
Median	27.61	13.87	10.72	8.32	10.07	2.71
Range Max.	28.61	22.25	15.19	24.8	12.59	4.36
Min.	22.54	8.49	2.22	5.04	7.48	0.03
Thickness Corresponding to Well Bottom	0.00	0.00	0.00	0.00	1.46	0.00

Table 14. Summary of Saturated Zone Thickness Data for the Bills Branch Study Spoil Bank (values in feet)

	C1	B1	B2	B3	B5
Number	75	76	76	68	63
Mean	29.49	16.37	1.90	15.54	19.69
Std. Dev.	1.0193	2.1238	2.0764	3.6658	0.5380
Median	28.78	15.70	0.99	17.38	19.57
Range Max.	31.19	24.25	8.14	20.48	21.96
Min.	28.2	14.15	0	9.17	18.55
Thickness Corresponding to Well Bottom	28.19	14.96	0.00	0.00	12.00

detected at the bottom of these wells may represent a trapped column of water above the true phreatic surface.

The record of hydrologic data taken for the study spoil banks confirms the presence of a saturated zone at each. This information also serves to illustrate the differences between the ponded and non-ponded spoil bank system (represented by the Indian Fork and Bills Branch Study Spoil Banks, respectively). During the course of the study all of the Indian Fork wells maintained a column of water, and the height of this column showed an associated response to seasonal variations in precipitation. The wells on the mining bench at the Bills Branch Study Spoil Bank show a more erratic seasonal variation and suggest the saturated zone beneath the bench is much smaller than at the Indian Fork Study Bank. The downslope wells at Bills Branch indicate the retention of a large volume of water.

The hydrologic data for the wells at both study spoil banks are presented in Figures 16 through 20 as plots of saturated zone thickness versus time. The datum for values of saturated zone thickness is the elevation of the impermeable layer previously defined for each well. As a result, the figures also represent the change in the phreatic surface with time. Dashed lines indicate extended periods when field data were unavailable.

Records of daily precipitation were available for the New River Area, and somewhat incomplete records were available for the two study basins. This information was previously summarized in Table 3, page 32. The precipitation records indicate the summer of

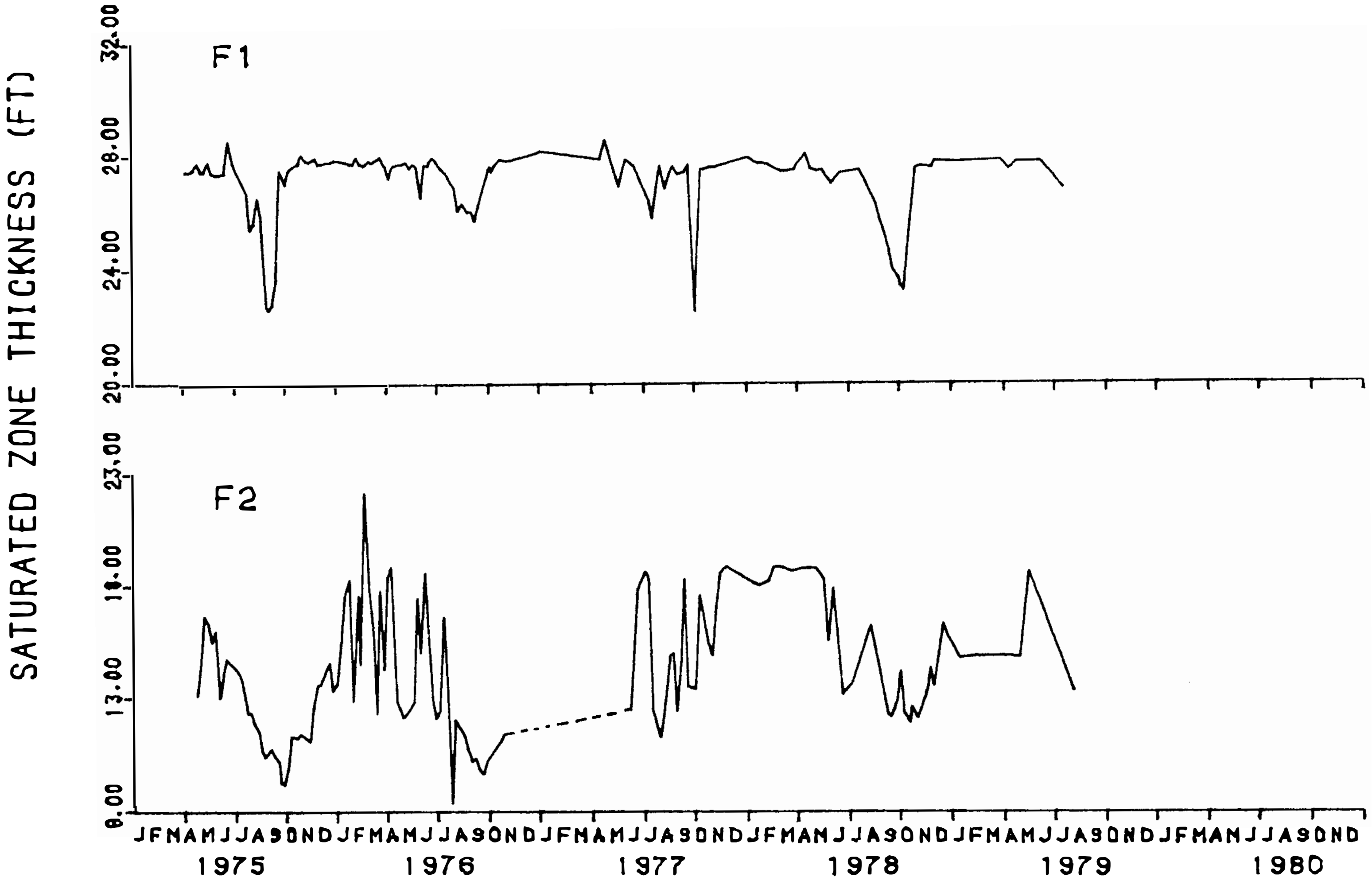


Figure 16. Saturated Zone Thickness with Time, Indian Fork F1 and F2 Wells.

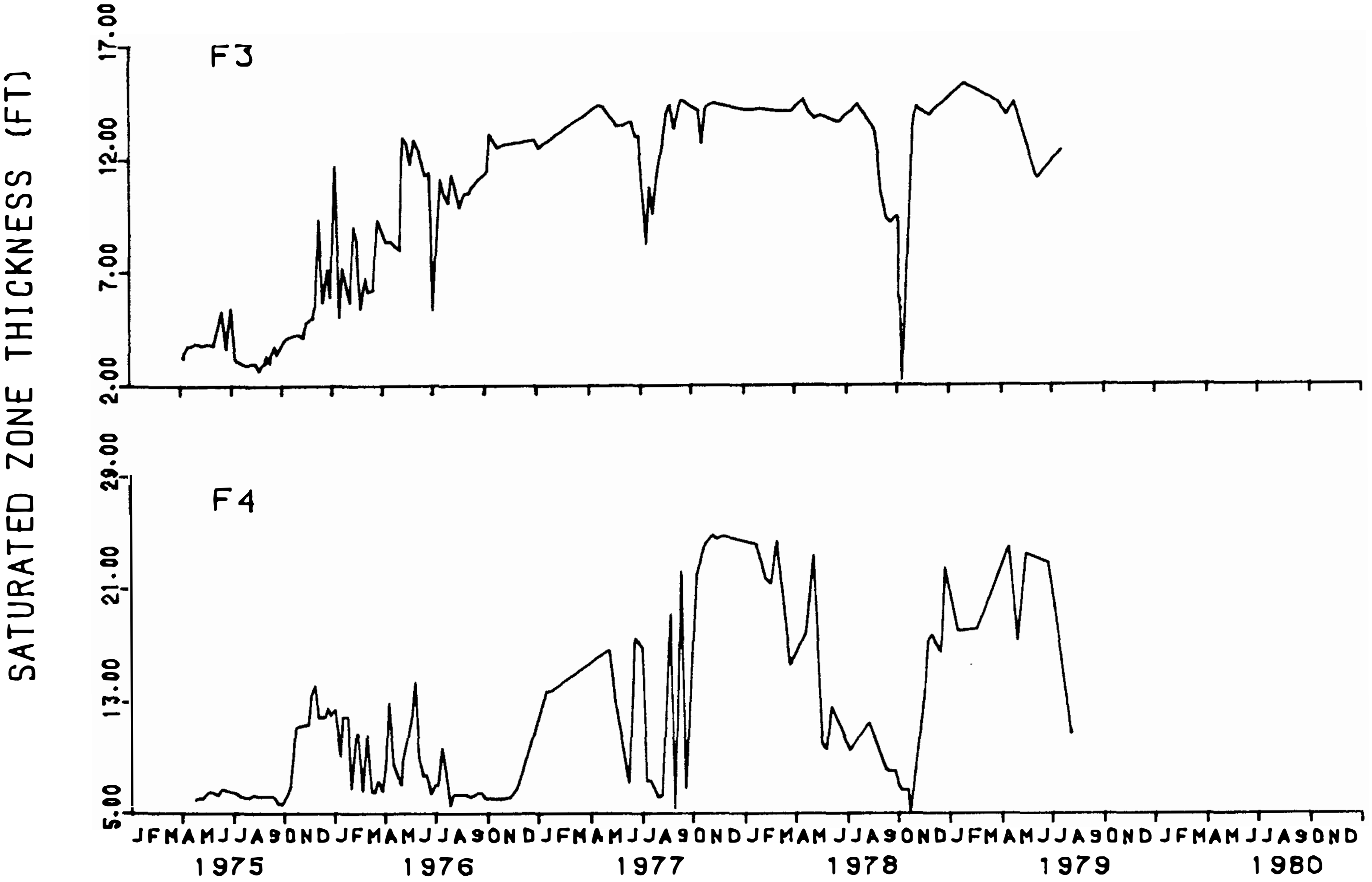


Figure 17. Saturated Zone Thickness with Time, Indian Fork F3 and F4 Wells.

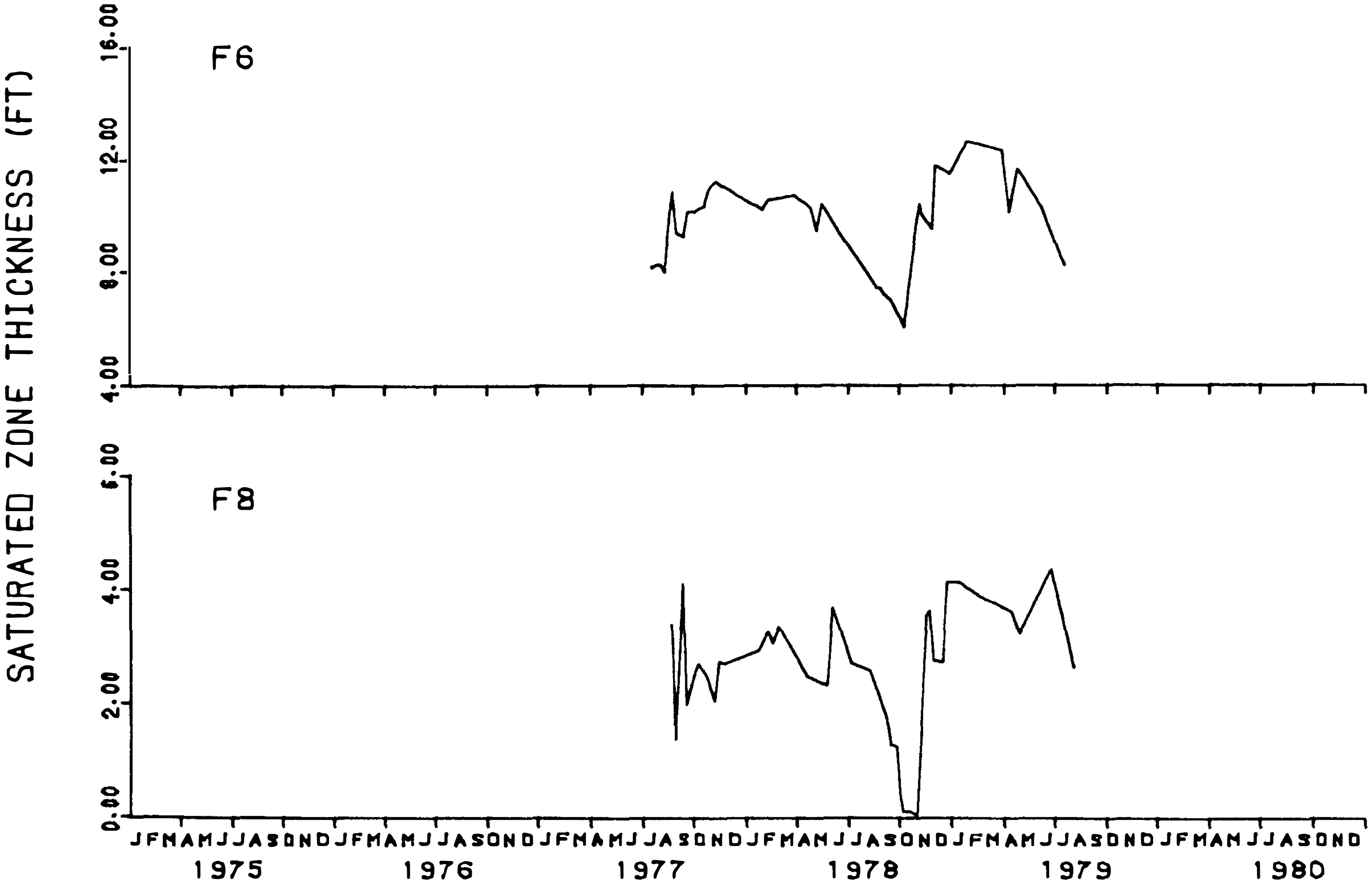


Figure 18. Saturated Zone Thickness with Time, Indian Fork F6 and F8 Wells.

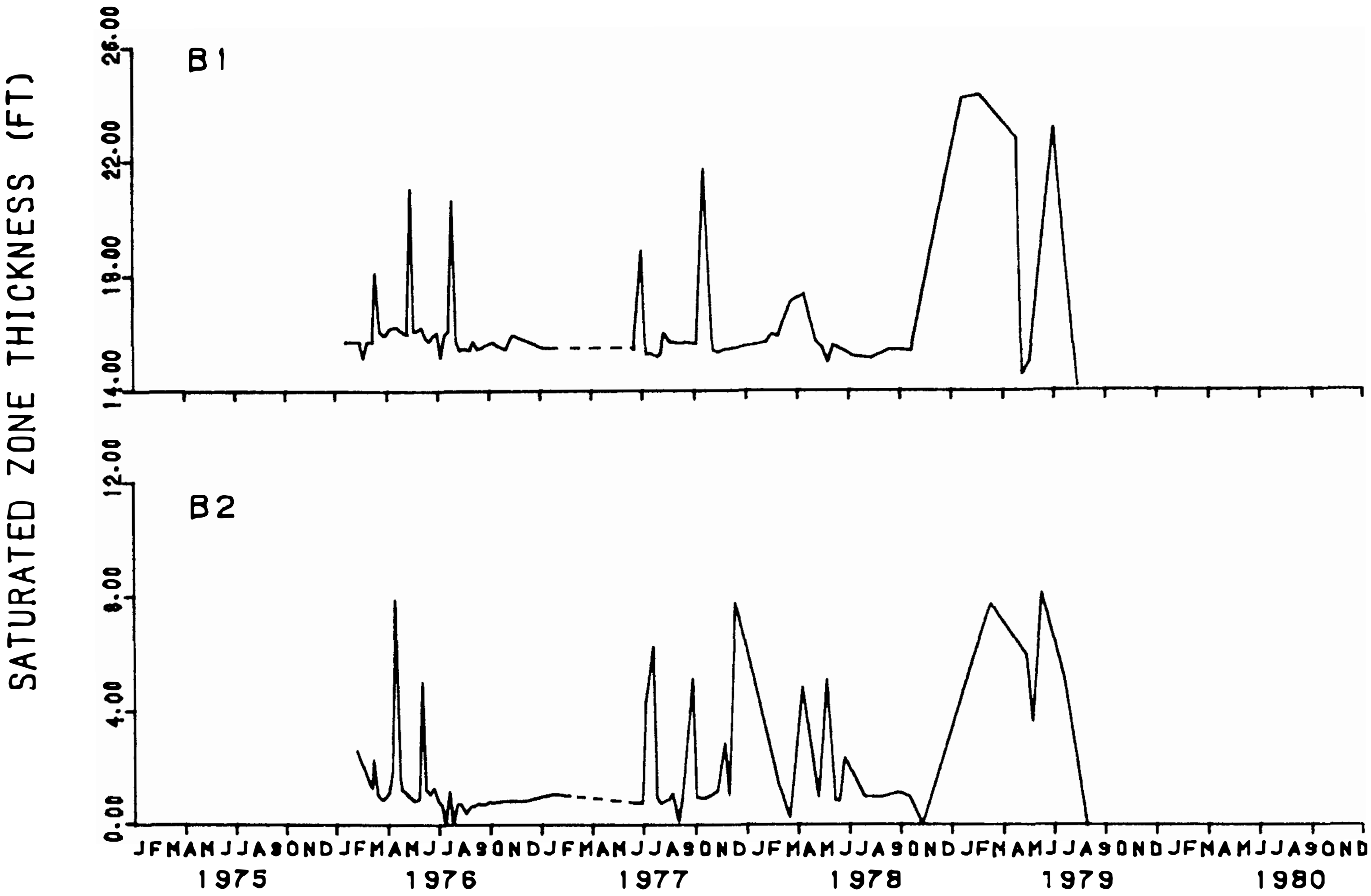


Figure 19. Saturated Zone Thickness with Time, Bills Branch B1 and B2 Wells.

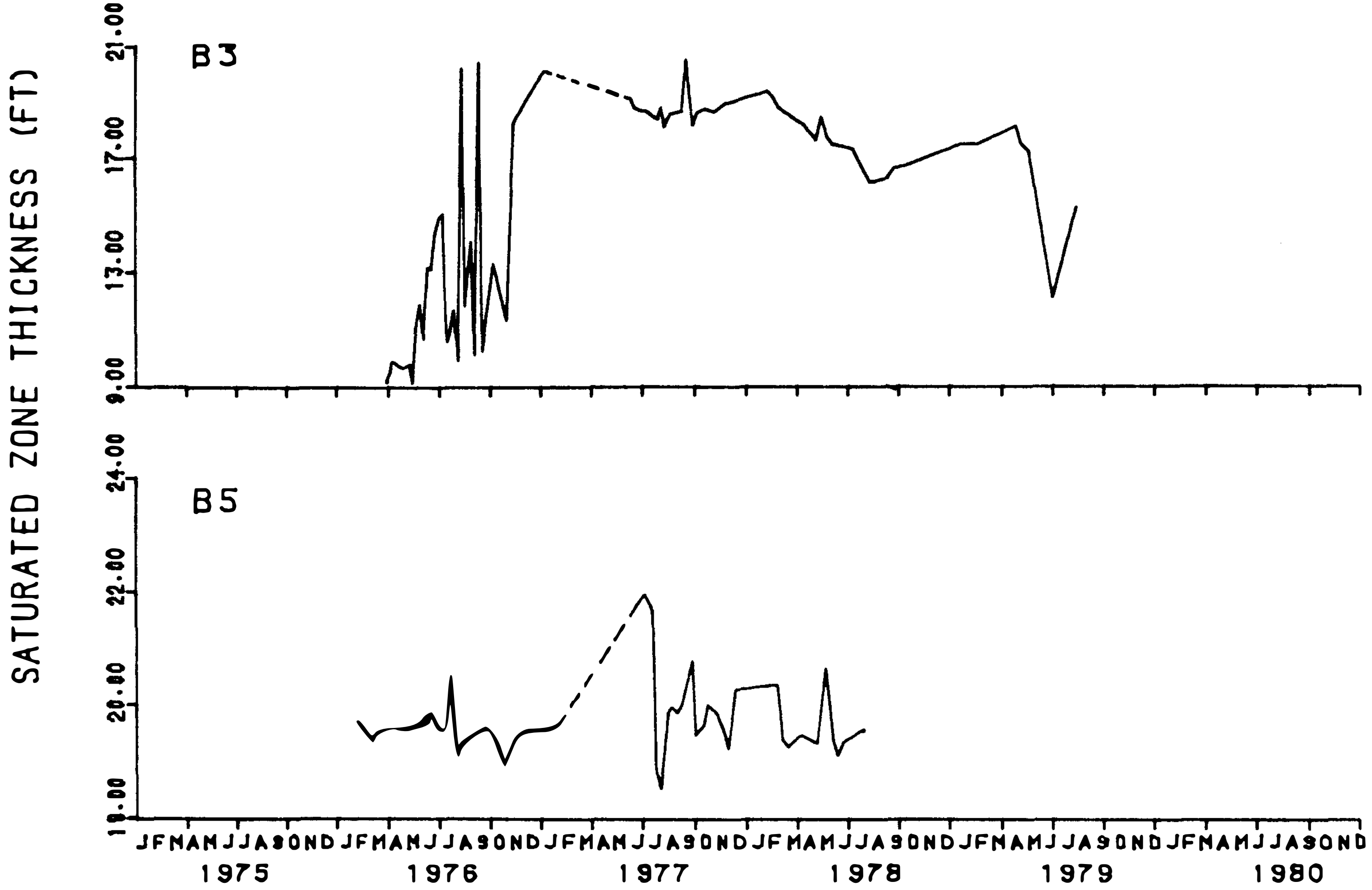


Figure 20. Saturated Zone Thickness with Time, Bills Branch B3 and B5 Wells.

1975 and the fall of 1978 were unusually dry. The fall of 1977 was wetter than normal, and the winter of 1978 experienced unusually heavy snowfall.

The major source of recharge to the groundwater system at the Indian Fork Study Spoil Bank is the surface water pond trapped on the bench. Secondary sources of recharge are direct infiltration of precipitation and seepage from the buried highwall and coal seam. The maximum surface elevation of the Indian Fork pond (F1) is controlled by the elevation of the culvert which drains it. The result is a source of constant hydraulic head for the groundwater system at the Indian Fork Study Spoil Bank under periods of water surplus. During dry periods the pond elevation drops, and the head provided the system decreases. The response of the F1 well is shown in Figure 16.

Downgradient wells at Indian Fork would be expected to respond to changes in the elevation of the F1 well. An examination of Figures 16, 17, and 18 shows this to be the case. Two other responses are revealed by these figures. Periods of recharge after drawdown during the winter and spring of 1976 and the fall of 1977 show erratic changes in the column of water found at the F2, F3, and F4 wells. In contrast, changes during 1978 and 1979 appear to be dampened. The F3 and F4 wells, and to a lesser degree the F2 well, show an increasing saturated zone thickness that reached a relatively constant value in late 1977 and was again achieved after the unusually dry fall of 1978. All of the Indian Fork wells behaved similarly during periods of drought.

The hydrologic response of the F2, F3, and F4 wells suggests that continued weathering and saturation of the study bank has occurred during the course of the research. The constant, maximum saturated zone thickness achieved in these wells and in the hand-driven wells at the toe indicate that the Indian Fork Study Spoil Bank is fully saturated and responding to the constant head input of the pond. The rapid change observed in the Indian Fork wells with changes in the elevation of the pond well, F1, suggests the residence time of water in the spoil bank may be shorter than the two years calculated by Crosby, Overton, and Minear (12).

The configuration of the fill at the Bills Branch Study Spoil Bank eliminates ponding. As a result, the major sources of recharge to the groundwater system are infiltration of precipitation and seepage from the covered highwall and coal seam. An examination of the hydrologic data for the Bills Branch wells, Figures 19 and 20, shows a different response from that seen at Indian Fork.

Figure 19 presents the hydrologic response of the Bills Branch bench wells, B1 and B2. As already noted, the B1 well does not fully penetrate the spoil to the impermeable layer. The tendency towards a minimum value of saturated zone thickness corresponding to the height of the well bottom above the impermeable layer supports the suspicion that observations from the B1 well often represent trapped water above the true phreatic surface. The position on the bench of the B2 well corresponds to that of Indian Fork F2 well site. The small column of water observed at B2 indicates the saturated zone beneath the bench is smaller than that at the Indian Fork Study Spoil Bank. The depth of fill at this position on both benches is approximately the same.

Since it did not reach the impermeable layer, hydrologic data from the B1 well must be viewed differently from that of B2. Several peak values of saturated zone thickness were observed that correspond with peaks seen at B2, and these are considered to be significant. However, a saturated zone thickness of 15 feet corresponds to the bottom of the B1 well. Seventy-five percent of the observations from the well lie between 15 and 16 feet, and all measurements made during dry periods fall within this range. The result is that values of saturated zone thickness less than 16 feet are considered to represent trapped water. Values above 16 feet are taken to represent observations where the phreatic surface had risen significantly above the bottom of the B1 well.

The hydrologic response of the B1 and B2 wells shows seasonal variation. Recharge was erratic and occurred in the winter and spring. During late summer the wells went dry. The response of the saturated zone was compared with daily rainfall records for the Bills Branch Study Basin. Although too voluminous for presentation here, the results indicate peaks observed in saturated zone thickness at the bench wells correspond to periods of concentrated precipitation. This suggests saturation beneath the bench at the Bills Branch Study Spoil Bank is temporal and linked to the infiltration. Percolation is apparently rapid. Figure 19 indicates increases of 4 feet (1.2 m) or more in the column of well water at B1 and B2 would often occur within a two week period.

The change in saturated zone thickness with time for B3 and B5 is shown in Figure 20. The B3 well was initially dry and during the first year showed an unstable response as it filled with a large column of water which was maintained for the remainder of the field record. It is interesting that the appearance of water in the B3 well corresponded with the movement of spoil material that destroyed the upslope C2 well. This and the subsequent response of B3 indicate that the downslope portion of the Bills Branch Study Spoil Bank had become saturated within two years of mining.

The surface configuration of the Bills Branch Study Bank prior to mining was that of a draw. The driller's log for B3 indicates that the original ground surface was buried 30 feet beneath the spoil and that the well penetrated an additional 20 feet of weathered residium material before intercepting intact strata. This indicates that the impermeable layer lies in a natural depression beneath B3 and may account for the large column of water that persists in the well. The storage of water at the toe of the Bills Branch Study Bank was confirmed with the shallow, hand-driven B4 and B5 wells. Although neither reached the impermeable layer, both were observed to maintain significant columns of water.

The B2 and B3 wells show an associated response to the dry summer conditions of 1976, 1977, and 1978. In addition, local maxima in the hydrologic response of B3 appear to correspond with peaks in the response of B2. These observations lend support to the hypothesis of a moving groundwater system at the Bills Branch Study Spoil Bank.

The B5 well showed only small changes in response to changes at the upgradient wells. The problems experienced with mud infiltration and the large volume of water stored at B3 may have produced a damping affect on the response of this well.

Configurations for the Indian Fork and Bills Branch Study Spoil Banks were presented in the chapter on Experimental Design. In these the mining spoil is viewed as a mass of unconsolidated, permeable material overlying the intact, relatively impermeable rock structure of the floor of the mining cut and the mountain slope below the bench. The values of saturated zone thickness presented for each well were calculated from the elevation of the phreatic surface above this impermeable layer. In a similar manner, the boundaries of the saturated zone lying above the impermeable layer can be defined, and the area of the resulting cross section calculated. The saturated zone cross section is of interest for it represents the lens of groundwater present in the spoil. Its area is a convenient measure of the size of this lens.

Models for saturated zone cross sections at the two study spoil banks are presented in Appendix C. The hydrologic data were used to calculate values of saturated zone cross section area for each observation date. Interpolated values were substituted for missing observations at individual wells. The two stainless steel wells at the toe of the Indian Fork Study Bank did not exist during the first 2-1/2 years of the research. During this period average values for their recharged or depleted condition (see Hydrology section of Chapter VI) were used with the appropriate condition assigned on the basis of hydrologic condition observed at the upgradient wells. The calculation of cross section area proceeded by the method of rectangular coordinates around the polygon described by the survey results defining the impermeable layer and the hydrologic data defining the phreatic surface. Tabulated values of saturated zone cross section area associated with each observation date are also included in Appendix C.

Profiles of the maximum, median, and minimum observed saturated zone cross section area at the Indian Fork and Bills Branch Study Spoil Banks are presented in Figures 21 and 22. These serve to further illustrate the difference in storage between the ponded and non-ponded spoil and the range of fluctuation of the phreatic surface within the embankment. Mounding under maximum conditions beneath the F4 and B5 wells suggests substantial infiltration of water on the slope below the bench. Note that at Indian Fork the saturated zone under maximum observed conditions nearly intersects the spoil slope below the F4 well. The dashed phreatic surface beneath the bench of the Bills Branch Bank for the median and minimum observed conditions in Figure 21 indicate its true position is not known. Some degree of mounding against the highwall would be expected, but since it occurs beneath the bottom of the B1 well, it cannot be quantified.

Figure 23 presents the response of the Indian Fork and Bills Branch cross section areas (IF Area 2 and BB Area 4, respectively) with time. The Indian Fork graph shows the same associated response to seasonal variations in precipitation observed at the individual wells. It illustrates the magnitude of change that occurs between

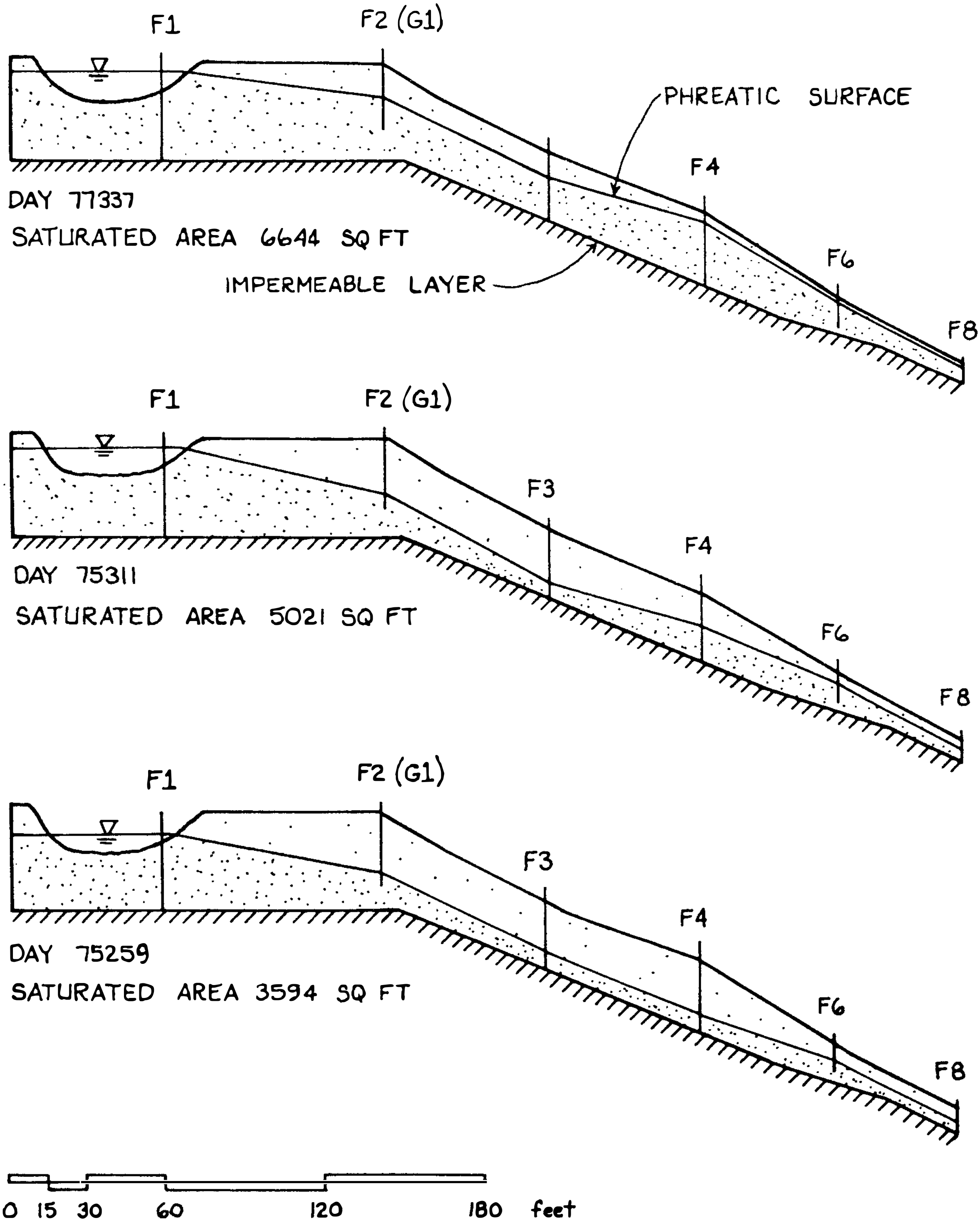


Figure 21. Maximum, Median, and Minimum Observed Saturated Zone Cross Section Areas, Indian Fork Study Spoil Bank.

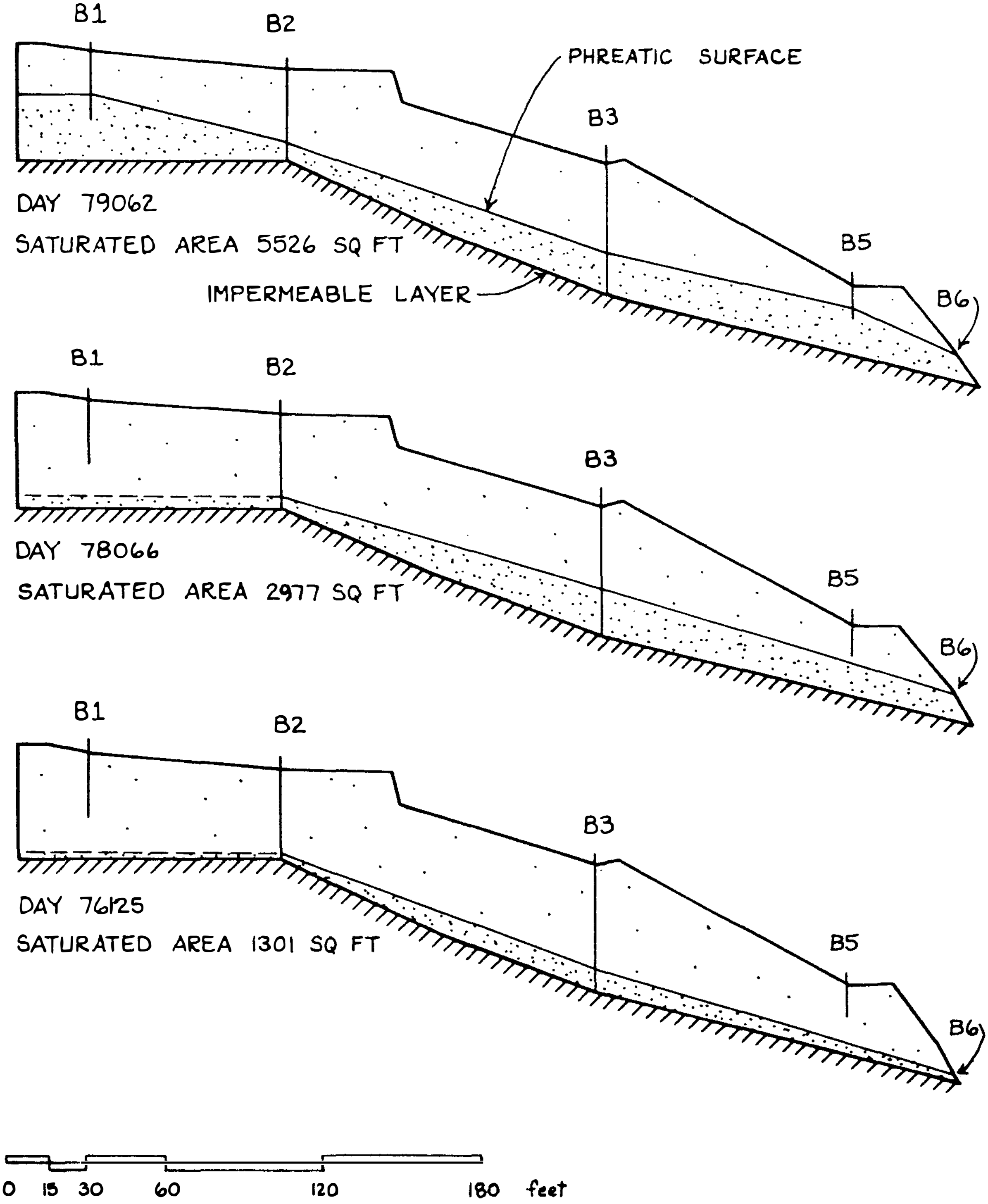


Figure 22. Maximum, Median, and Minimum Observed Saturated Zone Cross Section Areas, Bills Branch Study Spoil Bank.

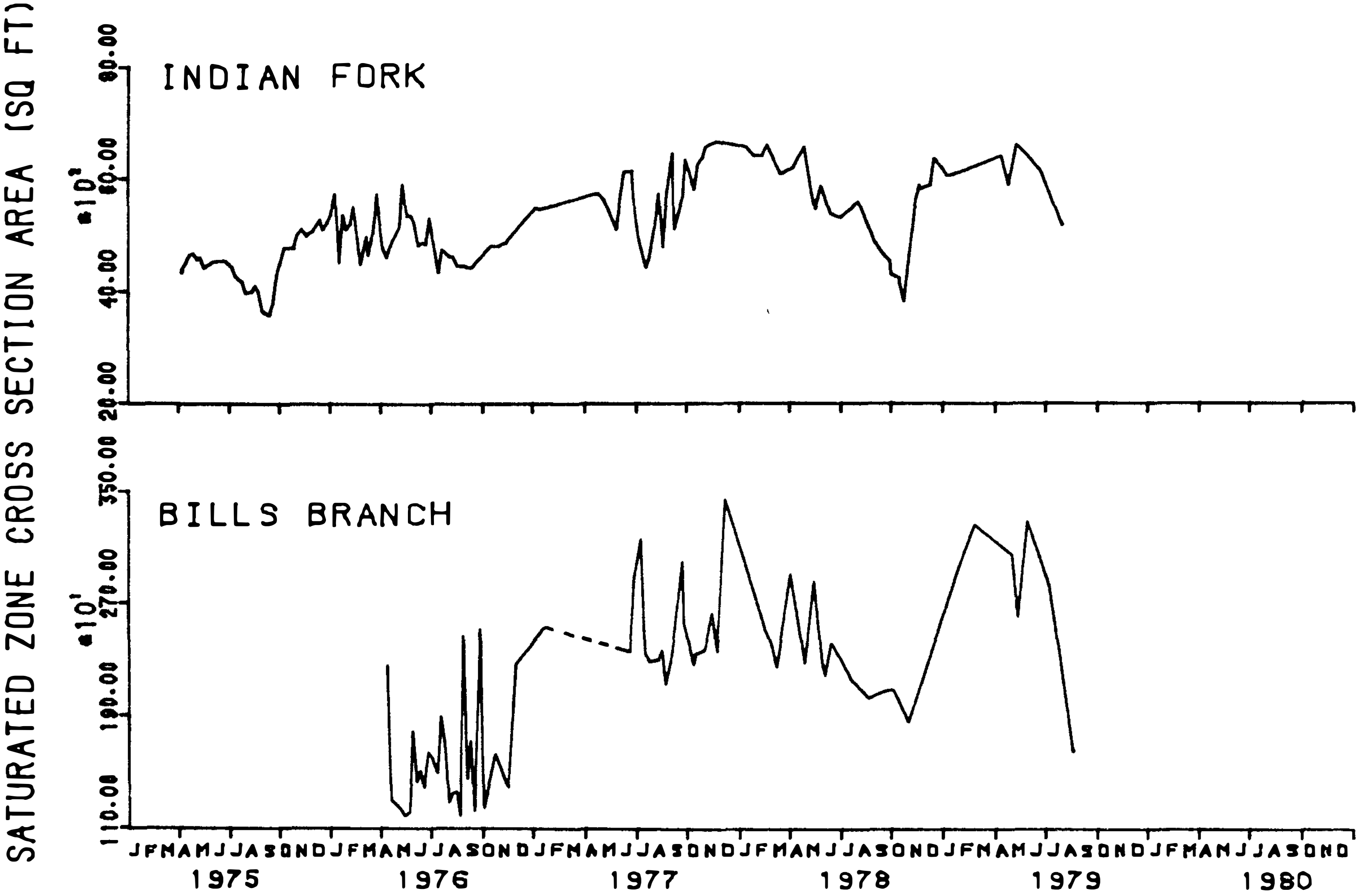


Figure 23. Saturated Zone Cross Section Area with Time, Indian Fork and Bills Branch Study Spoil Banks.

periods of water surplus and water deficit and the increasing degree of spoil saturation suggested by the saturated zone thickness response of the F2, F3, and F4 wells.

The time response of the Bills Branch saturated zone cross section area is dominated by the B3 well. Figure 23 documents the large increase in the size of the saturated zone associated with rapid saturation of the downslope spoil in 1976. After 1976, the column of water in B3 became relatively stable, and peaks observed in the response of the cross section area are due to changes in the bench wells. The cross section shows drawdown during periods of summer drought, though not as distinctly as that seen at Indian Fork. The overall response of the Bills Branch cross section area indicates saturation of the downslope spoil followed by an increasing degree of saturation beneath the bench.

Water Quality

Water quality data have been obtained for the saturated zone at the two study spoil banks, the observation wells, the permanent bench ponds in the Indian Fork Study Basin, and for undisturbed seepages in both study basins. Summaries of this information have been divided into major constituents, trace metals, and special analyses. Tabulations of the field data by study bank, well site, and sample day are contained in Appendices D through G. An overall summary is presented in Table 15 as an assay of constituent concentrations found in subsurface waters at the Indian Fork and Bills Branch Study Spoil Banks. Total concentrations are provided for

Table 15. Assay of Constituent Concentrations Found in Subsurface Water at the Indian Fork and Bills Branch Study Spoil Banks (values in mg/l, except pH)

	Concentration Range	Median Value	Detection Limit
Al Total	DL - 23.7	2.5	0.1
Dissolved	DL - 4.5	0.12	
Ca Total	17 - 284	58	--
Dissolved	4.4 - 182	70	
Cd Dissolved	DL - 0.0413	0.0004	0.0001
Co Total	DL - 0.158	0.018	0.001
Dissolved	DL - 0.500	0.013	
Cr Total	DL - 0.062	0.0028	0.0001
Dissolved	DL - 0.0046	0.0008	
Cu Total	DL - 0.030	0.0046	0.0001
Dissolved	0.0004 - 0.0149	0.0030	
Fe Total	DL - 185	16	0.001
Dissolved	DL - 123	5.4	
K Total	1.8 - 104	5.8	--
Mg Total	8.6 - 154	21	--
Dissolved	7.0 - 150	29	
Mn Total	0.12 - 30	3.7	--
Dissolved	0.012 - 34	3.05	
Na Total	0.3 - 2.4	1.2	--
Ni Total	0.0030 - 0.120	0.0094	--
Pb Total	DL - 0.073	0.0025	0.0001
Dissolved	DL - 0.0096	DL	
Si Dissolved	DL - 9.2	2.2	0.1
Zn Total	0.001 - 3.55	0.025	--
Dissolved	DL - 0.415	DL	0.001
pH	4.4 - 7.8	6.3	--

Table 15. (Continued)

	Concentration Range	Median Value	Detection Limit
Alkalinity as $CaCO_3$	16 - 809	192	--
Organic Carbon as C			
Total	2 - 336	22	--
Dissolved	DL - 66	11	2.0
Sulfate	DL - 800	76	2.0
Sulfide as S^{-2}	DL - 2.76	DL	0.05
Nitrate as NO_3^-	1.6 - 5.3	2.7	--
Phosphate as P	0.009 - 0.055	0.034	--

"DL" denotes concentrations below analytical detection limits comparison with the Beaver Creek and Illinois data presented in the literature review. Median values are given because they are not affected by extreme values as is the mean and better represent "average" conditions found in the spoil.

It is apparent from Table 15 that subsurface sulfate and total metal concentrations are generally lower than that found in the other spoil bank studies (8,9,45). The pH is slightly acidic falling between the neutral values observed in the Illinois area mining spoil and the highly acid drainage associated with contour mining in the Beaver Creek Study. Alkalinity is less than in the Illinois spoil, which contains glacial as well as sedimentary deposits, but is greatly elevated above that found at Beaver Creek. Nutrient concentrations appear to be less than that found in Illinois.

Table 16 is provided to contrast subsurface water quality at the two study spoil banks with drinking water and other standards (70,71), and with undisturbed ground water from the Cumberland Plateau of Tennessee (44). Comparison of the previous table with drinking water standards indicates no potential public health problems are to be expected from heavy metals in drainage from the spoils examined. Of the secondary standards, only iron and manganese were generally exceeded. The spoil drainage also appears suitable for livestock and irrigation purposes. The undisturbed groundwater quality outlined in Table 16 indicates major constituents in the spoil subsurface water are elevated two to twenty times that found in undisturbed strata of the region.

A summary of mean pH and Eh values for wells at the study spoil banks is presented in Figure 24 which serves to illustrate the spatial

Table 16. Water Quality Standards and Representative Groundwater Quality for the Cumberland Plateau of Tennessee (Total Constituent Values in mg/l) (44, 70, 71)

Constituent	Drinking Water Standards		Recommended Limits		Representative Groundwater Quality, Cumberland Plateau
	Primary	Secondary	Livestock	Irrigation	
Alkalinity as $CaCO_3$	--	--	--	--	98.4
Ca	--	--	--	--	16
Cd	0.01	--	0.05	0.01	--
Cr	0.05	--	1.0	0.1	--
Cu	--	1.0	--	--	--
Fe	--	0.3	--	--	1.0
K	--	--	--	--	1.2
Mg	--	--	--	--	3.5
Mn	--	0.05	--	--	--
Na	--	--	--	--	3.9
NO_3^-	--	45	45	--	0.8
Pb	0.05	--	0.1	5.0	--
Si	--	--	--	--	6.4
Sulfate	--	250	--	--	10
Zn	--	5.0	--	--	--

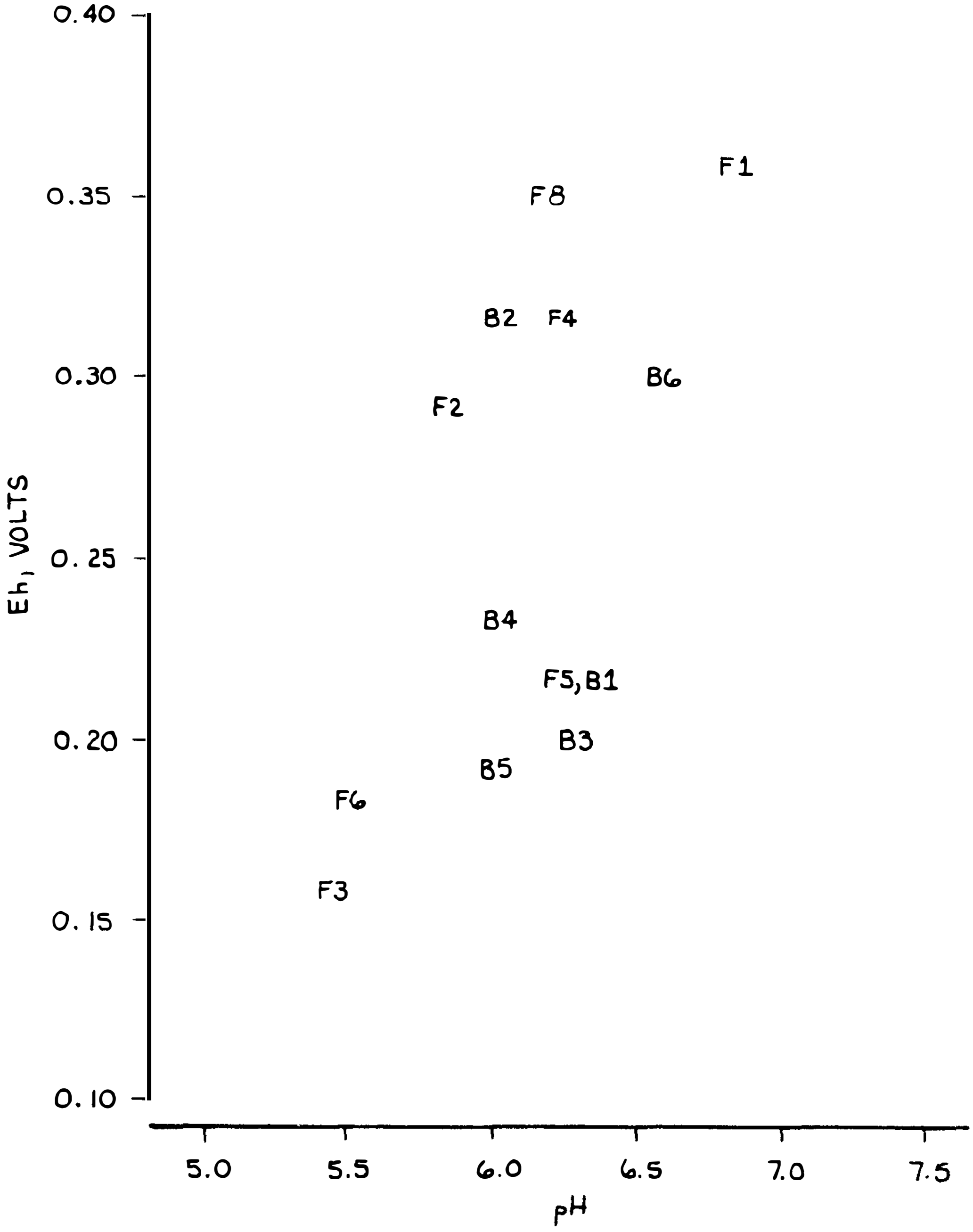


Figure 24. Redox Diagram, Mean Values for Study Spoil Bank Wells.

variation of redox and acid conditions within them. Subsurface water is more reduced and acidic than surface water trapped on the bench, represented here by the F1 well. However, a pattern of increasing reduction and acidity from the bench to the toe was not observed. The figure does suggest a correlation between redox and pH with the F3 and F6 wells the most reduced. Mobilized constituent concentrations would be expected to be greatest in these wells. The F4, F8, and B2 wells are the most oxidized. Constituent concentrations in these should be diminished.

During the course of this research, total constituent samples were often compromised by the presence of excessive solids. Pumping and bailing operations would resuspend spoil material which had infiltrated and settled at the bottom of the well, leading to an unrepresentative total sample. The occasional large difference seen in the concentrations of total and dissolved metal samples illustrates this problem. As a result, more faith is placed on total dissolved constituent samples from which all solids greater than 0.45 μm have been removed. Total constituent values are used only when dissolved data are unavailable.

Statistical summaries of subsurface pH, Eh, and dissolved constituent concentrations for Indian Fork, Bills Branch, and the study spoil banks combined are presented in Table 17. Values below analytical detection limits are indicated by "DL." These observations were omitted from statistical computation of mean and standard deviation. For this and the summaries to follow, pH data were

Table 17. Summary of pH, Eh and Dissolved Constituents Concentrations[a] for Study Spoil Banks

			Total Dissolved Concentrations, mg/l					
Data Set	pH[b]	Eh,v	Fe	Mn	Ca	Mg	Alkalinity as $CaCO_3$ mg/l	Sulfate mg/l
Indian Fork								
Mean	5.7	0.238	14.0	3.68	64.0	23.1	178.3	86.5
Std. Dev.	4.327E-6	0.1215	20.25	4.180	29.48	11.96	94.29	48.64
Median	6.2	0.225	5.7	2.1	56	20	160	70
Maximum	7.5	0.550	123	24	147	57	458	245
Minimum	4.4	-0.010	DL	0.01	21	7	25.8	8
Number	176	160	114	117	117	117	150	171
Bills Branch								
Mean	6.2	0.241	18.7	9.97	93.5	63.0	345.9	182.7
Std. Dev.	1.094E-6	0.0965	21.66	7.747	31.11	26.63	148.1	133.0
Median	6.3	0.230	7	9.3	87	52.5	390	195
Maximum	7.8	0.500	78	34	182	150	809	800
Minimum	5.0	0.010	0.045	0.049	4.4	7.8	18.3	5
Number	104	99	68	68	68	68	95	68
Banks Combined								
Mean	5.8	0.239	15.8	5.99	74.8	37.8	243.3	113.9
Std. Dev.	3.551E-6	0.1124	20.85	6.491	33.23	26.86	143.4	92.54
Median	6.3	0.230	6.2	3.1	70	29	200	82
Maximum	7.8	0.550	123	34	182	150	809	800
Minimum	4.4	-0.010	DL	0.01	4.4	7	18.3	5
Number	280	259	182	185	185	185	245	239

[a] "DL" indicates values below analytical detection limits

[b] Standard deviation values recorded for pH represent hydrogen ion concentrations

converted to molar hydrogen ion concentrations. Standard deviation remains in these units; other values represent the negative log transform of the statistical results. The Indian Fork pond well, F1, was omitted from this summary as was the toe F7 well. The former represents surface water, and the latter is known to have occasionally intercepted surface runoff, thus compromising the validity of its quality data. All quality observations from the Bills Branch bank were considered.

Table 17 provides comparison of subsurface water quality between the two study spoil banks. Overall pH and redox are similar although Indian Fork showed a greater range of pH values. Several observations of acid conditions at the F2 and F3 wells significantly depressed the mean hydrogen ion concentration calculated for this bank. Dissolved metal concentrations, alkalinity, and sulfate are higher at the Bills Branch Study Spoil Bank suggesting a greater degree of acid production and concomitant weathering of the spoil material. This result is consistent with the highwall characterizations made by Franks (20) and the paleoenvironment assessments by Rule and Briggs (54), and Briggs (2). The higher concentrations also suggest a longer hydraulic detention time at the non-ponded Bills Branch Study Bank than at Indian Fork.

Tables 18 and 19 present summary statistics for major constituent concentrations found in each well at the Indian Fork and Bills Branch Study Spoil Banks. In general, iron concentrations exceed manganese, and calcium concentrations exceed those of magnesium.

Table 18. Summary of pH, Eh, and Dissolved Constituent Concentrations[a] for Each Site at Indian Fork Bank

Well	pH[b]	Eh, v	Total Dissolved Concentrations, mg/l				Alkalinity, as $CaCO_3$, mg/l	Sulfate, mg/l
			Fe	Mn	Ca	Mg		
F1								
Mean	6.82	0.357	0.12	0.04	22.8	9.0	35.9	55
Std Dev	2.318E-7	0.0989	0.098	0.036	5.21	1.62	13.88	12.4
Median	7.1	0.335	0.1	0.04	22	9.1	32.2	51
Maximum	8.7	0.530	0.4	0.1	36	12	69.8	81
Minimum	6.0	0.200	DL	DL	14	5.8	6.2	33
Number	35	30	22	19	22	22	28	35
F2								
Mean	5.80	0.296	5.5	0.65	37.2	11.5	110.9	56.8
Std Dev	2.999E-6	0.0385	1.73	0.129	8.96	2.55	27.51	15.22
Median	6.3	0.285	5.0	0.65	35	11	115	60.5
Maximum	6.7	0.360	8.0	0.8	50	15	161	87
Minimum	4.9	0.240	4.0	0.5	29	8.9	68	36
Number	17	12	4	4	4	4	9	18
F3								
Mean	5.43	0.162	21.8	2.41	91.7	35.1	241.4	127.0
Std Dev	6.691E-6	0.0952	28.06	1.911	28.91	11.46	110.96	56.23
Median	6.1	0.155	8.6	2	86	36	225	125
Maximum	6.9	0.370	123	7.7	147	57	458	245
Minimum	4.4	-0.010	0.2	0.35	35	11	30	DL
Number	60	56	42	43	43	43	51	51

Table 18. (Continued)

			Total Dissolved Concentrations, mg/l					
Well	pH[b]	Eh, v	Fe	Mn	Ca	Mg	Alkalinity, as $CaCO_3$, mg/l	Sulfate, mg/l
F4								
Mean	6.20	0.316	3.2	2.87	51.5	17.1	150.1	78.7
Std Dev	8.312E-7	0.1080	8.58	5.122	8.93	3.56	51.85	37.82
Median	6.4	0.300	0.45	0.05	50	17	142	60
Maximum	7.3	0.520	43	24	87	24	325	200
Minimum	5.3	0.120	0.01	0.01	38	10	60	37
Number	51	47	34	35	35	35	45	51
F5								
Mean	6.22	0.217	21.1	6.4	49.8	17.3	168.0	57.0
Std Dev	5.326E-7	0.0890	10.43	2.46	12.92	4.41	48.95	15.07
Median	6.3	0.195	16	6.3	52	16	168	61
Maximum	7.2	0.430	38	11	76	25	245	82
Minimum	5.6	0.110	9.0	3.2	31	11	84	22
Number	19	16	11	11	11	11	14	21
F6								
Mean	5.52	0.180	23.5	9.91	55.7	17.4	191.5	76
Std Dev	2.373E-6	0.1031	5.84	3.166	14.18	4.37	69.90	37.6
Median	5.5	0.180	23	9.9	57	19	160	83
Maximum	6.2	0.460	32	18	74	22	321	130
Minimum	5.0	0.030	14	3.8	33	7	99.4	10
Number	17	17	13	13	13	13	19	18

Table 18. (Continued)

Well	pH[b]	Eh, v	Total Dissolved Concentrations, mg/l				Alkalinity, as $CaCO_3$, mg/l	Sulfate, mg/l
			Fe	Mn	Ca	Mg		
F7								
Mean	6.05	0.280	1.08	2.12	26.6	9.3	50.2	62
Std Dev	1.467E-6	0.1176	0.756	1.571	5.94	2.75	35.19	28.6
Median	6.3	0.255	1.4	2.1	24	8	46	55
Maximum	7.2	0.55	2.0	4.0	37	14	136	110
Minimum	5.3	0.160	0.2	0.2	23	7.1	16	22
Number	10	10	5	5	5	5	12	13
F8								
Mean	6.21	0.348	1.39	2.20	28.5	12.0	56.8	60
Std Dev	6.524E-7	0.1151	1.774	2.499	5.84	2.39	19.50	15.1
Median	6.35	0.300	0.6	1.8	30	12	58.5	60
Maximum	7.5	0.550	5.4	8.8	38	15	92	82
Minimum	5.6	0.190	DL	0.3	21	7	26	35
Number	12	12	11	11	11	11	12	12

---

[a] "DL" indicates concentrations below analytical detection limits

[b] Standard deviation values recorded for pH represent hydrogen ion concentrations

Table 19. Summary of pH, Eh, and Dissolved Constituent Concentrations for Each Site at Bills Branch Bank

Well	pH	Eh, v	Total Dissolved Concentrations, mg/l				Alkalinity, as $CaCO_3$, mg/l	Sulfate, mg/l
			Fe	Mn	Ca	Mg		
B1								
Mean	6.34	0.218	6.4	9.4	102.1	65.1	424.6	212.4
Std Dev	2.623E-7	0.0969	3.50	1.82	23.99	18.22	157.93	69.12
Median	6.3	0.230	5.4	8.6	108	73	455	195
Maximum	7.8	0.430	14	13	147	91	809	335
Minimum	6.0	0.010	1.1	7	62	34	142	123
Number	26	25	15	15	15	15	23	18
B2								
Mean	6.04	0.314	1.13	1.46	111.9	79	285.8	256.5
Std Dev	1.844E-6	0.1008	1.916	0.861	40.84	26.1	90.18	48.67
Median	6.3	0.280	0.4	1.5	99.5	70	278	237.5
Maximum	6.8	0.500	7.0	2.5	182	137	452	385
Minimum	5.0	0.150	0.045	0.049	50	46	136	205
Number	27	25	18	18	18	18	26	20
B3								
Mean	6.26	0.200	43.1	17.1	82.0	47.2	437.4	46.0
Std Dev	3.499E-7	0.0534	16.40	2.49	12.56	4.03	51.39	46.65
Median	6.3	0.200	42	18	79.5	47.5	425	36.5
Maximum	7.7	0.310	78	21	107	56	526	215
Minimum	5.9	0.100	8.9	11	60	38	309	5
Number	32	30	24	24	24	24	31	20

Table 19. (Continued)

			Total Dissolved Concentrations, mg/l					
Well	pH	Eh, v	Fe	Mn	Ca	Mg	Alkalinity, as $CaCO_3$, mg/l	Sulfate, mg/l
B4								
Mean	6.01	0.231	3.0	4.1	66.4	40.2	168.7	175.0
Std Dev	9.455E-7	0.0847	2.51	1.64	9.40	5.22	96.71	17.68
Median	6.3	0.190	2.3	3.8	67	42	166	160
Maximum	6.6	0.380	7.4	5.9	80	46	300	205
Minimum	5.6	0.180	1.4	2.5	54	32	31.3	160
Number	5	5	5	5	5	5	5	5
B5								
Mean	5.98	0.154	25.8	19.8	77.4	81.0	153.9	139.0
Std Dev	1.683E-6	0.1094	16.79	13.61	48.89	58.24	109.45	162.41
Median	6.6	0.193	27	21	99	83	193	91
Maximum	7.7	0.254	45	34	107	150	254	320
Minimum	5.3	0.183	4.2	3.1	4.4	7.8	18.3	6
Number	8	8	4	4	4	4	5	3
B6								
Mean	6.55	0.302	0.9	0.85	101.5	116	97.0	630.0
Std Dev	2.541E-7	0.0711	1.13	0.495	44.55	19.8	16.42	240.42
Median	6.7	0.310	----	----	----	----	105	----
Maximum	7.0	0.400	1.7	1.2	133	130	110	800
Minimum	6.1	0.180	0.1	0.5	70	102	70	460
Number	6	6	2	2	2	2	5	2

Subsurface concentrations are elevated above those observed in the Indian Fork pond. The breakout sites, F5 and B6, are more oxidized than nearby wells. The tables indicate spatial variation among the wells and suggest the inverse correlation between constituent concentration and pH observed by other researchers (37,46). A similar correlation is suggested for the redox potential, and metal cations show an association with alkalinity and sulfate. As with the pH and Eh data presented in previous Figure 24, no consistent increasing or decreasing pattern for constituent concentrations was observed down the spoil embankment. The elevated pH and Eh, and the depressed constituent concentrations seen in F4 and B2 appear anomalous when compared to their up and down gradient wells. The quality results for these sites suggest the percolation and storage of oxygenated water separate from input at the head of the spoil bank.

Major constituent summaries for the observation wells, permanent bench ponds in Indian Fork, and undisturbed seepage samples appear in Table 20. The results from Observation Wells 1 and 2 were significantly different from the other observation wells owing to the presence of acid mine drainage on the bench above them. Significantly higher values of calcium, magnesium, and sulfate for Seep 5 suggested it may not represent an undisturbed sample. Subsequent investigation found it lay downgradient of an abandoned mining operation and so was omitted from the statistical summary for seepage samples.

As a group, the observation wells were much less chemically reduced than the wells at the study spoil banks. As a result, iron and manganese

Table 20. Summary of pH, Eh, and Dissolved Constituent Concentrations for Observation Wells, Permanent Bench Ponds, and Undisturbed Seepages

Data Set	pH	Eh, v	Total Dissolved Concentrations, mg/l				Alkalinity, as $CaCO_3$, mg/l	Sulfate, mg/l
			Fe	Mn	Ca	Mg		
Observation Wells								
Mean	5.83	0.430	6.44	4.86	63.3	26.9	168.5	106
Std Dev	1.161E-3	0.0933	12.30	4.749	31.30	12.43	128.70	70.44
Median	6.00	0.485	1.8	3.4	55	25	158	100
Maximum	6.7	0.545	34	14.9	132	54	390	265
Minimum	5.3	0.320	DL	0.4	26	13	21.4	28
Number	9	9	9	9	9	9	8	9
Permanent Ponds								
Mean	6.10	0.370	DL	DL	25.0	10.3	40.82	79
Std Dev	1.163E-6	0.0739			17.28	11.80	23.44	102.13
Median	6.40	0.400			20	6.3	45.4	47
Maximum	6.90	0.440			58	34	78.5	285
Minimum	5.50	0.240			10	3	12.5	22
Number	6	6	6	6	6	6	6	6
Seepages								
Mean	4.10	0.450	DL	DL	1.2	1.4	3.27	12
Std Dev	6.221E-5	0.0459			0.713	0.542	2.462	1.966
Median	5.00	0.415			1.4	1.5	4.33	12
Maximum	6.5	0.490			1.7	2.2	6.38	16
Minimum	3.8	0.355			0.1	0.5	1.78	10
Number	6	6	6	6	6	6	6	6

concentrations were lower. The greater oxygen presence indicated by elevated Eh values in the observation wells may have been due to the temporary, one shot nature of their installation. These wells were generally shallower than those at the study spoil banks. Calcium, magnesium, alkalinity, and sulfate levels in the observation wells are similar to those found in the toe wells of the study banks. However, variation in constituent concentrations among the observation wells was of the same magnitude as that among the spoil bank wells. Median values for the permanent bench ponds compare well with those for the Indian Fork pond, F1. Mean values for alkalinity and sulfate were elevated by Pond 2 which is partially fed by surface runoff from mining disturbance above it. The seepage samples were taken to document undisturbed, shallow groundwater quality in the two study basins. The summary statistics presented in Table 20 indicate it is moderately acidic, weakly buffered, and contains little dissolved mineral material. The range of values in the data is small.

Trace metal constituents for the two study spoil banks are summarized in Table 21. A similar summary for observation wells and seepage samples is presented in Table 22. In addition to descriptive statistics, the fraction of detection limit values is indicated in the tables as the ratio of samples below the analytical detection limit to the total number of observations. Detection limit values were omitted from statistical computation of the mean and standard deviation. Analytical detection limits for the trace metals are outlined in Appendix A.

Table 21. Summary of Trace Metal Constituent Concentrations for Study Spoil Banks

Data Set	Total Dissolved Constituents, mg/l				Total Ni, mg/l	Total Dissolved mg/l	
	Cd	Co	Cr	Cu		Pb	Zn
Indian Fork							
Mean	0.0008	0.0237	0.0009	0.0032	0.0214	0.0010	0.035
Std. Dev	1.583E-3	2.629E-2	6.956E-4	2.534E-3	2.798E-2	5.663E-4	2.120E-2
Median	0.0004	0.015	0.0008	0.0024	0.010	0.0010	DL
Maximum	0.0072	0.138	0.0032	0.0097	0.120	0.0019	0.05
Minimum	DL	DL	DL	0.004	0.003	DL	DL
Fraction DL	3/22	11/84	4/22	0/22	0/25	11/22	17/19
Bills Branch							
Mean	0.0061	0.0324	0.0010	0.0042	0.0068	0.0036	0.102
Std. Dev	1.327E-2	7.918E-2	1.963E-3	2.866E-3	2.463E-3	3.438E-3	1.261E-1
Median	0.0008	0.0154	0.0012	0.0036	0.006	DL	DL
Maximum	0.0413	0.500	0.0046	0.0149	0.010	0.0096	0.415
Minimum	DL	DL	DL	0.0013	0.0035	DL	DL
Fraction DL	7/21	1/39	2/22	0/22	0/6	17/32	12/21
Banks Combined							
Mean	0.0031	0.0267	0.0012	0.0037	0.0186	0.0018	0.090
Std. Dev.	8.948E-3	5.078E-2	9.023E-4	2.716E-3	2.572E-2	2.202E-3	1.162E-1
Median	0.0006	0.015	0.0010	0.0030	0.0094	DL	DL
Maximum	0.0413	0.500	0.0046	0.0149	0.120	0.0096	0.415
Minimum	DL	DL	DL	0.0004	0.003	DL	DL
Fraction DL	10/43	12/123	6/44	0/44	0/31	28/44	29/40

Table 22. Summary of Trace Metal Concentrations for Observation Wells and Undisturbed Seepage Samples

		Total Dissolved Concentrations, mg/l						
Data Set		Cd	Co	Cr	Cu	Ni	Pb	Zn
Observation Wells								
Mean		0.0070	0.0227	0.0025	0.0159	0.0134	0.0063	0.265
Std Dev		9.751E-3	1.756E-2	2.105E-3	3.418E-2	7.061E-3	1.195E-2	0.2523
Median		0.0015	0.0210	0.0017	0.0031	0.0170	0.0019	0.280
Maximum		0.0230	0.0483	0.0066	0.0933	0.0180	0.0277	0.510
Minimum		0.0004	0.0015	0.0005	0.0008	0.0053	DL	0.006
Fraction DL	0/7	0/7	0/7	0/7	0/3	2/7	0/3	
Seepages								
Mean		0.0004	0.0033	DL	0.0005		DL	DL
Std Dev		1.414E-4			1.708E-4			
Median		0.0004	DL		0.0005			
Maximum		0.0005	0.0033		0.0007			
Minimum		0.0002	DL		0.0003			
Fraction DL	0/4	3/4	4/4	0/4		4/4	4/4	

As previously discussed, heavy metal concentrations in the spoil banks examined are low, seldom, if ever, exceeding levels described by drinking water standards. Table 21 indicates little difference in trace metal concentrations at the two study spoil banks. The majority of lead and zinc observations fall below analytical detection limits. Dissolved cadmium and chromium concentrations are on the order of 1 ppb, dissolved copper 5 ppb, and total nickel 10 ppb. Franks' highwall characterization indicates cobalt concentrations in the spoil material are less, by as much as an order of magnitude, than those of chromium, copper, nickel, lead, and zinc (20). Yet, cobalt was consistently found to exceed the trace metals other than zinc by a factor of ten. Dissolved cobalt and zinc concentrations were roughly equivalent. Mean and median observation well concentrations for cadmium, chromium, copper, lead, and zinc in Table 22 exceed those observed at the study spoil banks but still fall below drinking water standards. Ranges for these data overlap. The seepage samples show detectable amounts of cadmium, cobalt, and copper only, all at the 1 ppb level or less.

Special analyses made on limited sampling sets from the study spoil banks are summarized in Table 23 along with information for total potassium and sodium and total dissolved aluminum and silicon. Appreciable dissolved organic carbon was found in the Indian Fork and Bills Branch Banks at similar levels in each. The nature of this material is not known, but its presence complicates the spoil water chemistry by suggesting the possibility of organic chelates which

Table 23. Summary of Special Sample and Additional Constituent Concentrations for Study Spoil Banks

Data Set	Dissolved Organic Carbon as C mg/l	Sulfide as S^{2-} mg/l	Total Nitrate as NO_3^- mg/l	Total Dissolved Phosphate as P mg/l	Total Concentrations, mg/l		Total Dissolved Concentrations, mg/l	
					K	Na	Al	Si
Indian Fork								
Mean	19.0	1.44	2.28	0.029	10.1	1.5	0.43	2.65
Std. Dev.	18.55	0.906	1.038	1.732E-2	14.43	0.469	1.025	1.410
Median	9.5	0.35	1.65	0.039	5.9	1.5	0.12	2
Maximum	66	2.76	3.9	0.039	104	2.4	4.5	9.2
Minimum	DL	DL	1.6	0.009	1.8	0.3	DL	DL
Number	16	8	6	3	55	19	22	19
Bills Branch								
Mean	20.6	0.34	4.05	0.055	3.71	0.93	0.44	2.82
Std. Dev.	14.17		1.453		1.73	0.103	0.768	1.263
Median	13.5	DL	4.4		3.6	0.90	0.125	2.5
Maximum	51	0.34	5.3		6.6	1.1	3.45	4.9
Minimum	DL	DL	2.1		1.8	0.8	DL	DL
Number	9	6	4	1	7	6	22	20
Banks Combined								
Mean	19.6	1.22	2.99	0.036	9.38	1.36	0.44	2.74
Std. Dev.	16.75	0.926	1.461	1.921E-2	13.74	0.478	0.891	1.597
Median	13.5	DL	2.7	0.039	5.8	1.3	0.12	2.2
Maximum	66	2.76	5.3	0.055	104	2.4	4.5	9.2
Minimum	DL	DL	1.6	0.009	1.8	0.3	DL	DL
Number	25	14	10	4	62	25	44	39

can enhance the solubility of metal constituents (60). Sulfide, at detectable levels was found only under reduced conditions in the F3, B3, and B5 wells. Both it and carbon showed an inverse correlation with pH and redox. Spot sampling for nitrate and phosphate was conducted, and these concentrations proved to be low. Though not included in Table 23, special analyses were made for ferrous iron to determine its proportion of total dissolved iron in the spoil subsurface water. The results, tabulated in Appendix Table G-3, indicate ferrous iron is the major iron species in the spoil, accounting for 60 to 100% of the total.

Concentrations of sodium and potassium are small when compared to divalent cations in the spoil. The same is true for concentrations of aluminum and silicon. With the exception of a few extreme values for potassium, the range of these constituents is also small and essentially identical at the two study spoil banks. For the range of observed pH, silicon is undersaturated with respect to amorphous silica but is of the same magnitude as solubility with respect to crystalline quartz (saturation below pH 8.5 with respect to amorphous silica is approximately 60 mg/l and for quartz, 6.0 mg/l (21,60)). Aluminum concentrations in the spoil are most likely depressed by its insolubility in moderately acid and neutral solutions (total Al solubility for pH 4.0 to 8.0 is less than 1.0 mg/l (60)). These observations suggest spoil concentrations of the clay related constituents may be controlled by solubility. Previous X-ray diffraction work has identified quartz as a major solid phase in wells at the study spoil banks (52).

Soil Sampling

The soil sampling results indicate the assumption of homogeneous and isotropic conditions cannot be applied at the toe of the two study spoil banks. The spoil material sampled is a fine-grained, predominately clay soil with an effective diameter of approximately 0.2 μm. The soil matrix, however, is interspersed with sandstone and friable shale fragments of various size ranging from pebbles to boulders. Dry field density is approximately 105 lbs/ft^3 and specific gravity ranges from 2.65 to 2.75. The Unified Soil Classification would be "fine-grained, CL." The results of the spoil soil sampling are presented in Table 24. Data for individual soil samples are tabulated in Appendix H.

Visual inspection of the walls of sample pits dug for the soil sampling effort lead to the above conclusion on the anisotropic nature of the spoil. Saturation was sporadic across the soil profile and to some degree with depth. Seams of flowing water were encountered adjacent to dry material. No actual fractures were observed, but flow paths appeared to be associated with rock fragments. At depth all the spoil material was saturated and more weathered than the unsaturated profile above. Information in well driller's logs from the beginning of the research indicates segregation of fill materials was practiced at both study spoil banks during mining. This suggests the entire spoil profile is heterogeneous with both small and large nonuniformities.

The spoils examined are similar to the spoils of the Beaver Creek Study (8,9,43) but substantially finer grained than those of the Illinois researchers (45), Rogowski (49,50), and Pionke, Rogowski, and Montgomery (46). Laboratory determinations of soil pH using the paste method were conducted on several field samples of the spoil

Table 24. Study Spoil Bank Soil Sampling, Results

Study Bank & Sample	Dry Field Density (lbs/ft^3)	Specific Gravity	Unified Soil Classification				Porosity n	Void Ratio e	Notes
			Division and Group	% Passing No. 200 Sieve (<0.075mm)	% Clay (<0.002mm)	d_{10} (mm)			
INDIAN FORK									
Toe, unsaturated	107	2.65	Fine-grained, CL	68	32	0.0002	0.350	0.538	Heterogeneous soil profile; predominately clay with shale and sandstone fragments of various size.
saturated	94	2.67	Fine-grained, CL	48	25	0.0002	0.435	0.769	
BILLS BRANCH									
Lower Slope, unsaturated	112	2.74	Fine-grained, CL	52	20	0.0003	0.342	0.521	Moderately weathered soil profile; clay with friable shale.
Toe, saturated	102	2.72	Fine-grained, CL	62	21	0.0002	0.397	0.659	Highly weathered clay with sandstone fragments of varying size.

material. The results indicate the spoil at the two study banks would be classified as acid under Vimmerstedt and Struthers' system presented in the literature review (73). Chemical quality of the subsurface spoil water supports this classification.

CHAPTER VI

DISCUSSION

Hydrology

The time response of the hydrologic data presented in the preceding chapter suggests an overall pattern for saturated zone thickness observed in wells at the two study spoil banks. During periods of water surplus (as defined by the elevation of the pond well, F1), the Indian Fork wells indicate a recharged condition that was somewhat erratic in 1976 and became more stable in subsequent years. During dry periods the wells draw down to a depleted condition. Recharge following a period of depletion is rapid and sometimes unstable. The bench wells at the Bills Branch Study Spoil Bank show a general depleted condition that is broken by peaks of rapid recharge followed by drawdown. The downslope wells show less distinct recharged or depleted states, but do undergo drawdown during dry periods indicated by the response of the bench wells.

From these observations is a simple model describing the hydrologic response of the study wells. The water column in each well is viewed as fluctuating between a recharged and a depleted condition. These represent periods of water surplus and water deficit in the spoil bank. The depleted condition may also represent a base level of groundwater storage that changes very little with time. The classification of hydrologic condition for a particular value of saturated zone thickness is relative to the values that precede and follow it in time.

To check the validity of these hydrologic conditions, it is necessary to examine the distributions of the saturated zone thickness data. Hydrologic data that are normally distributed about the mean would indicate a trend towards one average condition with maximum and minimum values representing extreme events. Data which are highly skewed or bi-modal would lend support to the idea of two distinct conditions, one representing unusual conditions or both having equal weight.

The SAS UNIVARIATE procedure was used to compute descriptive statistics for the hydrologic data, to test for normality, and to produce histogram plots of the data distributions. The descriptive statistics have already been presented in the Chapter V. Table 25 presents an evaluation of the data distributions and the results of normality testing. An assessment of hydrologic condition is also provided for each well. The table indicates the saturated zone thickness observed in study wells does not tend towards one, central value (as would be indicated by a normal distribution) but is either weighted towards one extreme or is bi-modal. This suggests the model of hydrologic condition is a valid description of the hydrologic response seen in the study wells.

Periods of hydrologic condition have been assigned to each well at both study spoil banks. This information will be used later in the water quality discussion. Hydrologic condition was evaluated according to assessments made in Table 25 and according to local changes observed in response of the saturated zone thickness at each well.

Table 25. Saturated Zone Thickness, Nature of the Data (values in feet)

Well Site	F1	F2	F3	F4	F6	F8	B1	B2	B3	B5
EVALUATION OF DATA DISTRIBUTION	Heavily weighted toward maximum values, negative skew	Platykurtic distribution	Bi-modal distribution with negative skew	Heavily weighted toward minimum values, positive skew	Negative skew, small minimum mode	Weighted towards maximum values, negative skew	Heavily weighted towards minimum values, positive skew	Heavily weighted towards minimum values, positive skew	Bi-modal with negative skew	Leptokurtic distribution with positive skew
Mean	27.12	14.29	9.61	11.02	9.52	2.53	16.37	2.08	15.53	19.69
Median	27.61	13.87	10.72	8.32	10.07	2.71	15.70	0.99	17.38	19.57
Skewness	-2.2481	0.3080	-0.3855	1.1011	-0.4493	-0.7400	2.6427	1.7872	-0.5187	2.1256
Kurtosis	4.5736	-0.6754	-1.3982	0.0378	-0.5258	-0.1096	6.2364	2.1215	-1.3271	7.0442
D-statistic (W-statistic)	0.2995	0.0879	0.1395	0.1854	(0.9460)	(0.9136)	0.3813	0.3348	0.2040	0.2688
Probability > D (Probability < W)	<0.01	0.017	<0.01	<0.01	(0.072)	(<0.01)	<0.01	<0.01	<0.01	<0.01
Conclusions on Test of Normality[a]	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho
ASSESSMENT OF HYDROLOGIC CONDITION	Recharged above 26.5 ft.	Approximate division between recharged and depleted conditions at 13 ft.	Division between recharged and depleted conditions at 7.5 ft.	Initial recharged condition above 10 ft. after 1977 above 12.5 ft.	Recharged above 8.5 ft.	Recharged above 2 ft.	Recharged above 16.5 ft.	Recharged above 3 ft.	Recharged conditions above 15.5 ft. and defined by local condition	Recharged conditions above 20 ft. and defined by local condition

[a] Ho: Data are a random sample taken from a normal distribution.

The time response of the hydrologic data also suggests an associated response of the wells at each study spoil bank with each other and in the case of Indian Fork with the Indian Fork pond, F1. In addition to this associated response, the size of the saturated zone in each bank appears to have increased over the course of the study. These observations are subjected to statistical verification by correlation analysis in Tables 26 through 28.

The correlation matrix for saturated zone thickness at the Indian Fork Study Spoil Bank indicates a highly significant association in the hydrologic response of the wells. This is the expected result and confirms the presence of a flowing groundwater system controlled by the elevation of the bench pond. The analysis for Bills Branch confirms the hydrologic association between the bench wells, B1 and B2, but indicates the response of the mid-slope well, B3, is independent of hydrologic input at the head of the spoil. In contrast, the toe well, B5, shows a significant positive correlation with B2. Subsurface flow through the Bills Branch Study Spoil Bank is apparently small compared to the volume stored at the B3 well.

The significance of the observed increase in the size of the saturated zone at the study spoil banks is tested in Table 28. Rejection of the null hypothesis for saturated zone thickness at the major study wells and for median cross section area at each bank indicates the increasing degree of saturation with time is greater than what would be expected by chance alone. The apparent first order, linear slope for cross section area at Indian Fork is 0.952 $ft^2/$

Table 26. Correlation Matrix, Saturated Zone Thickness at the Indian Fork Wells

		F1	F2	F3´	F4	F6	F8
F1	R value	1.0000	0.4816	0.2290	0.2739	0.7281	0.7866
	Prob >|R|	0	0.0001	0.0105	0.0021	0.0001	0.0001
F2	R value		1.0000	0.4009	0.5812	0.6830	0.5512
	Prob >|R|		0	0.0001	0.0001	0.0001	0.0003
F3	R value			1.0000	0.5693	0.7760	0.7189
	Prob >|R|			0	0.0001	0.0001	0.0001
F4	R value				1.0000	0.7927	0.6874
	Prob >|R|				0	0.0001	0.0001
F6	R value					1.0000	0.8582
	Prob >|R|					0	0.0001
F8	R value						1.0000
	Prob >|R|						0

Table 27. Correlation Matrix, Saturated Zone Thickness at the Bills Branch Wells

		B1	B2	B3	B5
B1	R value	1.0000	0.4633	-0.0546	0.1491
	Prob >|R|	0	0.0001	0.6586	0.2434
B2	R value		1.0000	0.1098	0.5345
	Prob >|R|		0	0.3729	0.0001
B3	R value			1.0000	0.1802
	Prob >|R|			0	0.1880
B4	R value				1.0000
	Prob >|R|				0

Table 28. Correlations of Saturated Zone Thickness and Cross Section Area with Time

	Saturated Zone Thickness					
	F1	F2	F3	F4	F6	F8
Correlation Coefficient (R)	-0.0986	0.2607	0.7611	0.5667	0.0001	0.0338
Probability >|R|	0.2680	0.0031	0.0001	0.0001	0.9993	0.8384
Conclusion on Correlation[a]	Accept Ho	Reject Ho	Reject Ho	Reject Ho	Accept Ho	Accept Ho
Number of Observations	128	127	128	129	42	39

	Saturated Zone Thickness				Cross Section Area	
	B1	B2	B3	B5	Indian Fork (Area 2)	Bills Branch (Area 4)
Correlation Coefficient (R)	0.2387	0.3555	0.5920	0.1251	0.5761	0.6780
Probability >|R|	0.0379	0.0016	0.0001	0.3286	0.0001	0.0001
Conclusion on Correlation	Accept Ho	Reject Ho	Reject Ho	Accept Ho	Reject Ho	Reject Ho
Number of Observations	76	76	68	63	133	68

[a] Ho: Rho = 0, i.e., no significant correlation between the inputted variables and time.

day (0.089 m^2/day) and at Bills Branch, 1.13 ft^2/day (0.105 m^2/day). However, this increasing saturation must be independent of rainfall before it is significant with respect to weathering of the spoil material. Representative annual values of median saturated zone cross section area at each bank and mean annual rainfall from the Petros and Oak Ridge recording stations were examined with the results presented in Table 29. Although correlation coefficients were large, the small sample size produced insufficient evidence to reject the null hypothesis. This suggests the increasing saturation observed at the study spoil banks is independent of short-term trends in annual rainfall and may be associated with progressive surface and subsurface weathering of the spoil material.

From soil mechanics, increasing saturation when accompanied by an increase in pore water pressure is known to reduce shear strength along planes of weakness within an earthen fill (21). Thus, increases in the size of the saturated zone noted above raise question as to the long term stability of the study spoil banks. Cowan (11) has performed a geotechnical analysis of three contour surface mining spoils in the New River Basin which experienced major landslides within one year of mining. He identified two principle failure surfaces on the downslope of these spoils. One along the boundary of the fill and colluvial material of the original slope. The second along the deeper colluvium-rock interface. His results indicate saturation was a factor in the failure of the embankments. The configuration of these spoils was similar to that of the Bills Branch Study Spoil Bank. Long term slope stability of the contour

Table 29. Correlation of Mean Annual Saturated Zone Cross Section Area with Annual Rainfall

	Rainfall Recording Station	
Cross Section Area	Petros	Oak Ridge
Indian Fork (AREA 2)		
Correlation Coefficient (R)	0.5603	0.3734
Probability >|R|	0.3259	0.5358
Conclusion on Correlation[a]	Accept Ho	Accept Ho
Number of Years	5	5
Bills Branch (AREA 4)		
Correlation Coefficient (R)	0.8518	0.6840
Probability >|R|	0.1482	0.3160
Conclusion on Correlation	Accept Ho	Accept Ho
Number of Years	4	4

[a] Ho: Rho = 0, i.e., no significant correlation between annual values of cross section area and annual rainfall

surface mining spoil is of environmental concern because of the large sediment volumes generated by landslide areas during storm events.

The capacity of the contour surface mining spoil to capture and store water has been verified by the well systems at the two study spoil banks. Combining porosity data with the saturated zone cross section areas presented in the Results Chapter yields storage volumes for a one foot wide cross section of the study spoil bank profiles. At the ponded Indian Fork Bank maximum observed hydrologic conditions correspond to 2890 ft^3/ft (269 m^3/m), median conditions, 2184 ft^3/ft (203 m^3/m), and minimum conditions, 1564 ft^3/ft (145 m^3/m). At the non-ponded Bills Branch Study Bank maximum observed storage was 2194 ft^3/ft (204 m^3/m), median storage, 1182 ft^3/ft (110 m^3/m), and the minimum observed volume 516 ft^3/ft (48 m^3/m). If these values are representative of the contour mining spoil in general, a one mile section of ponded bench has a surface and subsurface storage capacity of over 265 acre-feet (3.28 E 5 m^3). A similar section of non-ponded spoil may store over 140 acre-feet (1.73 E 5 m^3) of groundwater. Since mining disturbance on a given seam may extend several miles through a watershed, storage in the contour surface mining spoil may substantially influence basin hydrology.

The existence of a saturated zone at locations other than the study spoil banks was confirmed by the success of the observation wells at accessing subsurface water in sufficient volume for chemical sampling. Of 15 installations, 12 had water. All ponded sites in the Indian Fork Study Basin were found to maintain large saturated zones. It must be noted that the observation wells were placed at locations where surface features suggested subsurface water was present. However, reconnaissance of the downslope spoil that accompanied the observation well effort indicates some degree of spoil saturation throughout most of the Indian Fork and Bills Branch Basins. Seepage areas, cattails, willow and cottonwood trees are plentiful near the toe as well as localized slope failures, creeping and sliding spoil on the slope below the mining bench. Based on field experience, the author feels confident in characterizing the spoils examined as generally containing a saturated zone. In addition, the size of this zone is known to vary spatially across the spoil bank and is a function of surface conditions.

Several results from this research conflict with the conclusions of Crosby, Overton, and Minear (12) for the ponded and non-ponded contour surface mining spoil. As stated in the Results, rapid change observed in the Indian Fork wells and associated with changes in the elevation of the pond well, F1, suggest the residence time of water in the ponded study spoil bank may be shorter than the two years calculated from their hydrologic modeling. The large volume of water stored at the B3 well and the increasing saturation observed beneath the bench at the Bills Branch Study Spoil Bank indicate a large saturated zone will form in the non-ponded contour surface mining spoil. Success of the observation wells at non-ponded sites in the two study basins verified the lateral extent of this saturation. The hydrologic response of the B1 and B2 wells indicates percolation through the spoil to the saturated zone is rapid. Both the hydrologic and water quality results from the Indian Fork F4 well suggest substantial infiltration and percolation of water separate of input from the surface water pond on the bench. Taken together these results suggest the assumptions underlying the work of Crosby, Overton, and Minear may need modification to better describe the spoil material and field conditions.

Water Quality

An ideal result of the subsurface quality investigation would be a set of constituent concentrations representative of spoil bank water quality throughout the study basins and perhaps the entire New River area. To this end, distributions of the quality data summarized in the Results Chapter for each study spoil bank and for both banks combined were tested for normality. The nature of the major constituent data is presented in Table 30 and that of the trace metals and additional constituents in Table 31. In both, the hypothesis that the data represent a random sample taken from a normally distributed population is evaluated using either the Shapiro-Wilk W-test or the Kolmogorov-Smirnov D-statistic depending upon sample size. Log and inverse transformations on the data were also evaluated.

With the exception of Eh, major constituents at the study banks tend toward log normality or have no normal form. This suggests the presence of underlying spatial and temporal variation as discussed in the Statistical Methods section of the Experimental Design. The

Table 30. Evaluations of Normality, Major Constituents at the Study Spoil Banks

			Total Dissolved Constituents					
Data Set	pH	Eh	Fe	Mn	Ca	Mg	Alkalinity as $CaCO_3$	Sulfate
Indian Fork								
D-statistic	0.1252	0.0601	0.2448	0.1904	0.1614	0.1779	0.1244	0.1479
Probability > D	<0.01	>0.15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Conclusion on Ho[a]	Reject Ho	Accept Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho
Evaluation of Distribution	No normal form	Normal	No normal form	Log normal	Log normal	Inverse form normal	No normal form	No normal form
Bills Branch								
D-statistic	0.1609	0.0826	0.2592	0.1529	0.0975	0.1763	0.1357	0.0981
Probability > D	<0.01	0.094	<0.01	<0.01	0.106	<0.01	<0.01	0.100
Conclusion on Ho	Reject Ho	Accept Ho	Reject Ho	Reject Ho	Accept Ho	Reject Ho	Reject Ho	Accept Ho
Evaluation of Distribution	No normal form	Normal	No normal form	No normal form	Normal	No normal form	Log normal	Normal
Banks Combined								
D-statistic	0.1249	0.0672	0.2251	0.1997	0.0828	0.1445	0.1307	0.1542
Probability > D	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Conclusion on Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho
Evaluation of Distribution	No normal form	No normal form	No normal form	No normal form	Log normal	No normal form	No normal form	No normal form

[a] Ho: Data are a random sample taken from a normal distribution

Table 31. Evaluations of Normality, Trace Metals and Addition Constituents at the Study Spoil Banks

	Total Dissolved Constituents							Total Constituents			
Data Set	Cd	Co	Cr	Cu	Pb	Zn	Al	Si	Ni	K	Na
Indian Fork											
W-statistic (D-statistic)	0.4221	0.2006	0.7384	0.8829	0.9501		0.3954	0.6352	0.6155	(0.3029)	0.9453
Probability < W (Probability > D)	<0.01	<0.01	<0.01	<0.01	0.622		<0.01	<0.01	<0.01	(<0.01)	0.341
Conclusion on Ho[a]	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Accept Ho		Reject Ho	Reject Ho	Reject Ho	Reject Ho	Accept Ho
Evaluation of Distribution	No normal form	Log normal	Log normal	Log normal	Normal		No normal form	Inverse SI Normal	Log normal	No normal form	Normal
Bills Branch											
W-statistic (D-statistic)	0.4819	0.3051	0.7967	0.7386	0.6996	0.6581	0.5646	0.9461	0.8785	0.9291	0.9157
Probability < W (Probability > D)	<0.01	<0.01	<0.01	<0.01	0.014	<0.01	<0.01	0.428	0.308	0.509	0.455
Conclusion on Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Accept Ho	Accept Ho	Accept Ho	Accept Ho
Evaluation of Distribution	Inverse Cd normal	Log normal	Log normal	Log normal	Inverse Pb normal	Log normal	Log normal	Normal	Normal	Normal	Normal
Banks Combined											
W-statistic (D-statistic)	0.3426	(0.3090)	0.7930	0.8472	0.5803	0.6148	0.4842	0.8054	0.5764	(0.3106)	0.9743
Probability < W (Probability > D)	<0.01	(<0.01)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	(<0.01)	0.718
Conclusion on Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Accept Ho
Evaluation of Distribution	No normal form	Log normal	Log normal	Log normal	Log normal	Log normal	No normal form	Log normal	Log normal	No normal form	Normal

[a] Ho: Data are a random sample taken from a normal distribution

combined data distributions reflect the lack of normality at each bank. Distributions for the trace metals are influenced by extreme maximum values and by a majority of observations at or near analytical detection limits. These sample sets are small and, except for cadmium, tend to be log normal. Aluminum and potassium are also influenced by extreme maximum values. Only the sodium data shows normality at both study spoil banks. Normality testing was also performed for major constituents at the observation wells, permanent bench ponds, seepage samples, and individual well sites. This work is summarized in Table 32 and was used to select data transformations necessary to ensure normality in the statistical testing that follows.

The general lack of normality for overall constituent data at each study spoil bank precludes direct statistical analysis of the observed difference between them. Table 32 indicates the transformations necessary for normality at each site are not uniform. Thus, site by site statistical comparison at each bank would be improper. In an attempt to develop constituent concentrations representative of subsurface water in the two study spoil banks, the average of median concentrations at each well was computed. The median values at each bank were found to approximate a normal distribution suggesting this approach is legitimate. T-tests for major constituents at the study spoil banks were performed on these data. These results and representative subsurface water quality are presented in Table 33. Although the concentration difference of all constituents between individual wells may be great, only calcium, magnesium, and alkalinity show statistically significant difference between the two banks.

Table 32. Evaluation of Sample Distributions, Observation Wells, Permanent Ponds, Seepage Samples, and Study Spoil Bank Wells.

			Total Dissolved Constituents					
Data Set	pH	Eh	Fe	Mn	Ca	Mg	Alkalinity as $CaCO_3$	Sulfate
Observation Wells	Normal	No normal form	Log Normal	Log Normal	Normal	Normal	Normal	Normal
Permanent Ponds	Normal	Normal			Log Normal	Log Normal	Normal	Log Normal
Seepage Samples	Normal	Normal			No normal form	Normal	Normal	Approx. Normal
Indian Fork								
F1	Normal	Log Normal	Log Normal	No normal form	Normal	Normal	Normal	Normal
F2	Normal	Normal	Log Normal	Log Normal	Normal	Normal	Normal	Normal
F3	No normal form	Normal	Log Normal	Log Normal	Normal	Normal	Normal	No normal form
F4	No normal form	Log Normal	Log Normal	Log Normal	Inverse Ca Normal	Normal	Log Normal	No normal form
F5	Normal	Normal	Log Normal	Normal	Normal	Normal	Normal	Normal
F6	Normal	Normal	Normal	Normal	Normal	Normal	Log Normal	Nomral
F8	Normal	Normal	Log Normal	Log Normal	Normal	Normal	Normal	Normal
Bills Branch								
B1	Proton normal	Normal	Normal	Normal	Normal	Normal	No normal form	Log Normal
B2	No normal form	Log Normal	No normal form	No normal form	Log Normal	Log Normal	Normal	No normal form
B3	No normal form	Normal	Normal	Normal	Log Normal	Normal	Normal	Log Normal
B4	Normal	No normal form	Log Normal	Normal	Normal	Normal	Normal	Normal
B5	Normal	Normal	Normal	Normal	No normal form	Normal	Normal	Normal

Table 33. Representative Subsurface Water Quality and Statistical Comparison of the Indian Fork and Bills Branch Study Spoil Banks

			Total Dissolved Concentrations (mg/l)					
	pH	Eh,v	Fe	Mn	Ca	Mg	Alkalinity as $CaCO_3$ (mg/l)	Sulfate (mg/l)
Means								
Indian Fork	6.16	0.236	8.94	3.45	51.7	18.5	144.8	74.9
Bills Branch	6.36	0.219	15.49	10.58	90.6	63.1	303.4	144.0
t-score	1.2449	-0.5131	0.7687	1.8366	3.4700	5.4502	2.6956	1.8383
Prob >|t|	0.2446	0.6202	0.4618	0.0994	0.0070	0.0004	0.0246	0.1297
Conclusion on Ho[a]	Accept Ho	Accept Ho	Accept Ho	Accept Ho	Reject Ho	Reject Ho	Reject Ho	Accept Ho

[a] Ho: population means are equal, i.e., no significant difference in constituent concentrations between the two wells

Summary statistics for individual wells presented in the Results indicate spatial variation of constituent concentrations within the two study spoil banks. The significance of this variation was tested with one way analysis of variance for fixed treatment effects on a balanced and normalized subset of the quality data. The results are presented in Table 34 and indicate the above variation is statistically significant. This result is similar to that of the Illinois researchers for the area mining spoil (45). Duncan's multiple range test was applied to the results of the analysis of variance to segregate the wells at each bank into groups of similar water quality. These results were inconclusive as the groupings for each quality constituent were different. In general, the Indian Fork F4 and F6 and the Bills Branch B2 and B3 wells always demonstrated significantly different constituent concentrations.

The spatial variation in subsurface water quality observed at the two study spoil banks suggests similar variation exists laterally throughout the spoil. As a result, the range of valves observed in the permanent wells may not adequately represent spoil water quality throughout the two study basins. T-tests of observation well quality data as a group against that of individual wells at the study spoil banks were made to verify that the bank quality data is not anomalous. This analysis is summarized in Table 35.

Rejection of the null hypothesis implies a significant difference between the observation wells and the study well tested. T-score probabilities falling outside the 0.01 rejection criteria (99 percent confidence level) are underscored in the table. The results

Table 34. Analysis of Variance for Spatial Variation at the Study Spoil Banks.

			Total Dissolved Constituents				Alkalinity as $CaCO_3$	
	pH	Eh	Fe	Mn	Ca	Mg		Sulfate
<u>Indian Fork</u>								
Wells: F3, F4, F5, F6, & F8								
F Score	4.46	9.76	29.34	44.10	37.64	23.90	23.08	5.99
Probability > F	0.0051	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0009
Conclusions on Ho[a]	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho
<u>Bills Branch</u>								
Wells: 81, B2, & 83								
F Score		5.21	19.72	61.67	2.42	6.96	4.94	13.01
Probability > F		0.0108	0.0001	0.0001	0.1225	0.0080	0.0139	0.0006
Conclusion on Ho		Reject Ho	Reject Ho	Reject Ho	Accept Ho	Reject Ho	Reject Ho	Reject Ho

[a] Ho: Treatment effects are equal, i.e., <u>no</u> significant spatial variation among constituent concentrations at the inputted sites

Table 35. T-tests of Observation Well Quality Data with That of the Study Spoil Bank Well Sites (values exceeding 0.01 rejection criteria are underscored)[a]

				Total Dissolved Constituents				Alkalinity as	
		pH	Eh	Fe	Mn	Ca	Mg	$CaCO_3$	Sulfate
Indian Fork									
F2	t score	-0.1481	3.9797	-1.7059	3.7616	2.2979	3.5545	1.2409	2.0753
	Prob >|t|	0.8836	0.0024	0.1351	0.0045	0.0438	0.0058	0.2519	0.0700
F3	t score		-6.8294	2.7678	-1.1945	2.4828	1.6476	1.4145	0.6795
	Prob >|t|		0.0001	0.0093	0.2591	0.0181	0.1086	0.1649	0.5005
F4	t score		-2.4695	-1.4641	-2.1279	-0.6410	-2.2304	0.5470	
	Prob >|t|		0.0177	0.1539	0.0411	0.5379	0.0543	0.6005	
F5	t score	1.4696	-5.6494	3.4976	1.7419	-1.2139	-2.2093	-0.0095	-2.0640
	Prob >|t|	0.1537	0.0001	0.0111	0.1137	0.2521	0.0526	0.9926	0.0717
F6	t score	2.1742	5.9730	-3.8402	-2.8686	0.7854	2.2688	-1.2402	1.5245
	Prob >|t|	0.0518	0.0001	0.0082	0.0183	0.4497	0.0480	0.2504	0.1566
F8	t score	-1.3945	1.7395	0.9949	1.5903	4.2727	3.5455	2.4361	1.6991
	Prob >|t|	0.1793	0.0981	0.3356	0.1292	0.0015	0.0069	0.0441	0.1208
Bills Branch									
B1	t score		-5.0527	2.0942	2.8904	2.8385	4.7358		3.2051
	Prob >|t|		0.0001	0.0767	0.0191	0.0119	0.0003		0.0099
B2	t score		-2.6259		-2.2673	2.9473	6.7035	2.7996	4.5879
	Prob >|t|		0.0145		0.0519	0.0083	0.0001	0.0099	0.0014
B3	t score		-6.7635	5.3741	7.1023	2.1027	3.9384	-5.8207	-2.5800
	Prob >|t|		0.0001	0.0001	0.0001	0.0654	0.0006	0.0001	0.0171
Toe (B4, B5)									
	t score	-0.9264	5.5302	-1.6901	-1.6692	-0.5386	-2.1617	0.1349	-0.5615
	Prob >|t|	0.3653	0.0001	0.1131	0.1145	0.5976	0.0577	0.8944	0.5828

---

[a] Ho: population means are equal, i.e., no significant difference between the Observation Wells and the Study Spoil Bank Well Site.

indicate the range of values seen at the observation wells falls within that of the study spoil banks. Thus, the permanent wells appear to adequately characterize spoil water quality for the Pewee and Big Mary seams in the Indian Fork and Bills Branch study basins, respectively. A similar testing procedure was employed to compare quality of the permanent bench ponds in Indian Fork with that of the spoil bank pond, F1. The results are presented in Table 36 which indicates no significant spatial variation in the quality of surface water trapped on the upper bench of the Indian Fork Study Basin.

This analysis procedure was also used to compare spoil water quality with that of the undisturbed seepage samples taken from the shallow groundwater system above mining disturbance in the study basins. With the exception of pH, a statistically significant difference in constituent concentrations was found for all spoil wells. This result indicates the spoil bank is the source of degraded water quality observed in the mining disturbed study basins.

In addition to spatial variation at the study spoil banks, temporal variation may underlie distributions of the quality data at each well site. Both long and short term trends need be considered. Long term temporal variation is related to the time span of degraded water quality associated with spoil drainage. A significant decrease in subsurface concentrations would suggest an ultimate return to premining conditions. Short term temporal variation is related to seasonal and hydrologic changes within the mining spoil.

Temporal variation in constituent concentrations at each well over the course of the study is examined in Table 37. Significant

Table 36. T-test of Permanent Bench Pond Quality Data with the Indian Fork Pond, F1

	pH	Eh	Alkalinity as $CaCO_3$	Sulfate
t-score	3.2241	-0.3430	-0.4951	0.2042
Probability > |t|	0.0026	0.7337	0.6389	0.8461
Conclusion on Ho[a]	Reject Ho	Accept Ho	Accept Ho	Accept Ho

	Total Dissolved Constituent			
	Fe	Mn	Ca	Mg
t-score			-0.3054	0.5495
Probability > |t|			0.7719	0.2461
Conclusion on Ho			Accept Ho	Accept Ho

[a] Ho: population means are equal, i.e., no significant difference between the permanent bench ponds and the Indian Fork pond, F1

Table 37. Correlations of Subsurface Constituent Concentrations with Time for the Study Spoil Bank Wells (significant correlation values are underscored)

Bank and Site		pH	Eh	Total Dissolved Constituents				Alkalinity as $CaCO_3$	Sulfate
				Fe	Mn	Ca	Mg		
Indian Fork									
F2	R value	-0.2960	0.0290	-0.5637	0.9859	-0.4321	-0.3688	0.4420	-0.4226
	Prob $\geq$|R|	0.2658	0.9324	0.4363	0.0141	0.5679	0.6311	0.2336	0.0911
	Slope[a]				3.329E-3				
F3	R value	0.5167	0.3853	-0.6518	-0.7698	0.1381	-0.1854	0.3732	0.1073
	Prob >|R|	0.0005	0.0185	0.0002	0.0001	0.4921	0.3546	0.0297	0.5213
	Slope	6.814E-3	0.0870	-0.0473	-3.905E-3			0.0981	
F4	R value	-0.1350	0.5965	-0.4899	-0.4924	-0.4355	-0.2571	-0.5324	-0.1724
	Prob >|R|	0.4127	0.0002	0.0151	0.0124	0.0295	0.2147	0.0014	0.2939
	Slope		0.1355	-0.0116	-6.898E-3	-0.0103		-0.0650	
F5	R value	-0.1792	0.4761	-0.6580	-0.4861	-0.3989	-0.3130	-0.4813	-0.5314
	Prob >|R|	0.4628	0.0623	0.0278	0.1296	0.2243	0.3486	0.0814	0.0132
	Slope			-0.0224					-0.0209
F6	R value	0.2218	0.0962	-0.6183	-0.4163	-0.8159	-0.3864	-0.5291	-0.0934
	Prob >|R|	0.4268	0.7330	0.0321	0.1783	0.0012	0.2147	0.0425	0.7508
	Slope			-0.0100		-0.0313			
F8	R value	-0.3067	0.6257	-0.2476	0.5786	0.4477	0.6681	0.2898	0.5085
	Prob >|R|	0.3322	0.0295	0.4903	0.0622	0.1673	0.0246	0.3608	0.0914
	Slope		0.1931				4.209E-3		
Bills Branch									
B1	R value	-0.3425	0.7237	0.4462	0.5275	-0.2172	-0.7187	-0.5841	0.2074
	Prob >|R|	0.1512	0.0007	0.2286	0.1445	0.5745	0.0446	0.0175	0.5177
	Slope		0.2560					-0.3241	
B2	R value	-0.4260	0.7012	-0.5850	-0.4326	-0.6048	-0.7283	-0.2958	-0.4219
	Prob >|R|	0.0690	0.0012	0.0457	0.1601	0.0372	0.0072	0.2334	0.1510
	Slope		0.1626				-0.0449		
B3	R value	-0.4225	0.2931	0.3895	0.5089	-0.8825	-0.6372	-0.0720	-0.5342
	Prob >|R|	0.0354	0.1646	0.1101	0.0310	0.0001	0.0001	0.7383	0.0126
	Slope					-0.0243	-6.545E-3		-0.0666
B4	R value	0.4986	0.3440	-0.6957	-0.4265	0.1700	0.3128	0.6477	-[illegible].775[illegible]
	Prob >|R|	0.3926	0.5708	0.1921	0.4739	0.7846	0.6083	0.2373	0.1237
	Slope								
B5	R value	-0.7759	0.3608	-0.9047	-0.7660	-0.9891	-0.8839	-0.8277	-0.9934
	Prob >|R|	0.0236	0.3799	0.0953	0.2339	0.0109	0.1161	0.0836	0.0731
	Slope	-1.491E-3				-0.1302			

[a] Apparent 1st order linear slope for significant correlations, units of constituent concentration per day

trends detected by the correlation analysis are underscored, and a value of the apparent first order, linear slope is provided. Most notable are decreases in iron and manganese seen at the F3 and F4 wells. These were accompanied by an apparent increase in pH, Eh, and alkalinity. The Bills Branch bench wells experienced a significant increase in Eh, and the B3 well showed significant decrease in concentrations of calcium, magnesium, and sulfate.

Figures for the time response of constituent concentrations at each well were generated as a part of this research. Three will be presented here to discuss temporal variations indicated for the F3 and B3 wells. The pH and Eh for the F3 well in Figure 25 suggest a steady increase over time, whereas dissolved iron and manganese concentrations indicated in Figure 26 dropped sharply in the spring of 1977 to relatively constant levels. Although not shown, the time response of these constituents at the F4 well was identical. Comparison of Figures 25 and 26 with previous Figure 17, page 100, presenting the time response of saturated zone thickness at the F3 and F4 wells indicate these changes correspond to the large recharge that was observed in the spring of 1977 and generally maintained for the remainder of the study. A close comparison of the figures for the summer of 1977 illustrates short term temporal variation in the spoil and suggests a relationship between constituent concentration and hydrologic condition.

Figure 27 presents the time response of dissolved calcium and magnesium at the B3 well. Apparent first order, linear slopes for the rather dramatic decreases are -0.02 and -0.006 mg/l-day, respectively.

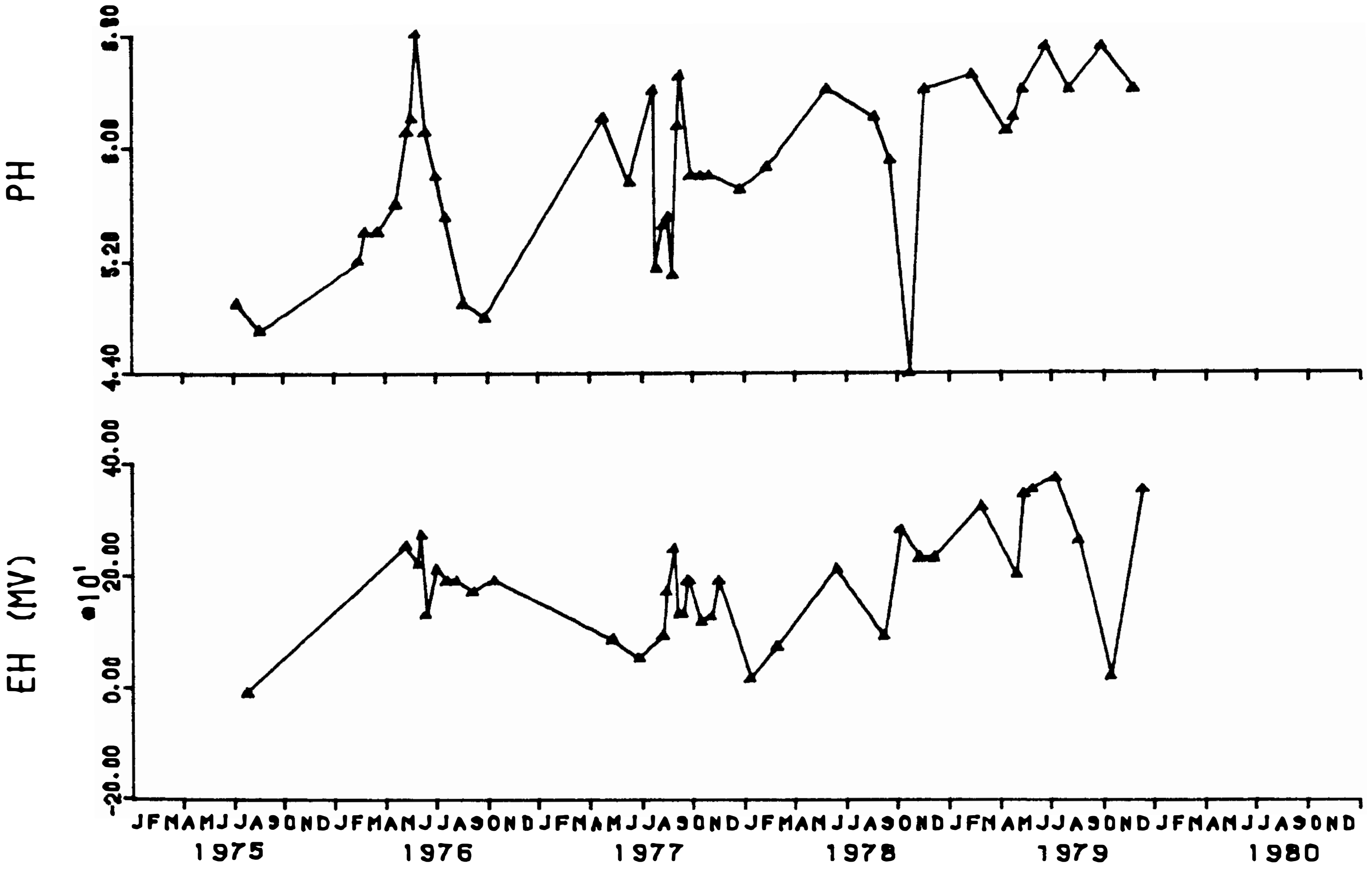


Figure 25. Response of pH and Eh with Time at the Indian Fork F3 Well.

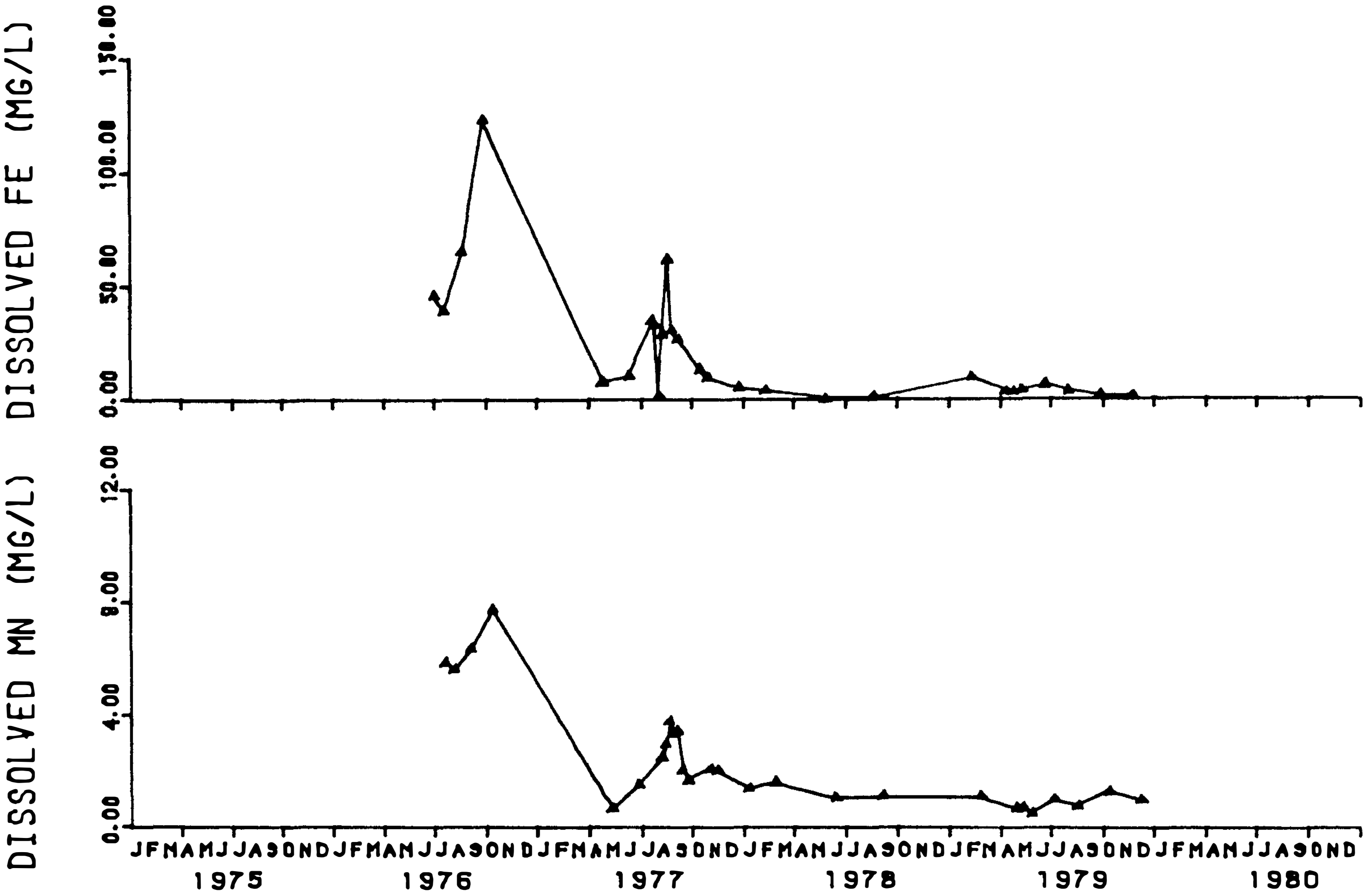


Figure 26. Response of Dissolved Iron and Manganese with Time at the Indian Fork F3 Well.

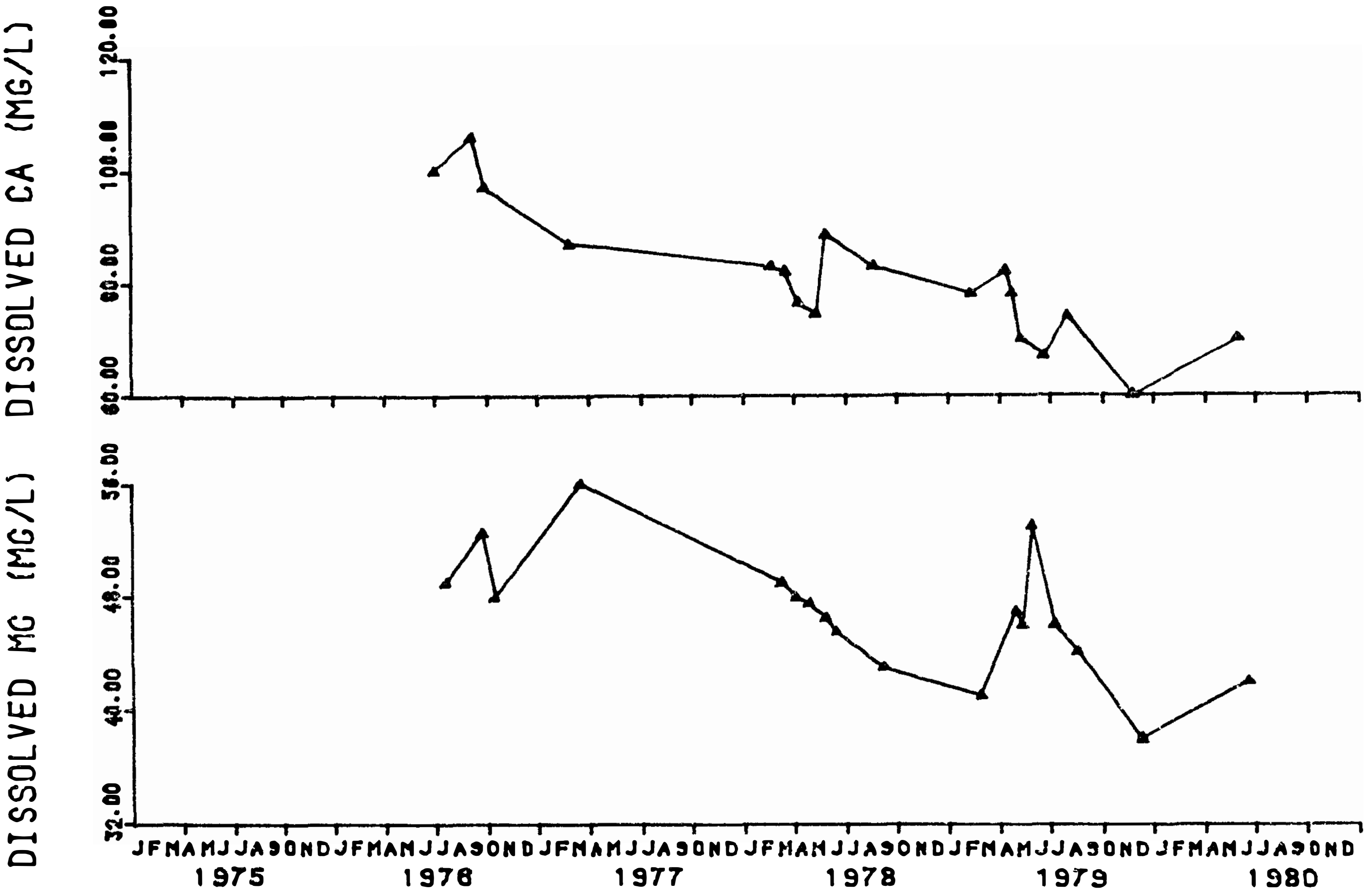


Figure 27. Response of Dissolved Calcium and Magnesium with Time at the Bills Branch B3 Well.

Comparison of this figure with the hydrologic response for B3 presented in Figure 20, page 103, indicates the decrease in constituent concentrations began with the large and permanent increase in the size of the saturated zone in November 1976. The decrease of sulfate concentrations in the well parallels those of calcium and magnesium.

The hydrologic and quality response of the F3 and F4 wells suggests increasing saturation results in a tempering of pH and redox conditions with a resulting decrease in iron and manganese concentrations and an increase in alkalinity. The obvious dilution of the initial masses of calcium, magnesium, and sulfate at the B3 well indicated by its hydrologic and quality response suggest this is the mechanism by which hydrologic changes affect subsurface constituent concentrations in the spoil.

Variation of constituent concentrations with hydrologic conditions developed earlier is evaluated for selected spoil bank wells in Table 38. Examination of mean recharged and depleted quality data suggests a significant difference. Elevated constituent concentrations are generally associated with periods of water deficit in the spoil. The pH and Eh are depressed. The testing results indicate variation with hydrologic condition at the F4 well is significant. The small sample size (few quality observations for depleted conditions were available) and large standard deviation of the data from F3 and B2 may account for the failure to produce overall significant results at these sites. In general, subsurface quality data at the study spoil banks shows an association with hydrologic condition. Although significant long term trends are suggested for

Table 38. T-tests of Hydrologic Condition for Subsurface Constituent Concentrations at Selected Study Spoil Bank Wells

			Total Dissolved Constituents					
Well	pH	Eh	Fe	Mn	Ca	Mg	Alkalinity as $CaCO_3$	Sulfate
F3								
Means								
Recharged	5.85	153	8.24	1.54	110	39.4	282	124
Depleted	5.52	88.8	31.9	3.00	85.0	37.3	220	164
t-score	-1.3474	1.7588	2.9968	4.3896	-1.6969	-0.3390	-1.0253	2.0834
Prob >|t|	0.2386	0.1125	0.0282	0.0014	0.1206	0.7416	0.3294	0.0638
Conclusion on Ho[a]	Accept Ho	Accept Ho	Reject Ho	Reject Ho	Accept Ho	Accept Ho	Accept Ho	Reject Ho
F4								
Means								
Recharged	6.49	320	0.19	0.23	46.8	13.9	117	67
Depleted	6.03	192	14.3	10.2	61.0	19.8	209	72
t-score	-3.5580	-3.4035	6.2859	2.9817	2.1661	3.5293	3.2578	0.2988
Prob >|t|	0.0035	0.0059	0.0001	0.0307	0.0729	0.0042	0.0062	0.7702
Conclusion on Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Accept Ho
B2								
Mean								
Recharged	6.05	389	0.31	0.66	80.2	58.5	252	241
Depleted	6.41	291	2.47	1.38	144	100	364	293
t-score	1.3426	-1.7787	1.6234	1.8173	3.0058	3.2060	2.6804	1.1863
Prob >|t|	0.2326	0.1057	0.1788	0.1067	0.0169	0.0125	0.0231	0.3072
Conclusion on Ho	Accept Ho	Accept Ho	Accept Ho	Accept Ho	Reject Ho	Reject Ho	Reject Ho	Accept Ho

[a] Ho: population means are equal, i.e., <u>no</u> significant difference between recharged and depleted constituent concentrations

several constituents at individual wells, no overall decrease in spoil concentrations is indicated by the data.

Similar to the storage volumes presented for each study spoil bank in the hydrologic discussion the mass of major quality constituents may be developed at each bank. Using representative subsurface concentrations calculated earlier from median values at the study wells, median observed saturated zone cross section area, and porosity, mobilized subsurface constituent masses for a unit width of the spoil profile are computed. These results are presented in Table 39 as kilograms per foot width of the profile.

Subsurface concentrations at the non-ponded Bills Branch Study Spoil Bank are larger than at Indian Fork, but since its volume is small, constituent masses at both banks are similar. If conditions at the study banks as outlined in Table 39 are assumed representative of the spoil in general, a one mile section of ponded bench along the Pewee coal contains 6380 lbs. (2900 kg) of mobilized iron, 2420 lbs. (1100 kg) of manganese, 37,180 lbs. (16,900 kg) of calcium, 13,200 lbs. (6000 kg) of magnesium, 104,060 lbs. (47,300 kg) of alkalinity as $CaCO_3$, and 53,680 lbs. (24,400 kg) of sulfate. It is interesting to note that the alkalinity calculated here is equivalent to 26.5 metric tons of lime with a neutralizing capacity for 46.4 metric tons of sulfuric acid. Masses in an equivalent section of non-ponded spoil along the Big Mary coal are similar in magnitude. Thus, the contour mining spoil represents a tremendous reservoir of mobilized constituent mass.

Table 39. Representative Subsurface Concentrations and Mobilized Constituent Mass at the Study Spoil Banks Under Median Observed Hydrologic Conditions

Study Bank	Total Dissolved Constituents Fe	Mn	Ca	Mg	Alkalinity as $CaCO_3$	Sulfate
<u>Indian Fork</u>						
Representative Subsurface Concentrations (mg/l)	8.94	3.45	51.7	18.5	144.8	74.9
Mobilized Subsurface Constituent Mass (kg/ft)	0.553	0.213	3.20	1.14	8.96	4.63
<u>Bills Branch</u>						
Representative Subsurface Concentrations (mg/l)	15.42	10.58	90.6	63.1	303.4	144.0
Mobilized Subsurface Constituent Mass (kg/ft)	0.516	0.354	3.03	2.11	10.16	4.82

For the spoils examined, however, trace metal mass is small. In the one mile section described above, 265 acre-feet (3.28 E 5 m^3). of surface and subsurface water contain less than 4 lbs. (2 kg) of each trace constituent.

Chemical Relationships in the Water Quality Data

The summary statistics and the time response of the study wells suggest associations among constituents monitored at the spoil bank. These are explored in Table 40. As before, significant correlations are underscored. The apparent first order, linear slope is provided for the column variables as a function of each row. Significant Eh and pH association indicated by the data is not surprising. Many of the half cells which may control redox potential in the spoil have underlying dependence upon hydrogen ion activity. For example, the redox equilibria between ferrous iron and amorphous ferric hydroxide,

$$Fe(OH)_3 \text{ (amorph, s)} + 3H^+ + e = Fe^{+2} + 3H_2O \qquad (6.1)$$

or between sulfide and sulfate (60),

$$SO_4^{2-} + 9H^+ + 8e = HS^- + 4H_2O. \qquad (6.2)$$

The inverse association of iron and pH is related to the kinetics of ferrous iron oxidation and subsequent precipitation as ferric hydroxide. This reaction is sufficiently rapid above pH 6.0 to control total iron concentrations in the spoil and is second order with respect to increasing hydroxide ion activity ($k''_{\text{pH } 6.0}$ = -0.25/day; $k''_{\text{pH } 7.0}$ = -25/day). In contrast, manganese oxidation

Table 40. Correlation Between Selected Subsurface Constituents at the Study Spoil Banks (significant correlations are underscored)

			Total Dissolved Constituents				Alkalinity as	
Constituent		Eh	Fe	Mn	Ca	Mg	$CaCO_3$	Sulfate
pH								
	R value	0.1588	-0.3004	-0.0476	0.0414	0.0974	0.1999	0.0428
	Prob >|R|	0.0116	0.0001	0.5296	0.5841	0.1973	0.0022	0.5135
	Slope[a]	33.42	-12.91				59.50	
	Number	252	175	177	177	177	232	235
Eh								
	R value		-0.330	-0.2780	-0.2807	-0.1226	-0.3044	0.0879
	Prob >|R|		0.0001	0.0002	0.0001	0.1029	0.0001	0.2002
	Slope		-0.0583	-0.0156	-0.0800		-0.3848	
	Number		176	178	178	178	228	214
Sulfate								
	R value	0.0879	-0.2876	-0.2923	0.5042	0.6450	0.1592	
	Prob >|R|	0.2002	0.0001	0.0001	0.0001	0.0001	0.0192	
	Slope		-0.0730	-0.0217	0.1901	0.1651	0.2674	
	Number	214	170	170	170	170	216	
Alkalinity								
	R value	-0.3044	0.3016	0.5398	0.7209	0.6650		0.1592
	Prob >|R|	0.0001	0.0001	0.0001	0.0001	0.0001		0.0192
	Slope	-0.2408	0.0451	0.0239	0.1761	0.1251		0.0948
	Number	228	176	178	178	178		216
Fe, Mn			Ca, Mg			Al, Si		
	R value	0.5875		R value	0.8222		R value	0.4561
	Prob >|R|	0.0001		Prob >|R|	0.0001		Prob >|R|	0.0067
	Slope	1.883		Slope	1.055		Slope	0.2758
	Number	183		Number	185		Number	34

---

[a] Apparent first order linear slope significant correlations, units of constituent concentration per unit concentration.

requires pH in excess of 9.0 (60). Since spoil waters seldom exceed pH 7.0, manganese and pH show no significant association.

Dissolved levels of iron and manganese would be expected to increase under reduced conditions where their oxidation to insoluble forms is retarded. Table 40 indicates this to be the case. The strong inverse association of calcium and alkalinity with redox is interesting. If acid production is associated with reduced conditions as is suggested by the positive correlation of pH and Eh, alkalinity produced from the dissolution of carbonates should be diminished. The well data, however, suggest either the partial pressure of carbon dioxide is increased under reduced conditions (suggesting increased subsurface microbial activity) thus driving more alkalinity into the system, or calcium and alkalinity in the spoil originate from exchange and neutralization reactions with the aluminosilicate minerals.

Since sulfate concentration is a measure of the extent of pyrite oxidation, the negative correlation of iron and sulfate is initially puzzling. Also puzzling is the lack of association between sulfate and redox. One would expect a greater yield of sulfate under oxidizing than under reducing conditions. However, once mobilized, constituents traveling through the spoil experience varying redox conditions as indicated by the spatial variation seen among the study wells. Iron mobilized at the head of the spoil bank may be oxidized and precipitate by the time it reaches down gradient wells. The same is true for manganese. Sulfate, on the other hand, is a relatively conservative constituent and once mobilized will stay in solution. These factors may explain the observed relationships.

Calcium and magnesium are related to sulfate indirectly through charge balance considerations and the concomitant weathering of spoil material in response to acid production. The latter mechanism may account for the association of alkalinity and sulfate, especially if alkalinity results from reactions of the aluminosilicates. The positive correlation of the dissolved metals with alkalinity is most certainly related to cation/anion balance in the spoil. Iron and manganese concentrations are related through their similar response to redox conditions. The association of calcium and magnesium results from their similar chemical characteristics and suggests a similar parent source, either carbonate or clay. Association of aluminum and silicon is to be expected since their only source is the clay minerals.

Molar ratios developed to characterize quality relationships in the spoil and obtain clues as to the source of dissolved constituents are presented in Table 41. The distribution for many of these ratios was influenced by extreme maximum values, resulting in a mean unrepresentative of the data's overall response. For this reason the median and the 50 percent spread about the median (Q1-Q3) are presented for comparison against the mean and standard deviation. The range of the ratio data and evaluations of its distribution are also provided. All were centered at the median, leptokurtic, or normal indicating median values will adequately estimate field conditions.

Table 41. Molar Ratios and Charge Balance for Selected Subsurface Constituents at the Study Spoil Banks

	Fe/Mn	Fe/SO_4	Ca/Mg	Ca/Alkalinity	Ca/Si
Mean	3.09	0.655	1.46	0.935	21.2
Std. Dev.	3.882	1.937	0.557	0.7064	12.43
Median	1.62	0.0724	1.50	0.817	19.2
Q1-Q3	3.61	0.480	0.76	0.3730	15.96
Maximum	19.7	14.4	5.72	8.32	59.6
Minimum	0.018	0.0003	0.342	0.191	1.67
Number	182	160	185	178	28
Evaluation of Distribution	Centered at median, large positive skew	Centered at median, large positive skew	Leptokurtic	Leptokurtic with positive skew	Normal

	Mg/Alkalinity	Mg/Si	Alkalinity/SO_4	Alkalinity/Si	$\frac{\text{Cations}}{\text{Anions}}$
Mean	0.702	16.5	4.38	27.7	1.04
Std. Dev.	0.5586	12.67	10.50	15.61	0.312
Median	0.520	13.9	1.91	27.5	1.01
Q1-Q3	0.3627	14.32	1.79	25.12	0.204
Maximum	5.48	56.3	97.0	58.6	3.81
Minimum	0.148	1.82	0.147	1.18	0.370
Number	178	29	207	30	159
Evaluation of Distribution	Leptokurtic with positive skew	Leptokurtic with positive skew	Centered at median, large positive skew	Normal	Leptokurtic with positive skew

Ratios of iron to manganese, calcium to magnesium, and alkalinity to sulfate were computed to further characterize constituent concentrations in the spoils examined. Iron concentration exceeds manganese by a factor of 1.6, calcium concentration exceeds magnesium by 1.5, and from the alkalinity to sulfate ratio, bicarbonate appears to be the major anion at molar concentrations approximately twice that of sulfate.

From considerations of pyrite oxidation, the iron to sulfate ratio should be 0.50 (eq 2.1, p. 21). The data indicate a large attenuation of iron occurs in the spoil. This may be through exchange reaction with the clays or oxidation of ferrous iron to insoluble ferric hydroxide. Assuming a carbonate solid phase system, calcium and magnesium to alkalinity ratios should both be less than or equal to 0.50 depending upon the cation composition of the parent material (i.e., $Ca_xMg_yCO_3(s) = xCa^{+2} + yMg^{+2} + CO_3^{-2}$, where $x + y = 1$ and $[alkalinity] = 2[CO_3^{-2}]$) (60). From this perspective the data indicate a portion of the original alkalinity has been consumed, presumably in neutralizing the acid products of pyrite oxidation.

An alternative explanation may be the release of additional calcium and magnesium through the acid weathering of clay minerals. For the aluminosilicates previously identified by X-ray diffraction at the two study spoil banks (34,52), the theoretical molar cation to silicon ratios from acid weathering will all be less than one (21,60). Particular examples from the Geochemical Factors section of the Literature Review are calcium from Ca-montmorillonite, 0.125 (eq 2.9), and magnesium from illite, 0.208 (eq 2.10). The large ratio values in Table 41 suggest acid weathering of clay minerals may account for only a small portion of total calcium and magnesium in the spoil. The possible independence of these cations from the aluminosilicates is additionally supported by their failure to produce significant associations when correlated with corresponding silicon data. However, in the Results Chapter possible attenuation of dissolved silicon due to saturation with respect to quartz was noted. This indicates large ratios of calcium and magnesium to silicon may result from incongruent solubility controls on silicic acid released in the weathering aluminosilicate minerals.

The possibility that substantial alkalinity is produced in the spoil through the reaction of aluminosilicates with carbon dioxide is examined with a molar ratio for alkalinity to silicon. The general equation presented in the Literature Review (eq 2.6) indicates this ratio should be one. The actual ratio is 27.5 suggesting alkalinity production in excess of the aluminosilicates. Again, however, possible attenuation of silicon concentrations suggested by the spoil data makes this result inconclusive.

Overall, the ratio data cannot confirm or deny clay mineral contribution of calcium, magnesium, and alkalinity to spoil waters. The incongruent nature of aluminosilicate weathering obviously complicates interpretation of the silicon ratios presented in Table 41. However, generally small concentrations of potassium and sodium in the spoil lend support to the idea that clay mineral weathering is small compared to the congruent dissolution of carbonates. Freeze and Cherry (21, p. 269) in a discussion of quartz dissolution and solubility state, "Quartz and amorphous silica generally do not exert an important influence on the level of silica in groundwater." If this is the case for the spoils examined, the clay minerals are not the major source of calcium, magnesium, and alkalinity found in subsurface waters.

A charge balance for the major quality constituents (Fe, Mn, Ca, Mg, Alkalinity, and SO_4) is included in Table 41. Its purpose was to verify overall adequacy of the chemical analyses performed in this research. The leptokurtic distribution and closeness of the mean and median to 1.00 indicate on the whole the data are good and the major constituents have been accounted for.

Relation of the Spoil Saturated Zone to Basin Hydrology and Surface Water Quality

The ultimate goal of this research is to relate spoil subsurface water quality to stream quality observed at the mouth of the study basins. Tables 42 and 43 present pre and post mining surface water quality for the Lowe Branch, Indian Fork, and Bills Branch basins. Lowe Branch was an undisturbed, "near-pristine" watershed of approximately one square mile area located ten miles north of Indian Fork and Bills Branch. Mining activity entered the basin in May of 1980. Its topography and underlying geology are similar to the other basins. Monitoring of flow and water quality at Lowe Branch as well as at the mouth of Indian Fork and Bills Branch was conducted between 1975 and 1981 under the comprehensive study of which this thesis is a part.

The premining record for Lowe Branch is assumed to represent undisturbed water quality and hydrology in the New River Area. With

Table 42. Pre and Post Mining Surface Water Quality, Major Constituents; Lowe Branch, Indian Fork and Bills Branch Study Basins

Basin	pH[b]	Total Dissolved Concentrations[a] (mg/l)				Alkalinity as $CaCO_3$ mg/l	Sulfate mg/l
		Fe	Mn	Ca	Mg		
<u>Lowe Branch (Premining)</u>							
Mean	6.02	0.17	0.002	1.27	1.47	6.66	11.4
Std. Dev.	1.365E-6	0.1581	0.0016	0.3997	0.2315	2.881	4.328
Median	6.30	DL	DL	1.1	1.4	6.3	11
Maximum	7.60	0.79	0.008	2.5	2.30	19.7	22
Minimum	5.10	DL	DL	0.85	1.1	0.24	DL
Fraction DL	0/86	58/84	57/88	0/89	0/87	0/89	3/89
<u>Indian Fork (Post Mining)</u>							
Mean	6.84	0.67	0.80	68.4	26.6	29.87	358.7
Std. Dev.	2.153E-7	1.337	0.4389	30.74	10.73	10.740	203.3
Median	7.20	0.2	0.74	61	24.6	28.45	305
Maximum	8.00	10.5	2.47	170	59	71.4	1000
Minimum	5.80	DL	0.19	19.3	9.3	6.9	88
Fraction DL	0/120	46/123	0/123	0/123	0/123	0/122	0/123
<u>Bills Branch (Post Mining)</u>							
Mean	6.76	0.14	0.082	10.5	7.07	17.08	46.1
Std. Dev.	2.069E-7	0.1502	0.1175	3.192	1.943	6.044	14.43
Median	7.00	DL	DL	10.4	7.2	16.2	46.5
Maximum	8.30	0.86	0.84	18	11.15	36.5	84
Minimum	6.00	DL	DL	4.75	2.8	4	5
Fraction DL	0/113	77/116	65/117	0/114	0/115	1/116	0/116

[a] "DL" indicates values below analytical detection limits

[b] Standard deviation values recorded for pH represent hydrogen ion concentrations

Table 43. Pre and Post Mining Surface Water Quality, Trace Metals; Lowe Branch, Indian Fork, and Bills Branch Study Basins

	Total Dissolved Concentrations[a] mg/l				Total Ni mg/l	Total Dissolved (mg/l)	
Basin	Cd	Co	Cr	Cu		Pb	Zm
<u>Lowe Branch (Premining)</u>							
Mean	0.0003	DL	0.0003	0.0028	0.0016	0.0005	0.07
Std. Dev.	5.595E-4		8.32E-5	2.624E-3	3.019E-3	4.346E-4	
Median	DL	DL	DL	0.0011	DL	DL	DL
Maximum	0.0029			0.018	0.0153	0.0015	0.07
Minimum	DL		DL	DL	DL	DL	DL
Fraction DL	43/70	36/36	22/35	28/87	63/86	38/51	32/33
<u>Indian Fork (Post Mining)</u>							
Mean	0.0007	0.0060	0.0011	0.0035	0.0166	0.0004	0.038
Std. Dev.	1.374E-3	3.591E-3	1.356E-3	3.743E-3	9.450E-3	4.331E-4	6.554E-2
Median	DL	0.0052	DL	0.0022	DL	0.0002	0.012
Maximum	0.0060	0.0193	0.0060	0.023	0.067	0.0012	0.47
Minimum	DL	0.0010	DL	DL	DL	0.0001	DL
Fraction DL	54/101	0/116	70/101	4/120	54/75	0/112	39/113
<u>Bills Branch (Post Mining)</u>							
Mean	0.0012	0.0011	0.0011	0.0037	0.0048	0.0007	0.033
Std. Dev.	2.286E-3	1.154E-3	1.304E-3	3.167E-3	9.686E-3	4.651E-4	3.456E-2
Median	DL	DL	DL	0.0026	0.0004	DL	DL
Maximum	0.0090	0.0039	0.007	0.017	0.0070	0.0022	0.14
Minimum	DL	DL	DL	DL	DL	DL	DL
Fraction DL	86/109	82/92	74/107	2/88	34/107	58/73	84/103

[a] "DL" indicates values below analytical detection limits

the exception of pH, a comparison of median values for this basin in Table 42 with the undisturbed seepage samples in previous Table 20, page 128, reveals little or no difference in constituent concentrations. This lends support to the above assumption for undisturbed water quality.

Tables 42 and 43 along with additional quality data for streams in the New River Area indicate pH is elevated, and major constituent concentrations in mining disturbed streams generally lower than those found in the spoil. Sulfate replaces alkalinity as the major anion. In contrast, trace metals in disturbed streams appear similar to spoil concentrations. While Bills Branch was disturbed only along the Big Mary seam, seven coals have been mined in Indian Fork under a variety of techniques. Rose (51) indicated acid drainage from auger holes and abandoned deep mines influences stream quality in Indian Fork, especially during periods of low flow. This is reflected in the surface quality data by low alkalinity and high sulfate concentrations.

The bulk of surface mining disturbance in the basin is split between the Pewee/Walnut Mountain and Big Mary coals. Constituent concentrations in Indian Fork, especially sulfate, greater than representative concentrations developed for these spoils in Tables 33 and 39 (pages 153 and 167, respectively) indicate point sources of elevated concentration within the study basin. Observation wells numbers 1 and 2 were placed on the slope below a stripped-over deep mine entrance which was known to drain acid waters. Sulfate concentrations in excess of 1000 mg/l were found. Other constituents were elevated above levels found elsewhere in the spoil. These wells confirm the presence of anomalously high point sources in the Indian Fork basin.

Continuous five minute flow measurement was performed for the stream basins over the course of the comprehensive study. In 1976, Minear and Tschantz (42) reported undisturbed streams in the New River area go dry during periods of rainfall deficit whereas disturbed streams maintain a measurable flow. Figure 28 quantifies this relationship with a flow duration analysis of area normalized mean daily flow for the geologically and hydrologically similar Lowe Branch, Indian Fork, and Bills Branch Study Basins. It was constructed on a log scale to amplify the low flow difference between mining disturbed and undisturbed streams. A flow of 10^{-5} cfs/acre (6.9E-7 m^3/s-ha) is the detection limit for measurement at the stream gaging stations and corresponds to approximately 0.01 cfs (2.8E-4 m^3/s). Values less than 0.01 cfs are assumed to be zero. Field observations confirm this assumption. Note that the horizontal axis indicates the frequency (or percentage of time) a given flow is exceeded.

At A_{90} (i.e., flow value exceeded 90 percent of the time) the undisturbed Lowe Branch is dry. Bills Branch sustained a flow of 0.06 cfs (1.7E-3 m^3/s) and Indian Fork 1.50 cfs (0.042 m^3/s). For these basins flow less than Q_{90} is defined "sustained flow" and is assumed to originate from spoil storage. When plotted in an arithmetic scale, the slope of the flow curves flatten towards an asymptotic limit at approximately Q_{75}. As a functional definition flow less than Q_{75} is considered "low flow" and represents the stream flow component independent of direct rainfall response. Q_{75} for Lowe Branch is

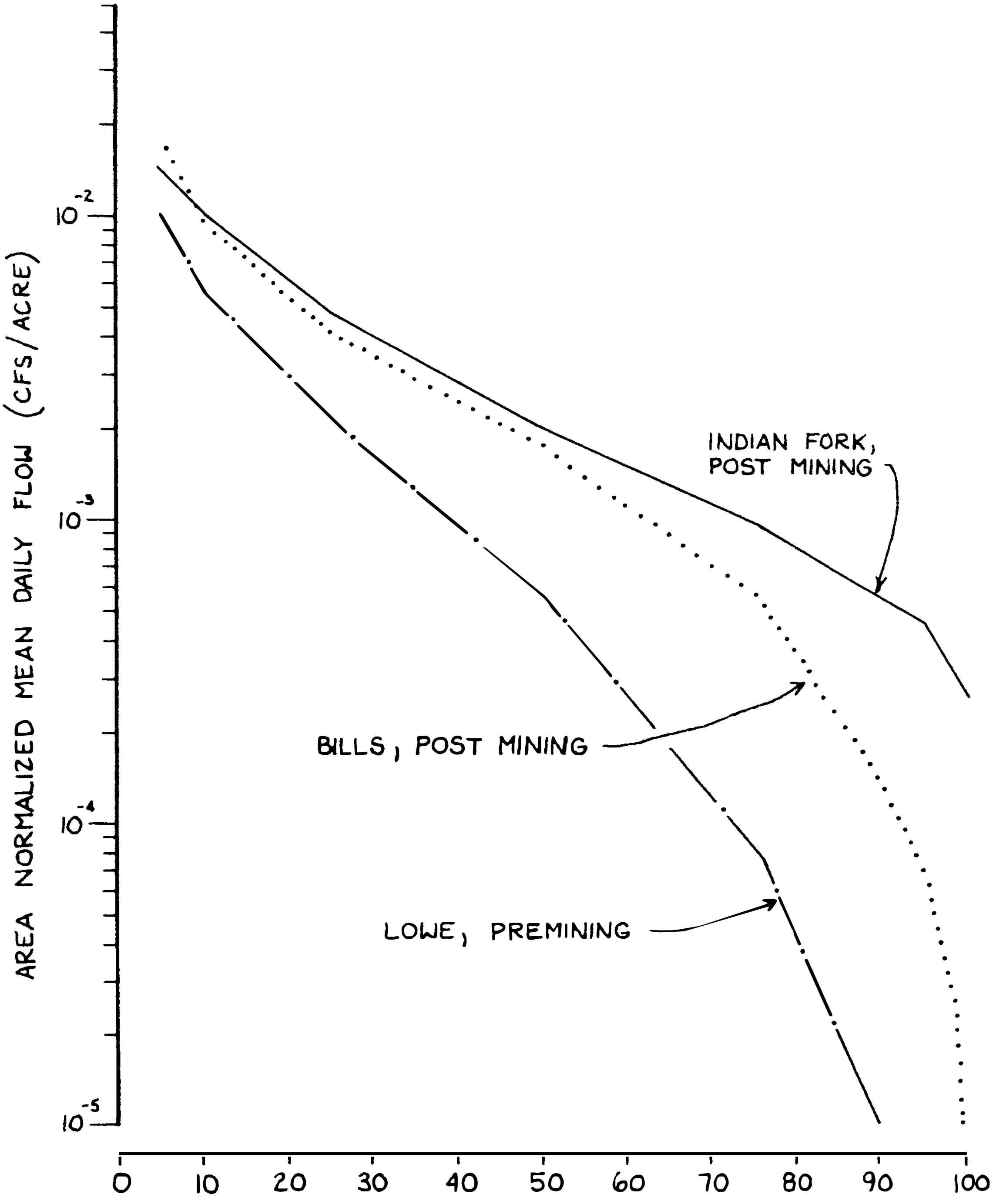


Figure 28. Flow Duration Analysis by Disturbance Period for the Lowe Branch, Indian Fork, and Bills Branch Study Basins.

0.05 cfs (1.4E-3 m^3/s), for Bills Branch, 0.25 cfs (7.0E-3 m^3/s), and for Indian Fork, 2.70 cfs (0.076 m^3/s).

A hydrologic balance based on median sustained and low flows can be used to estimate gross contribution of the spoil to stream flow in the disturbed study basins (21). For this analysis stream flow, Q_S, is assumed to result from spoil output, Q_B, and a contribution from the shallow, undisturbed groundwater system, Q_G, such that

$$Q_S = Q_B + Q_G \tag{6.3}$$

Q_G is obtained from Lowe Branch data and under sustained flow conditions is zero. Results are presented in Table 44.

Flow rates computed from the spoil in Indian Fork and Bills Branch are two orders of magnitude less than the range calculated from hydraulic properties for similar spoil materials in the Beaver Creek Study (8,9). The cast overburden configuration of the Beaver Creek spoils may account for this difference. Under sustained flow conditions total flow computed from the spoil in Indian Fork is three times that of Bills Branch. For low flow stream conditions it is 1.6 times greater. The permanent bench ponds in Indian Fork should account for this. However, elevated sulfate concentrations in the stream indicate seepage from auger holes and abandoned deep mines also contributes to the calculated spoil bank flow.

Q_B calculated for Bills Branch originates entirely from the spoil. The sustained flow output corresponds to an annual rainfall over the basin of 0.61 inches (1.55 cm). Low flow output corresponds to 1.48 inches (3.76 cm). When normalized for the area of the spoil,

Table 44. Estimate of Spoil Contribution to Stream Flow from Flow Duration Data for Lowe Branch, Indian Fork, and the Bills Branch Study Basins

			Sustained Flow Conditions ($Q \leqq Q_{90}$)			Low Flow Conditions ($Q \leqq Q_{75}$)		
Study Basin	Basin Area (acres)	Area of Mining Disturbance (acres)	Q_{95} (cfs/acre)	Q_B[a] (cfs)	Q_B, Normalized for Disturbance Area (cfs/acre spoil)	$Q_{87.5}$ (cfs/acre)	Q_B (cfs)	Q_B Normalized for Disturbance Area (cfs/acre spoil)
Lowe Branch	588	0	0	-	-	1.70E-5	-	-
Indian Fork	2765	641	4.70E-4	1.3	2.03E-3	6.15E-4	1.65	2.57E-3
Bills Branch	429	46	6.99E-5	0.03	6.52E-4	1.86E-4	0.073	1.59E-3

[a] $Q_B = Q_S - Q_G$, see text for definition of terms

these become 5.7 and 13.8 inches (14.5 and 35.0 cm), respectively. Thus, storage in the non-ponded, contour mining spoil is a substantial component of basin hydrology. Under low flow conditions, the undisturbed groundwater system in Bills Branch contributes only 9 percent of the total stream flow volume.

Constituent mass output from the spoil can be estimated from surface quality and hydrologic data. This has been done in Table 45 for sustained and low flow conditions in the two mining disturbed basins. Descriptive statistics for stream quality under these conditions are presented in Appendix I. The mass output data, expressed in terms of Kg/acre spoil-day, reflect differences in stream quality and flow between the Indian Fork and Bills Branch basins. It must be noted that part of the mass leaving Indian Fork originates at point sources of high concentration separate from the mining spoil. Of the total, low flow constituent mass leaving each study basin, the Lowe Branch data indicate the shallow, undisturbed groundwater system may account for only 10 percent. This result serves to illustrate the impact of the contour surface mining spoil on the hydrologic system of disturbed basins.

Constituent mass outputs for the spoil derived from surface quality and hydrologic data in Bills Branch were used to obtain estimates of flow from the mining spoil based upon constituent mass balances between the bank and stream. Similar to the hydrologic balance already presented, constituent mass in the stream, Q_SC_S, results from spoil mass output, Q_BC_B, and a contribution from the shallow, undisturbed groundwater system, Q_GC_G, such that

Table 45. Constituent Mass Output from the Study Spoil Banks Indicated by Surface Hydrologic and Quality Data

	Constituent Mass Output (Kg/acre spoil - day)					
	Total Dissolved Constituents					
Basin	Fe	Mn	Ca	Mg	Alkalinity as $CaCO_3$	Sulfate
Indian Fork						
Sustained Flow Conditions	1.69E-3	9.82E-3	0.624	0.238	0.0586	4.02
Low Flow Conditions	2.27E-3	9.57E-3	0.592	0.246	0.130	3.46
Bills Branch						
Sustained Flow Conditions	1.0E-5	9.57E-5	0.0207	0.0143	0.0405	0.0925
Low Flow Conditions	1.0E-5	1.78E-4	0.0493	0.0331	0.0856	0.210

$$Q_S C_S = Q_B C_B + Q_G C_G. \tag{6.4}$$

Here, C represents the appropriate constituent concentration. $Q_G C_G$ is obtained from Lowe Branch data and under sustained flow conditions is zero. Representative spoil bank subsurface concentrations, C_B, were developed in previous Tables 33 and 39, pages 153 and 167, respectively. Since $Q_S C_S$ is known, overall flow from the spoil may be calculated,

$$Q_B = \frac{Q_S C_S + Q_G C_G}{C_B} \tag{6.5}$$

The results are presented in Table 46 for sustained and low flow conditions. Most important is the ratio of flow predicted from the constituent mass balance to flow derived from surface hydrologic data. All are less than one indicating attenuation of constituent mass between the spoil bank and stream.

This result is not surprising for attenuation of iron, manganese, and alkalinity have already been observed within the spoil profile. Waters leaving the spoil bank enter the shallow groundwater system of the basin and may become channelized into surface runoff before reaching the main body of the stream. Exposure to the atmosphere will oxidize and precipitate iron and manganese. Reaction with soil acids will consume alkalinity. Adsorption, ion exchange and other reactions are possible. The data indicate greater than 99 percent of the iron and manganese leaving the spoil is stored somewhere between the spoil bank and the mouth of the Bills Branch basin. Ninety-two percent of the alkalinity is consumed or stored.

Table 46. Estimate of Spoil Contribution to Stream Flow Based on Constituent Mass Balances in the Bills Branch Study Basin

	Total Dissolved Constituents				Alkalinity as $CaCO_3$	Sulfate
	Fe	Mn	Ca	Mg		
Representative Study Bank Subsurface Concentrations (mg/l)	15.42	10.58	90.6	63.1	303.4	144.0
<u>Sustained Flow Conditions</u>						
Representative Stream Concentrations (mg/l)	DL	0.06	13.0	8.95	25.4	58
Flow from Mining Spoil Computed from Constituent Mass Balance (cfs)	--	1.70E-4	4.30E-3	4.25E-3	2.51E-3	1.21E-2
$\frac{Q_B\text{, Mass Balance}}{Q_B\text{, Surface Hydrologic Data}}$		0.0057	0.144	0.142	0.0837	0.403
<u>Low Flow Conditions</u>						
Representative Stream Concentrations (mg/l)	DL	0.046	12.7	8.52	22.05	54
Flow from Mining Spoil Computed from Constituent Mass Balance (cfs)	--	3.45E-4	1.11E-2	1.06E-2	5.62E-3	2.95E-2
$\frac{Q_B\text{, Mass Balance}}{Q_B\text{, Surface Hydrologic Data}}$		0.0048	0.152	0.145	0.0767	0.402

Some 85 percent of the calcium and magnesium does not reach the mouth of the basin. Sulfate, true to its conservative nature, is least attenuated with 40 percent of the initial mass apparently leaving the watershed. The large attenuation of constituents leaving the spoil indicates long-term recovery of stream water quality in mining disturbed basins will depend not only upon exhaustion of pollutants within the spoil, but upon the ability of the basin and stream to flush themselves of stored pollutant mass.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The contour surface mining spoils examined are a heterogeneous, apparently anisotropic, predominately clay material interspersed with weathering fragments of sandstone and shale of various size. They are generally saturated along the lower boundary with the floor of the mining cut and the mountain slope below the bench. The size of this saturated zone, however, is known to vary laterally across the mine site and is a function of surface conditions. Under the soil classification of Vimmerstedt and Struthers (73) the spoil material represents an acid soil.

Concentrations of dissolved mineral constituents found in the saturated zone are moderate compared to spoils of acid drainage areas in Eastern Kentucky (8,9,43) and of area mining in glaciated areas of Illinois (45). Overall pH is slightly acidic. Calcium and magnesium are the major cations; bicarbonate the major anion. Acid and reducing conditions were found to be associated. Constituent concentrations show negative correlation with redox potential and positive associations with alkalinity and sulfate. These relationships are similar to those observed by other researchers examining spoil water quality (37,46,49,73).

Major conclusions from this work are as follows:

1. Contour surface mining spoils in the basins examined are generally saturated along their lower boundary with the

floor of the mining cut and the mountain slope below the bench. The volume of stored water is substantial and contributes significantly to low streamflow volume.

2. Rapid and associated changes in saturated zone thickness observed in the study wells support the hypothesis of a moving groundwater system at the two study spoil banks. Recharge to the saturated zone from direct infiltration on the bench and slope is apparently large.
3. The size of the saturated zone at the two study spoil banks is increasing with time, apparently independent of short-term trends in annual rainfall. This result raises question as to the long term stability of swale and pasture backfill spoil embankments in the New River area.
4. Dissolved constituent concentrations in spoil subsurface water are significantly elevated above those found in the shallow, undisturbed groundwater system of the watersheds examined. This water is also of poorer quality than deep groundwaters found in other parts of the Cumberland Plateau of East Tennessee.
5. Statistically significant spatial variations in spoil water quality were observed among the wells of each study spoil bank. However, the range of values observed in the line of wells at each bank appears to adequately characterize overall quality in the spoil.
6. No overall, long-term decreasing trend in subsurface constituent concentrations, suggestive of recovery, was

observed in the available six years of spoil quality data. However, short-term variations with hydrologic condition were noted. Maximum constituent concentrations correspond to depleted hydrologic conditions in the spoil.

7. The possibility that weathering of aluminosilicate minerals contributes substantial calcium, magnesium, and alkalinity to subsurface spoil waters could not be positively confirmed or denied with the available quality data. Indirect evidence, however, suggests the above contribution may be small compared to the dissolution of carbonate materials.
8. The contour surface mining spoil has been shown to represent a large reservoir of mobilized mineral constituent mass. Significant attenuation of these constituents occurs between the spoil bank and the mouth of the mining disturbed watershed.
9. Heavy metal concentrations mobilized within the spoils examined are small, generally less than levels described by drinking water standards. This and similar low levels observed in streams draining mining disturbed basins in the study area indicate no potential public health problems are to be expected from heavy metals in drainage from spoils on the Big Mary and Pewee coal seams. Except for point sources of acid mine drainage associated with auger holes and abandoned deep mines, this water appears suitable for livestock, irrigation and, with conventional treatment technology, water supply purposes.

10. The contour surface mining spoil has been shown to have a substantial impact on the low flow hydrology of disturbed watersheds. Of total low flow volume and constituent mass in the Bills Branch Study Basin, approximately 90 percent was determined to originate from spoil storage. Mining disturbance accounts for 11 percent of the Bills Branch Basin area.

CHAPTER VIII

SUGGESTIONS FOR FUTURE WORK

Legal requirements for reclamation and thus contour surface mining practice have changed during the period of research described in this thesis. As a result, characterizations of the spoils examined may not apply to the present back-to-approximate-original-contour configuration required by the Federal Surface Mining Control and Reclamation Act of 1977. A set of wells, similar to those employed in this research, should be installed at a back-to-contour spoil on either the Big Mary or Pewee coal seam and monitored for groundwater elevations to determine if saturation occurs and define the overall configuration of this zone. Subsurface water quality should be similar to that observed at the Indian Fork and Bills Branch Study Spoil Banks. This hypothesis can be tested with quality data from the new site.

The increasing saturating observed at the study spoil banks is a significant result of this work and should be investigated further from a geotechnical point of view. If the legal requirements for fill placement at the mine site result in a configuration that is ultimately unstable, the intent of environmental protection has not been served and the additional cost of compliance wasted. It must be kept in mind that actual surface mining practice in the New River area, while meeting legal requirements, does not result in the idealized and well compacted configuration envisioned in the law.

In the opinion of the author, previous attempts to model spoil bank hydrology are inadequate for obtaining true estimates of residence time and recharge mechanism, especially for the non-ponded spoil. This inadequacy relates to the heterogeneous and anisotropic nature of the spoil material that was not fully taken into account by Turnmire (67), and Crosby, Overton, and Minear (12). The expanded hydrologic data developed in this research should be used for a hydraulic analysis of the flow regime in both the ponded and non-ponded spoil. This work would be an important part of the geotechnical investigation described above.

The possibility of solubility controls on dissolved silicon in spoil subsurface waters hindered a conclusive result as to the contribution of aluminosilicate minerals to spoil water quality. This and the chemistry of clay minerals in the spoil warrant further investigation. Finally, the attenuation observed in constituent mass between the spoil bank and stream could be better quantified with a set of monitoring wells in the shallow groundwater system extending from the toe of the mining spoil downgradient to the stream channel.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Agnew, A. F., "A Quarter to Zero--Surface Mining and Water Supplies," Mining Congress Journal, Vol. 52, Oct., 1966, pp. 29-40.

2. Briggs, G., "Middle Pennsylvanian Depositional Environments of the Northern Plateau of Tennessee," in Minear, R. A., et al., Environmental Aspects of Coal Production in the Appalachian Region, Progress Report, June 1, 1977-May 31, 1978, Energy and Environment Center, The University of Tennessee, Knoxville, pp. K470-483.

3. Caruccio, F. T., "An Evaluation of Factors Affecting Acid Mine Drainage Production and the Ground Water Interactions in Selected Areas of Western Pennsylvania," Second Symposium on Coal Mine Drainage Research, Coal Industry Advisory Committee to the Ohio River Valley Sanitation Commission, Pittsburgh, Pennsylvania, May 14-15, 1968, pp. 107-151.

4. Caruccio, F. T., "The Quantification of Reactive Pyrite by Grain Size," Third Symposium on Coal Mine Drainage Research, Coal Industry Advisory Committee to the Ohio River Valley Sanitation Commission, Pittsburgh, Pennsylvania, May 19-20, 1970, pp. 123-131.

5. Caruccio, F. T., et al., Paleoenvironment of Coal and Its Relation to Drainage Quality, United States Environmental Protection Agency 600/7-77-067, Industrial Environmental Research Laboratory, Office of Research and Development, Cincinnati, Ohio, June, 1977.

6. Caruccio, F. T., Geidel, G., and Pelletier, A., "The Assessment of a Stratum's Capability to Produce Acidic Drainage," Symposium on Surface Mining Hydrology, Sedimentation and Reclamation, University of Kentucky, Lexington, Kentucky, Dec. 1-5, 1980, pp. 437-443.

7. Caruccio, F. T., Geidel, G., and Sewell, J. M., "The Character of Drainage as a Function of the Occurrence of Framboidal Pyrite and Ground Water Quality in Eastern Kentucky," Sixth Symposium on Coal Mine Drainage Research, National Coal Association and Bituminous Coal Research, Inc., Louisville, Kentucky, Oct. 19-21, 1976, pp. 1-16.

8. Collier, C. R., "Influences of Strip Mining of the Hydrologic Environment of Parts of Beaver Creek Basin Kentucky, 1955-59," Hydrologic Influences of Strip Mining, United States Geological Survey Professional Paper 427-B, United States Government Printing Office, Washington, D.C., 1964.

9. Collier, C. R., Pickering, R. J., and Musser, J. J., "Influences of Strip Mining on the Hydrologic Environment of Parts of Beaver Creek Basin Kentucky, 1955-66," Hydrologic Influence of Strip Mining, United States Geological Survey Professional Paper 427-C, United States Government Printing Office, Washington, D.C., 1970.

10. Corbett, D. M., "Groundwater Hydrology Pertaining to Surface Mining for Coal--Southwest Indiana," Second Symposium on Coal Mine Drainage Research, Coal Industry Advisory Committee to the Ohio River Valley Water Sanitation Commission, Pittsburgh, Pennsylvania, May 14-15, 1968, pp. 164-189.

11. Cowan, J. D., Analysis of Landslides and Slope Stability in Coal Surface Mining, Master's Thesis, Department of Civil Engineering, The University of Tennessee, Knoxville, June, 1977.

12. Crosby, E. C., Overton, D. E., and Minear, R. A., "A Simulation Model of Spoil Bank Hydrology," in Minear, R. A., et al., Environmental Aspects of Coal Production in the Appalachian Region, Progress Report, June 1, 1976-May 31, 1977, Energy and Environment Center, The University of Tennessee, Knoxville, pp. 130-158.

13. Curtis, W. R., "Chemical Changes in Streamflow Following Surface Mining in Eastern Kentucky," Fourth Symposium on Coal Mine Drainage Research, Coal Industry Advisory Committee to the Ohio River Valley Water Sanitation Commission, Pittsburgh, Pennsylvania, April 26-27, 1972, pp. 19-31.

14. Curtis, W. R., "Strip Mining Increases Flood Potential of Mountain Watersheds," Watersheds in Transition, American Water Resources Association Symposium, Colorado State University, 1972, pp. 357-360.

15. Curtis, W. R., "Surface Mining and the Hydrologic Balance," American Mining Congress Journal, Vol. 65, No. 7, July, 1979, pp. 35-40.

16. Dettmann, E. H., Olsen, R. D., and Vinikour, W. S., "Effects of Coal Strip Mining on Stream Water Quality: Preliminary Results," Sixth Symposium on Coal Mine Drainage Research, National Coal Association and Bituminous Coal Research, Inc., Louisville, Kentucky, Oct., 19-21, 1976, pp. 51-63.

17. Dyer, K. L. and Curtis, W. R., Effect of Strip Mining on Water Quality in Small Streams in Eastern Kentucky, 1967-1975, United States Department of Agriculture, Forest Service Research Paper NE-372, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania, 1977.

18. Emrich, G. H. and Merritt, G. L., "Effects of Mine Drainage on Ground Water," *Groundwater*, Vol. 7, No. 3, May-June, 1969, pp. 27-32.

19. Fern, J. C., "Carboniferous Environmental Models in the Eastern United States and Their Significance," in Briggs, G., *Carboniferous Systems of the Southeastern United States, Geological Society of America, Special Paper 148*, pp. 79-95.

20. Franks, C. D., *Heavy Metal Content of the Coals and Associated Rocks in the Indian Fork Watershed, Anderson County, Tennessee, Master's Thesis, Department of Geology, The University of* Tennessee, Knoxville, March, 1976.

21. Freeze, R. A., and Cherry, J. A., *Groundwater*, Prentice-Hall, Englewood Cliffs, New Jersey, *1979, Chapters* 3, 6, 7, and 10.

22. Gang, M. W. and Langmurr, D., "Controls on Heavy Metals in Surface and Ground Waters Affected by Coal Mine Drainage; Clarion River-Redbank Creek Watershed, Pennsylvania," *Fifth Symposium on Coal Mine Drainage Research*, National *Coal Association, Louisville, Kentucky, October* 22-24, 1974, pp. 39-69.

23. Garman, R. K., Ferguson, C. C., and Jones, M. L., *Geological Map and Mineral Resource Summary of the Fork Mountain Quadrangle, Tennessee Department of Conservation, Division of Geology,* 1975.

24. Geidel, G., and Caruccio, F. T., "Time as a Factor in Acid Mine Drainage Pollution," *Seventh Symposium on Coal Mine Drainage Research*, National *Coal Association and Bituminous Coal Research*, Inc., Louisville, Kentucky, Oct. 18-20, 1977, pp. 41-50.

25. Glenn, L. C., *The Northern Tennessee Coal Field*, Tennessee Division of *Geology, Bulletin 33-B, 1925*.

26. Grim, E. C., and Hill, R. D., *Environmental Protection in Surface Mining of Coal*, *United States Environmental Protection Agency 670/2-74-093*, National Environmental Research Center, Office of Research and Development, Cincinnati, Ohio, Oct., 1974.

27. Grubb, H. F., and Ryder, P. O., *Effects of Coal Mining on the Water Resources of the Tradewater River Basin, Kentucky, United States Geological Survey Water Supply Paper 1940, United States Government Printing Office*, Washington, D.C. 1972.

28. Hackbarth, D. A., "The Effects of Surface Mining of Coal on Water Quality Near Grande Cache, Alberta," Canadian Journal of Earth Sciences, Vol. 16, No. 6, June, 1979, pp. 1242-1253.

29. Herring, W. C., "Groundwater Re-establishment in Cast Overburden," Seventh Symposium on Coal Mine Drainage Research, National Coal Association and Bituminous Coal Research, Inc., Louisville, Kentucky, Oct. 18-20, 1977, pp. 71-87.

30. Hines, W. W., and Montgomery, D. C., Probability and Statistics in Engineering and Management Science, John Wiley and Sons, New York, 1980, Chapters 10 and 11.

31. Hopkins, T. C., Physical and Chemical Water Quality from the Effects of Mine Drainage in Western Maryland, Department of Water Resources, State of Maryland, 1967.

32. Hounslow, A., et al., Overburden Mineralogy as Related to Ground-Water Chemical Changes in Coal Strip Mining, United States Environmental Protection Agency PB-286 996, Office of Research and Development, Robert S. Kerr Environmental Research Laboratory, Ada Oklahoma, August, 1978.

33. Johnson, R. C., and Luther, L. T., Strippable Coal in the Northern Cumberland Plateau Area of Tennessee, Tennessee Department of Conservation, Division of Geology, 1972.

34. Ketelle, R. H., Characterization of the Mineral and Metal Content of Suspended Sediment, New River Basin, Tennessee, Master's Thesis, Department of Geology, The University of Tennessee, Knoxville, August, 1977.

35. Lilliefors, H. W., "On the Kolmogorov-Smirnov Test for Normality with Mean and Variance Unknown," Journal of the American Statistical Association, June, 1967, pp. 399-402.

36. Luther, L. T., The Coal Reserves of Tennessee, Tennessee Department of Conservation, Division of Geology, Bulletin 63, 1959.

37. Massey, H. F., and Barnhisel, R. I., "Copper, Nickel, and Zinc Released from Acid Coal Mine Spoil Materials of Eastern Kentucky," Soil Science, Vol. 113, No. 3, March, 1972, pp. 207-212.

38. McWhorter, D. B., et al., Surface and Subsurface Water Quality Hydrology in Surface Mined Watersheds, Part I, United States Environmental Protection Agency 600/7-79-193a, Office of Research and Development, Cincinnati, Ohio, August, 1979.

39. McWhorter, D. B., Skogerboe, R. K., and Skogerboe, G. V., "Water Pollution Potential of Mine Spoils in the Rocky Mountain Region," Fifth Symposium on Coal Mine Drainage Research, National Coal Association, Louisville, Kentucky, Oct. 22-24, 1974, pp. 25-38.

40. Milici, R. C., "Stratigraphy and Depositional Environments of Upper Mississippian and Lower Pennsylvanian Rocks in the Southern Cumberland Plateau in Tennessee," in Briggs, G., Carboniferous Systems of the Southeastern United States, Geological Society of America, Special Paper 148, 1974, pp. 115-133.

41. Milici, R. C., et al., The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States, Tennessee, United States Geological Survey Professional Paper 1110-G, United States Government Printing Office, Washington, D. C., 1979.

42. Minear, R. A. and Tschantz, B. A., "The Effect of Coal Surface Mining on the Water Quality of Mountain Drainage Basin Streams," Journal Water Pollution Control Federation, Vol. 48, No. 11, November, 1976, pp. 2549-2569.

43. Musser, J. J., "Description of Physical Environment and of Strip-Mining Operations in Parts of Beaver Creek Basin Kentucky," Hydrologic Influences of Strip Mining, United States Geological Survey Professional Paper 427-A, United States Government Printing Office, Washington, D.C., 1963.

44. Newcome, R., and Smith, O., Ground-Water Resources of the Cumberland Plateau in Tennessee, State of Tennessee, Division of Water Resources, Nashville, 1958.

45. Pietz, R. I., Peterson, J. R., and Lue-Hing, C., "Groundwater Quality at a Strip-Mine Reclamation Area in West Central Illinois," Second Research and Applied Technology Symposium on Mined-Land Reclamation, National Coal Association, Louisville, Kentucky, Oct. 22-24, 1974, pp. 124-143.

46. Pionke, H. B., Rogowski, A. S., and Montgomery, C. A., Percolate Quality of Strip Mine Spoil, Proceedings Paper No. 78-2581, American Society of Agricultural Engineers, 1978 Winter Meeting, Chicago, Illinois, December 18-20, 1978.

47. Plass, W. T., "Changes in Water Chemistry Resulting from Surface-Mining of Coal on Four West Virginia Watersheds," Green Lands (Quarterly of the West Virginia Surface Mining and Reclamation Association), Vol. 22, Winter, 1976.

48. Rahn, P. H., "Ground Water in Coal Strip-Mine Spoils--Powder River Basin," Abstract of paper presented at the Fall, 1978 Meeting, American Geophysical Union, EOS, Vol. 59, No. 12, Dec., 1976, pp. 1067.

49. Rogowski, A. S., "Acid Generation within a Spoil Profile: Preliminary Experimental Results," Seventh Symposium on Coal Mine Drainage Research, National Coal Association and Bituminous Coal Research, Inc., Louisville, Kentucky, Oct. 18-20, 1977, pp. 25-40.

50. Rogowski, A. S., "Water Regime in Strip Mine Spoil," Surface Mining and Fish and Wildlife Needs in the Eastern United States, Proceedings, edited by D. E. Sammuel, West Virginia University and the United States Fish and Wildlife Service, 1978, pp. 137-145.

51. Rose, R. R., Aspects of Water Quality and Their Relationships to Hydrology in Coal Mined Drainage Basins in the Cumberland Mountains, Master's Thesis, Water Resources Program, The University of Tennessee, Knoxville, 1975.

52. Rose, R. R., "X-Ray Analysis of Well Solids," in Minear, R. A., et al., Environmental Aspects of Coal Production in the Appalachian Region, Progress Report, June 1, 1979-May 31, 1980, Energy and Environment Center, The University of Tennessee, Knoxville, Appendix 5.

53. Rose, R. R., Valentine, G. E., and Minear, R. A., "Water Quality Changes Resulting from Coal Surface Mining in the New River Basin of Tennessee," Proceedings of the West Virginia Academy of Science, April 5-6, 1979, Vol. 51, No. 3, pp. 146-167, Published 1980.

54. Rule, J. H., and Briggs, G., "Distribution of Heavy Metals in Sediments of Strip Mine Watersheds," Task 3 in Minear, R. A., et al., Environmental Aspects of Coal Production in the Appalachian Region, Progress Report, June 1, 1976-May 31, 1977, Energy and Environment Center, The University of Tennessee,

55. SAS Institute, Inc., Statistical Analysis System User's Guide, The SAS Institute, Raleigh, North Carolina, 1979.

56. Shapiro, S. S., and Wilk, M. B., "An Analysis of Variance Test for Normality (complete samples)," Biometrika, Vol. 52, 1965, pp. 591-611.

57. Singer, P., and Stumn, W., "Kinetics of the Oxidation of Ferrous Iron," Second Symposium on Coal Mine Drainage Research, Coal Industry Advisory Committee to the Ohio River Valley Water Sanitation Commission, Pittsburgh, Pennsylvania, May 14-15, 1968, pp. 12-34.

58. Sokal, R. R., and Rohlf, F. J., Biometry, W. H. Freeman and Company, San Francisco, 1969, pp. 112-120.

59. Stephens, M. A., "EDF Statistics for Goodness of Fit and Some Comparisons," Journal of the American Statistical Association, Vol. 69, No. 374, Sept., 1974, pp. 730-737.

60. Stumn, W., and Morgan, J. J., Aquatic Chemistry, 2nd Edition, John Wiley and Sons, New York, 1981, Chapters 4, 5, 6, 7, and 9.

61. Temple, K. L., and Koehler, W. A., Drainage from Bituminous Coal Mines, Engineering Experiment Station Bulletin Number 25, West Virginia University, Morgantown, West Virginia, 1954.

62. Tennessee Valley Authority, Data Services Section, Monthly and Annual Precipitation Reports for the Tennessee Valley Region, 1935-1980.

63. Thompson, C. M., Characterization of the Heavy Metal Content of Coal-Bearing Stratigraphy from the New River Basin, Tennessee: Heavy Metals Released by Static Leaching of the Big Mary Coal Sequence, Master's Thesis, Department of Geology, The University of Tennessee, Knoxville, 1977.

64. Thompson, C. M., and Rule, J. H., "Heavy Metal Content of Rock Layers Associated with Coal Seams in the New River Basin, Fork Mountain Quadrangle, Tennessee," in Minear, R. A., et al., Environmental Aspects of Coal Production in the Appalachian Region, Progress Report, June 1, 1976-May 31, 1977, Energy and Environment Center, The University of Tennessee, Knoxville, pp. 159-185.

65. Traux, C. N. "Water Storage Potential of Surface Mined Coal Lands," Mining Congress Journal, Vol. 51, No. 11, Nov., 1965, pp. 40-46.

66. Tung, H. S., Impacts of Contour Coal Mining on Streamflow, A Case Study of the New River Watershed, Tennessee, Ph.D. Dissertation, The University of Tennessee, August, 1975.

67. Turnmire, J. B., Simulation of Flow in Strip Mine Spoil, Master's Thesis, Department of Civil Engineering, The University of Tennessee, Knoxville, December, 1974.

68. United States Army, Corps of Engineers, New River Comprehensive Study, Final Report, prepared by Robert Kimball and Associates for Corps of Engineers, Nashville District, April, 1979.

69. United States Department of Commerce, National Oceanic and Atmospheric Administration, Local Climatological Data, Oak Ridge, Tennessee, National Climatic Center, Asheville, North Carolina, 1980.

70. United States Environmental Protection Agency, Water Quality Criteria, EPA R3 73033, United States Government Printing Office, Washington, D.C., 1972.

71. United States Environmental Protection Agency, "National Primary Interim Drinking Water Standards," Federal Register, Vol. 40, No. 48, Dec. 24, 1975.

72. Upham, G. A., A Study of Trace Metals Found in a Stream Before and During Strip Mining of Coal in the Cumberland Plateau of Eastern Tennessee, Master's Thesis, Department of Geology, The University of Tennessee, Knoxville, December, 1975.

73. Vimmerstedt, J. P., and Struthers, P. H., "Influences of Time and Precipitation on Chemical Composition of Spoil Drainage," Second Symposium on Coal Mine Drainage Research, Coal Industry Advisory Committee to the Ohio River Valley Water Sanitation Commission, Pittsburgh, Pennsylvania, May 14-15, 1968, pp. 152-163.

74. Walpole, R. E., and Myers, R. H., Probability and Statistics for Engineers and Scientists, 2nd Edition, Macmillan Company, New York, 1978, Chapters 7 and 10.

APPENDICES

APPENDIX A

ANALYTICAL DETECTION LIMITS

ANALYTICAL DETECTION LIMITS

Assuming all other conditions are correct, the analytical methods employed in this research have threshold limits below which they do not produce a detectable response, i.e., a response significantly above the background level for the analysis. Table A-1 lists detection limits for the water quality variables examined in this research. The following discussion is to supplement the table. Although a detection limit is presented for each variable, the most important are those given for the trace metals.

Wet Chemistry

For pH and Eh measurements the detection limit is defined by the limitations of the electrodes and the response measuring equipment to discern small changes in concentration or electric potential. The lower limit for the potentiometric alkalinity determination is difficult to define and is closely related to ionic strength. For the range of concentrations and sample volumes used in this research the detection limit for alkalinity is approximately 0.2 mg/l as $CaCO_3$. The sulfate detection limit for the research was determined experimentally with known standards.

Metals and Trace Metals

The lower level of detection for metals by atomic absorption is limited by the strength of the absorbance signal produced by the atomizing equipment, the optics, and electronics of the particular instrument used. The values given in Table A-1 were taken from the

United States Environmental Protection Agency's Methods for Chemical Analysis of Water and Wastes and represent typical detection limits for atomic absorption using flame and furnace techniques. Under ideal conditions a ten fold improvement in detection limit was obtained for several trace metals on the Perkin-Elmer equipment used in this research. The improved detection limits are indicated by parentheses.

Special Analysis

The detection limits for the special analyses were determined experimentally using known standards.

Table A-1. Analytical Detection Limits

Variable	Method	Analytical Detection Limit
Wet Chemistry		
pH	Potentiometric Standard Methods, 15th edition Method 423; U.S. EPA Method 150.1	± 0.05 pH units
Eh	Selective ion electrode	± 10 millivolts
Alkalinity	Potentiometric Titration (pH 4.5) Standard Methods, 15th edition Method 403; U.S. EPA Method 310.1	approx. 0.2 mg/l as $CaCO_3$
Sulfate	Turbidimetric Standard Methods, 15th edition Method 426C; U.S. EPA Method 375.4	2 mg/l as SO_4
Metals	Atomic Absorption Spectrophotometry Standard Methods, 15th edition Methods 303 and 304; U.S. EPA Methods, Section 200	
Fe	Flame Furnace	0.05 mg/l 0.001
Mn	Flame Furnace	0.01 0.0002
Ca	Flame	0.01
Mg	Flame	0.001
Trace Metals		
Cd	Flame Furnace	0.005 0.0001
Co	Flame Furnace	0.05 0.001

Table A-1. (Continued)

Variable	Method	Analytical Detection Limit
Trace Metals (cont)		
Cr	Flame	0.05 mg/l
	Funrace	0.001 (0.0001)
Cu	Flame	0.02
	Furnace	0.001 (0.0001)
Ni	Flame	0.04
	Furnace	0.001
Pb	Flame	0.1
	Furnace	0.001 (0.0001)
Al	Flame	0.1
	Furnace	0.003
K	Flame	0.01
Na	Flame	0.002
Si	Flame	0.1
Zn	Flame	0.005
	Furnace	0.00005
Special Analysis		
Organic Carbon	Combustion-Infrared Standard Methods, 15th edition Method 505; U.S. EPA Method 415.1	2.0 mg/l as Carbon
Ferrous Iron	Phenanthroline Method Standard Methods, 15th edition Method 315B	0.05 mg/l
Sulfide	Selective ion electrode	0.05 mg/l as Sulfide
Nitrate	Selective ion electrode Standard Methods, 15th edition Method 418B	0.5/mg/l as Nitrate

Table A-1. (Continued)

Variable	Method	Analytical Detection Limit
Special Analysis (cont)		
Phosphate	Absorbic Acid Method with persulfate digestion Standard Methods, 15th edition Methods 424C and F U.S. EPA Method 365.3	0.001 mg/l as Phosphorus

APPENDIX B

HYDROLOGIC DATA

Table B-1. Indian Fork Study Spoil Bank Groundwater Elevations (Feet)

CALENDAY	JULIAN	F1	F2	F3	F4	F6	F8
8APR75	75098	143.51	129.20	94.46	70.46	----	----
15APR75	75105	143.53	130.73	94.92	70.61	----	----
22APR75	75112	143.59	132.60	94.93	70.64	----	----
29APR75	75119	143.80	132.32	95.07	70.96	----	----
6MAY75	75126	143.49	131.55	95.04	71.09	----	----
13MAY75	75133	143.52	132.05	94.94	70.97	----	----
20MAY75	75140	143.86	129.01	94.99	70.82	----	----
27MAY75	75147	143.44	130.01	95.02	71.25	----	----
3JUN75	75154	143.41	130.80	94.95	71.10	----	----
20JUN75	75171	143.47	130.20	96.47	70.92	----	----
27JUN75	75178	144.60	129.92	94.83	70.74	----	----
7JUL75	75188	143.71	128.43	96.62	70.64	----	----
14JUL75	75195	----	128.44	94.34	70.55	----	----
21JUL75	75202	----	127.98	----	70.78	----	----
28JUL75	75209	142.69	127.60	94.12	70.70	----	----
5AUG75	75217	141.39	126.70	94.12	70.70	----	----
13AUG75	75225	141.66	126.57	94.17	70.70	----	----
20AUG75	75232	142.59	126.80	94.17	70.70	----	----
27AUG75	75239	141.89	126.50	93.92	70.70	----	----
4SEP75	75247	138.74	126.30	94.17	70.30	----	----
9SEP75	75252	138.58	125.48	94.42	70.10	----	----
16SEP75	75259	138.74	125.23	94.22	70.10	----	----
22SEP75	75265	139.66	126.05	94.92	70.70	----	----
29SEP75	75272	143.57	127.48	94.59	71.24	----	----
9OCT75	75282	143.05	127.36	95.17	75.40	----	----
14OCT75	75287	143.57	127.51	95.32	75.60	----	----
31OCT75	75304	143.80	127.15	95.42	75.65	----	----
7NOV75	75311	144.09	128.60	95.42	77.80	----	----
14NOV75	75318	143.89	129.50	95.32	78.60	----	----
21NOV75	75325	143.86	129.60	96.02	76.20	----	----
1DEC75	75335	143.93	130.36	96.17	76.23	----	----
8DEC75	75342	143.77	130.65	96.82	76.95	----	----
15DEC75	75349	143.78	129.44	100.54	76.44	----	----
22DEC75	75356	143.82	129.73	96.84	76.90	----	----
31DEC75	75365	143.82	132.07	98.32	73.57	----	----
5JAN76	76005	143.89	133.57	97.09	76.32	----	----
15JAN76	76015	143.91	134.32	102.84	76.32	----	----
22JAN76	76022	143.86	128.90	96.21	71.27	----	----
30JAN76	76030	143.82	133.65	98.42	75.23	----	----
5FEB76	76036	143.80	130.52	----	75.07	----	----
12FEB76	76043	143.74	138.24	96.84	71.07	----	----
19FEB76	76050	143.95	133.98	100.25	75.15	----	----
26FEB76	76057	143.78	132.07	99.50	71.07	----	----

Table B-1. (Continued)

CALENDAY	JULIAN	F1	F2	F3	F4	F6	F8
4MAR76	76064	143.70	128.32	96.59	70.98	----	----
11MAR76	76071	143.82	133.82	98.00	71.82	----	----
17MAR76	76077	143.78	130.32	97.25	71.07	----	----
25MAR76	76085	143.91	134.48	97.42	72.90	----	----
1APR76	76092	143.99	134.98	100.50	77.40	----	----
8APR76	76099	143.74	130.57	----	73.07	----	----
12APR76	76103	143.68	128.90	----	72.73	----	----
20APR76	76111	143.24	128.27	99.49	71.52	----	----
26APR76	76117	143.70	128.23	99.54	73.19	----	----
11MAY76	76132	143.78	128.82	99.21	76.32	----	----
18MAY76	76139	143.85	133.52	104.13	78.82	----	----
25MAY76	76146	143.60	131.07	103.84	73.48	----	----
1JUN76	76153	143.78	134.65	102.90	72.15	----	----
9JUN76	76161	143.61	132.07	103.98	72.32	----	----
15JUN76	76167	142.57	128.98	103.50	70.90	----	----
22JUN76	76174	143.74	128.27	103.04	71.36	----	----
29JUN76	76181	143.66	128.40	102.42	71.48	----	----
6JUL76	76188	143.95	132.65	102.59	74.15	----	----
13JUL76	76195	143.82	129.86	96.48	72.57	----	----
20JUL76	76202	143.61	124.48	99.92	69.98	----	----
27JUL76	76209	143.49	128.09	102.25	70.82	----	----
3AUG76	76216	143.39	127.77	101.59	70.82	----	----
10AUG76	76223	143.07	127.40	101.25	----	----	----
17AUG76	76230	142.86	126.82	102.46	70.82	----	----
24AUG76	76237	142.07	126.32	101.84	70.65	----	----
30AUG76	76243	142.32	126.40	101.00	70.73	----	----
7SEP76	76251	142.07	125.96	101.67	70.98	----	----
14SEP76	76258	142.07	125.77	101.67	70.90	----	----
21SEP76	76265	141.74	126.23	101.96	70.64	----	----
18OCT76	76292	143.66	127.23	102.67	70.48	----	----
22OCT76	76296	143.53	127.46	104.25	70.48	----	----
5NOV76	76310	143.91	----	103.59	70.57	----	----
18NOV76	76323	143.86	----	103.79	71.15	----	----
11JAN77	77011	144.12	----	103.96	78.07	----	----
19JAN77	77019	144.16	----	103.59	78.07	----	----
5MAY77	77125	143.91	----	105.44	80.98	----	----
17MAY77	77137	144.57	----	105.35	77.63	----	----
9JUN77	77160	142.92	128.58	104.55	71.57	----	----
23JUN77	77174	143.90	133.81	104.59	81.71	----	----
6JUL77	77187	143.70	134.68	104.77	81.23	----	----
13JUL77	77194	----	134.39	104.02	71.86	----	----
20JUL77	77201	----	128.54	104.13	71.86	----	----
3AUG77	77215	142.44	127.32	99.39	70.59	----	----
10AUG77	77222	141.83	128.23	101.93	70.72	54.21	----

Table B-1. (Continued)

CALENDAY	JULIAN	F1	F2	F3	F4	F6	F8
18AUG77	77230	142.65	130.97	100.74	78.58	----	----
24AUG77	77236	143.67	131.00	102.33	83.60	54.33	31.51
1SEP77	77244	142.85	128.47	103.72	69.76	54.04	29.51
9SEP77	77252	143.35	130.67	105.13	78.67	55.80	31.02
16SEP77	77259	143.61	134.31	105.47	86.56	56.85	32.25
21SEP77	77264	143.37	129.52	104.39	71.20	55.35	30.08
6OCT77	77279	143.43	129.44	105.64	81.31	55.27	30.63
12OCT77	77285	143.67	133.63	105.62	86.27	56.17	30.83
28OCT77	77301	138.53	131.39	105.39	88.57	56.19	30.60
4NOV77	77308	143.55	130.93	105.26	----	----	----
11NOV77	77315	143.58	132.89	103.74	89.21	56.35	30.14
18NOV77	77322	143.62	134.49	105.37	88.83	56.89	30.85
3DEC77	77337	143.63	134.93	105.52	89.15	57.19	30.81
29JAN78	78029	143.93	134.08	105.22	88.55	56.51	31.03
14FEB78	78045	143.73	134.28	105.24	86.02	56.34	31.38
25FEB78	78056	143.74	134.88	105.31	85.59	56.23	31.18
7MAR78	78066	143.69	134.95	105.27	88.78	56.59	31.47
1APR78	78091	143.45	134.71	105.15	79.90	----	----
25APR78	78115	143.52	134.83	105.14	82.06	56.73	30.60
13MAY78	78133	144.04	134.85	105.70	87.72	----	----
26MAY78	78146	143.49	134.34	105.19	74.47	56.28	----
2JUN78	78153	143.46	131.53	104.90	73.92	55.41	30.42
13JUN78	78164	143.48	133.96	104.94	77.02	56.38	31.82
29JUN78	78180	142.99	129.25	----	----	----	----
18JUL78	78199	143.41	129.70	104.71	73.85	55.31	30.85
21AUG78	78233	143.49	132.23	105.44	75.84	54.38	30.71
19SEP78	78262	142.24	128.33	104.35	72.60	53.48	29.88
26SEP78	78269	141.78	128.21	103.34	72.46	53.49	29.41
5OCT78	78278	141.39	123.98	101.58	72.51	53.25	29.40
14OCT78	78287	140.63	130.22	100.43	71.50	53.09	28.54
20OCT78	78293	140.01	128.41	100.33	71.16	52.86	28.22
31OCT78	78304	139.66	127.96	100.49	71.11	52.44	28.23
3NOV78	78307	139.45	128.78	100.44	69.45	52.31	28.23
11NOV78	78315	139.29	128.15	93.38	----	52.04	28.16
30NOV78	78334	143.59	129.32	104.47	77.99	55.68	31.64
7DEC78	78341	143.60	130.41	105.40	81.58	56.37	31.76
12DEC78	78346	143.62	129.58	105.23	82.01	56.05	30.89
29DEC78	78363	143.55	132.33	104.96	80.73	55.51	30.84
4JAN79	79004	143.80	131.81	105.17	86.80	57.73	32.28
29JAN79	79029	143.75	130.73	105.67	82.20	57.48	32.28
3MAR79	79062	----	130.93	106.35	82.37	58.59	32.03
5MAY79	79125	143.32	130.90	105.54	88.30	58.27	31.74
18MAY79	79138	143.49	130.81	104.94	81.59	56.09	31.33
2JUN79	79153	143.72	134.75	105.50	87.33	57.61	----
14JUL79	79195	143.30	132.06	102.22	87.18	56.28	32.49
25AUG79	79237	142.35	129.45	103.40	75.26	54.23	30.76

Table B-2. Indian Fork Study Spoil Bank Saturation Zone Thickness (Feet)

CALENDAY	JULIAN	F1	F2	F3	F4	F6	F8
8APR75	75098	27.52	13.21	3.30	6.05	----	----
15APR75	75105	27.54	14.74	3.76	6.20	----	----
22APR75	75112	27.60	16.61	3.77	6.23	----	----
29APR75	75119	27.81	16.33	3.91	6.55	----	----
6MAY75	75126	27.50	15.56	3.88	6.68	----	----
13MAY75	75133	27.53	16.06	3.78	6.56	----	----
20MAY75	75140	27.37	13.02	3.83	6.41	----	----
27MAY75	75147	27.45	14.02	3.86	6.84	----	----
3JUN75	75154	27.42	14.81	3.79	6.69	----	----
20JUN75	75171	27.48	14.21	5.31	6.51	----	----
27JUN75	75178	28.61	13.93	3.67	6.33	----	----
7JUL75	75188	27.72	12.44	5.46	6.23	----	----
14JUL75	75195	----	12.45	3.18	6.14	----	----
21JUL75	75202	----	11.99	----	6.37	----	----
28JUL75	75209	26.70	11.61	2.96	6.29	----	----
5AUG75	75217	25.40	10.71	2.96	6.29	----	----
13AUG75	75225	25.67	10.58	3.01	6.29	----	----
20AUG75	75232	26.60	10.81	3.01	6.29	----	----
27AUG75	75239	25.90	10.51	2.76	6.29	----	----
4SEP75	75247	22.75	10.31	3.01	5.89	----	----
9SEP75	75252	22.59	9.49	3.26	5.63	----	----
16SEP75	75259	22.75	9.24	3.06	5.69	----	----
22SEP75	75265	23.67	10.06	3.76	6.29	----	----
29SEP75	75272	27.58	11.49	3.43	6.83	----	----
9OCT75	75282	27.06	11.37	4.01	10.99	----	----
14OCT75	75287	27.58	11.52	4.16	11.19	----	----
31OCT75	75304	27.81	11.16	4.26	11.24	----	----
7NOV75	75311	28.10	12.61	4.26	13.39	----	----
14NOV75	75318	27.30	13.51	4.16	14.19	----	----
21NOV75	75325	27.37	13.61	4.86	11.79	----	----
1DEC75	75335	27.94	14.37	5.01	11.82	----	----
8DEC75	75342	27.78	14.66	5.66	12.54	----	----
15DEC75	75349	27.79	13.45	9.38	12.03	----	----
22DEC75	75356	27.83	13.74	5.68	12.49	----	----
31DEC75	75365	27.83	16.08	7.16	9.16	----	----
5JAN76	76005	27.90	17.58	5.93	11.91	----	----
15JAN76	76015	27.92	18.33	11.68	11.91	----	----
22JAN76	76022	27.87	12.91	5.05	6.86	----	----
30JAN76	76030	27.83	17.66	7.26	10.82	----	----
5FEB76	76036	27.81	14.53	----	10.66	----	----
12FEB76	76043	27.75	22.25	5.68	6.66	----	----
19FEB76	76050	27.96	17.99	9.09	10.74	----	----
26FEB76	76057	27.79	16.08	8.34	6.66	----	----
4MAR76	76064	27.71	12.33	5.43	6.57	----	----
11MAR76	76071	27.83	17.83	6.34	7.41	----	----

Table B-2. (Continued)

CALENDAY	JULIAN	F1	F2	F3	F4	F6	F8
17MAR76	76077	27.79	14.33	6.09	6.66	----	----
25MAR76	76085	27.92	18.49	6.26	8.49	----	----
1APR76	76092	28.00	18.39	9.34	12.09	----	----
8APR76	76099	27.75	14.53	----	8.66	----	----
12APR76	76103	27.69	12.91	----	8.32	----	----
20APR76	76111	27.25	12.23	8.33	7.11	----	----
26APR76	76117	27.71	12.24	8.33	8.79	----	----
11MAY76	76132	27.79	12.83	8.05	11.91	----	----
18MAY76	76139	27.36	17.53	12.97	14.41	----	----
25MAY76	76146	27.61	15.08	12.68	9.07	----	----
1JUN76	76153	27.79	18.66	11.74	7.74	----	----
9JUN76	76161	27.62	16.08	12.82	7.91	----	----
15JUN76	76167	26.58	12.99	12.34	6.49	----	----
22JUN76	76174	27.75	12.28	11.38	6.95	----	----
29JUN76	76181	27.67	12.41	11.26	7.07	----	----
6JUL76	76188	27.36	16.66	11.43	9.74	----	----
13JUL76	76195	27.83	13.87	5.32	8.16	----	----
20JUL76	76202	27.62	8.49	8.76	5.57	----	----
27JUL76	76209	27.50	12.10	11.09	6.41	----	----
3AUG76	76216	27.40	11.78	10.43	6.41	----	----
10AUG76	76223	27.08	11.41	10.09	----	----	----
17AUG76	76230	26.87	10.83	11.30	6.41	----	----
24AUG76	76237	26.08	10.33	10.68	6.24	----	----
30AUG76	76243	26.33	10.41	9.84	6.32	----	----
7SEP76	76251	26.08	9.97	10.51	6.57	----	----
14SEP76	76258	26.08	9.78	10.51	6.49	----	----
21SEP76	76265	25.75	10.24	10.80	6.23	----	----
18OCT76	76292	27.67	11.24	11.51	6.07	----	----
22OCT76	76296	27.54	11.47	13.09	6.97	----	----
5NOV76	76310	27.92	----	12.43	6.16	----	----
18NOV76	76323	27.37	----	12.63	6.74	----	----
11JAN77	77011	28.13	----	12.80	13.66	----	----
19JAN77	77019	28.17	----	12.43	13.66	----	----
5MAY77	77125	27.92	----	14.28	16.57	----	----
17MAY77	77137	28.58	----	14.19	13.22	----	----
9JUN77	77160	26.93	12.59	13.39	7.16	----	----
23JUN77	77174	27.91	17.82	13.43	17.30	----	----
6JUL77	77187	27.71	18.69	13.61	16.82	----	----
13JUL77	77194	----	18.40	12.86	7.45	----	----
20JUL77	77201	----	12.55	12.97	7.45	----	----
3AUG77	77215	26.45	11.33	8.23	6.18	----	----
10AUG77	77222	25.84	12.30	10.77	6.31	8.21	----
18AUG77	77230	26.66	14.93	9.58	14.17	----	----
24AUG77	77236	27.68	15.91	11.17	19.19	8.33	3.38

Table B-2. (Continued)

CALENDAY	JULIAN	F1	F2	F3	F4	F6	F8
1SEP77	77244	26.86	12.49	12.56	5.35	8.04	1.38
9SEP77	77252	27.36	14.68	13.97	14.26	9.80	2.89
16SEP77	77259	27.62	13.32	14.31	22.15	10.[illegible]5	4.12
21SEP77	77264	27.38	13.53	13.23	6.79	9.35	1.95
12OCT77	77285	27.68	17.64	14.45	21.86	10.17	2.70
28OCT77	77301	22.54	15.40	14.23	24.16	10.19	2.47
4NOV77	77308	27.56	14.94	14.10	----	----	----
11NOV77	77315	27.59	16.90	12.58	24.80	10.35	2.01
18NOV77	77322	27.63	18.50	14.21	24.42	10.89	2.72
3DEC77	77337	27.64	18.94	14.36	24.74	11.19	2.68
29JAN78	78029	27.94	18.09	14.06	24.14	10.51	2.90
14FEB78	78045	27.74	18.29	14.08	21.61	10.34	3.25
25FEB78	78056	27.75	18.89	14.15	21.18	10.23	3.05
7MAR78	78066	27.70	18.96	14.11	24.37	10.59	3.34
1APR78	78091	27.46	18.72	13.99	15.49	----	----
25APR78	78115	27.53	18.84	13.98	17.65	10.73	2.47
13MAY78	78133	28.05	18.86	14.54	23.31	----	----
26MAY78	78146	27.50	18.35	14.03	10.06	10.28	----
2JUN78	78153	27.47	15.54	13.74	9.51	9.41	2.29
13JUN78	78164	27.49	17.97	13.78	12.61	10.38	3.69
29JUN78	78180	27.00	13.26	----	----	----	----
18JUL78	78199	27.42	13.71	13.55	9.44	9.31	2.72
21AUG78	78233	27.50	16.24	14.23	11.43	8.38	2.58
19SEP78	78262	26.25	12.34	13.19	8.19	7.48	1.75
26SEP78	78269	25.79	12.22	12.18	8.05	7.48	1.28
5OCT78	78278	25.40	12.99	10.42	8.10	7.25	1.27
14OCT78	78287	24.69	14.23	9.27	7.09	7.09	0.41
20OCT78	78293	24.02	12.42	9.17	6.75	6.86	0.09
31OCT78	78304	23.67	11.97	9.33	6.70	6.44	0.10
3NOV78	78307	23.46	12.79	9.28	5.94	6.31	0.10
11NOV78	78315	23.30	12.16	2.22	----	6.04	0.03
30NOV78	78334	27.59	13.33	13.31	13.58	9.68	3.51
7DEC78	78341	27.61	14.42	14.24	17.17	10.37	3.63
12DEC78	78346	27.63	13.59	14.07	17.60	10.05	2.76
29DEC78	78363	27.56	16.34	13.80	16.32	9.51	2.71
4JAN79	79004	27.81	15.82	14.01	22.39	11.73	4.15
29JAN79	79029	27.76	14.74	14.51	17.79	11.48	4.15
3MAR79	79062	----	14.94	15.19	17.96	12.59	3.90
5MAY79	79125	27.83	14.91	14.33	23.89	12.27	3.61
18MAY79	79138	27.50	14.82	13.78	17.18	10.09	3.20
2JUN79	79153	27.73	18.76	14.34	23.42	11.61	----
14JUL79	79195	27.81	16.07	11.06	22.77	10.28	4.36
25AUG79	79237	26.86	13.49	12.24	10.85	8.23	2.63

Table B-3. Bills Branch Study Spoil Bank Groundwater Elevations (Feet)

CALENDAY	JULIAN	C1	B1	B2	B3	B5
22JAN76	76022	120.52	107.43	94.39	----	40.58
17FEB76	76048	----	107.47	92.98	----	40.25
19FEB76	76050	120.27	107.31	94.06	----	40.33
26FEB76	76057	120.27	106.89	92.81	----	40.42
4MAR76	76064	120.36	107.47	92.64	----	40.42
11MAR76	76071	120.44	107.44	92.64	----	40.42
17MAR76	76077	120.36	109.39	92.86	----	40.50
25MAR76	76085	120.44	107.81	93.64	----	40.50
1APR76	76092	120.44	107.64	99.64	52.22	40.50
8APR76	76099	120.36	107.81	93.48	52.47	40.42
13APR76	76104	120.44	107.89	92.98	52.88	40.42
20APR76	76111	120.48	107.97	92.81	52.84	40.42
27APR76	76118	120.52	107.97	92.73	52.72	40.50
4MAY76	76125	120.48	107.85	92.56	52.63	40.50
11MAY76	76132	120.52	107.72	92.60	52.76	40.50
19MAY76	76139	120.48	112.80	96.81	52.13	40.71
25MAY76	76146	120.40	107.76	92.98	53.97	40.50
1JUN76	76153	119.94	107.85	92.85	54.92	40.75
8JUN76	76160	120.44	107.93	93.06	53.67	40.58
15JUN76	76167	120.36	107.56	92.64	56.22	40.42
22JUN76	76174	120.46	107.47	92.52	56.09	40.46
29JUN76	76181	121.77	107.64	90.81	57.34	40.42
6JUL76	76188	120.44	107.81	92.93	57.98	41.42
13JUL76	76195	120.11	106.89	91.43	58.05	40.42
20JUL76	76202	120.52	107.72	92.48	53.55	40.00
27JUL76	76209	120.36	107.85	92.48	53.97	40.25
3AUG76	76216	120.15	112.39	92.14	54.67	40.25
10AUG76	76223	120.27	107.47	92.39	52.88	----
17AUG76	76230	120.31	107.14	92.39	63.17	40.33
24AUG76	76237	120.27	107.22	92.48	54.80	40.42
31AUG76	76244	120.56	107.14	92.43	57.13	40.46
7SEP76	76251	120.27	107.43	92.43	53.09	40.50
14SEP76	76258	120.27	107.22	92.56	63.30	40.46
21SEP76	76265	120.27	107.22	92.48	53.22	40.42
11OCT76	76285	120.44	107.47	92.56	56.30	39.83
5NOV76	76310	120.11	107.14	92.56	54.30	40.42
19NOV76	76324	120.52	107.68	92.56	61.22	40.42
11JAN77	77011	120.40	107.23	92.81	63.05	40.46
15JUN77	77166	120.40	107.29	92.51	62.01	----
23JUN77	77174	120.21	107.18	96.08	61.76	42.82
6JUL77	77187	120.40	110.66	97.97	61.61	42.54
13JUL77	77194	120.15	106.99	92.73	61.61	39.75
20JUL77	77201	120.21	107.03	92.48	61.52	39.41

Table B-3. (Continued)

CALENDAY	JULIAN	C1	B1	B2	B3	B5
3AUG77	77215	121.15	106.93	92.67	61.33	40.76
10AUG77	77222	122.05	107.04	92.89	61.76	40.85
18AUG77	77230	122.52	107.76	91.87	61.06	40.77
26AUG77	77238	121.79	107.45	92.69	61.51	40.84
16SEP77	77259	122.93	107.38	96.91	61.62	41.65
21SEP77	77264	121.93	107.45	92.71	63.44	40.37
6OCT77	77279	121.90	107.37	92.69	61.11	40.50
12OCT77	77285	122.18	107.39	92.73	61.58	40.90
28OCT77	77301	122.45	113.49	92.87	61.67	40.75
11NOV77	77315	122.50	107.08	94.63	61.57	40.43
18NOV77	77322	121.51	107.06	92.78	61.67	40.10
3DEC77	77337	122.44	107.19	99.56	61.85	41.15
14FEB78	78045	122.84	107.43	93.26	62.32	41.25
25FEB78	78056	121.95	107.69	92.74	62.15	40.27
7MAR78	78066	122.73	107.59	92.02	61.76	40.13
1APR78	78091	122.01	108.83	96.57	61.30	40.36
25APR78	78115	122.59	109.16	92.73	61.09	40.19
13MAY78	78133	122.70	107.43	96.83	60.55	41.51
26MAY78	78146	122.44	107.28	92.63	61.40	40.27
2JUN78	78153	122.17	106.70	92.53	60.67	39.99
13JUN78	78164	122.42	107.32	94.13	60.46	40.20
20JUL78	78201	122.32	106.96	92.70	60.25	40.45
21AUG78	78233	122.26	106.89	92.73	59.10	----
19SEP78	78262	122.42	107.17	92.91	59.27	----
5OCT78	78278	122.49	107.19	92.30	59.58	----
31OCT78	78304	121.96	107.09	91.16	59.75	----
29JAN79	79029	122.69	115.93	97.53	60.44	----
3MAR79	79062	122.70	115.99	99.51	60.45	----
8MAY79	79128	122.85	114.49	97.67	61.04	----
19MAY79	79139	122.23	106.24	95.34	60.42	----
2JUN79	79153	122.71	106.76	99.83	60.15	----
25AUG79	79237	121.00	105.39	91.17	58.24	----
14JUL79	79195	122.91	114.91	96.86	60.40	----

Table B-4. Bills Branch Study Spoil Bank Saturation Zone Thickness (Feet)

CALENDAY	JULIAN	C1	B1	B2	B3	B5
22JAN76	76022	28.78	15.69	2.65	----	19.72
17FEB76	76048	----	15.73	1.24	----	19.39
19FEB76	76050	28.53	15.57	2.32	----	19.47
26FEB76	76057	28.53	15.15	1.07	----	19.56
4MAR76	76064	28.62	15.73	0.90	----	19.56
11MAR76	76071	28.70	15.70	0.90	----	19.56
17MAR76	76077	28.62	18.15	1.12	----	19.64
25MAR76	76085	28.70	16.07	1.90	----	19.64
1APR76	76092	28.70	15.90	7.90	9.26	19.64
8APR76	76099	28.62	16.07	1.74	9.51	19.56
13APR76	76104	28.70	16.15	1.24	9.92	19.56
20APR76	76111	28.74	16.23	1.07	9.88	19.56
27APR76	76118	28.78	16.23	0.99	9.76	19.64
4MAY76	76125	28.74	16.11	0.82	9.67	19.64
11MAY76	76132	28.78	15.98	0.86	9.80	19.64
18MAY76	76139	28.74	21.06	5.07	9.17	19.85
25MAY76	76146	28.66	16.02	1.24	11.01	19.64
1JUN76	76153	28.20	16.11	1.11	11.96	19.39
8JUN76	76160	28.70	16.19	1.32	10.71	19.72
15JUN76	76167	28.62	15.82	0.90	13.26	19.56
22JUN76	76174	28.72	15.73	0.78	13.13	19.60
29JUN76	76181	30.03	15.90	0.00	14.38	19.56
6JUL76	76188	28.70	16.07	1.19	14.92	20.56
13JUL76	76195	28.37	15.15	0.00	15.09	19.56
20JUL76	76202	28.78	15.98	0.74	10.59	19.14
27JUL76	76209	28.62	16.11	0.74	11.01	19.39
3AUG76	76216	28.41	20.65	0.40	11.71	19.39
10AUG76	76223	28.53	15.73	0.65	9.92	----
17AUG76	76230	28.57	15.40	0.65	20.21	19.47
24AUG76	76237	28.53	15.48	0.74	11.84	19.56
31AUG76	76244	28.82	15.40	0.69	14.17	19.60
7SEP76	76251	28.53	15.69	0.69	10.13	19.64
14SEP76	76258	28.53	15.48	0.82	20.34	19.60
21SEP76	76265	28.53	15.48	0.74	10.26	19.56
11OCT76	76285	28.70	15.73	0.82	13.34	18.97
5NOV76	76310	28.37	15.40	0.82	11.34	19.56
19NOV76	76324	28.78	15.94	0.82	18.26	19.56
11JAN77	77011	28.66	15.49	1.07	20.09	19.60
15JUN77	77166	28.66	15.55	0.77	19.05	----
23JUN77	77174	28.47	15.44	4.34	18.80	21.96
6JUL77	77187	28.66	18.92	6.23	18.65	21.68
13JUL77	77194	28.41	15.25	0.99	18.65	18.89
20JUL77	77201	28.47	15.29	0.74	18.56	18.55

Table B-4. (Continued)

CALENDAY	JULIAN	C1	B1	B2	B3	B5
3AUG77	77215	29.41	15.19	0.93	18.37	19.90
10AUG77	77222	30.31	15.30	1.15	18.80	19.93
18AUG77	77230	30.78	16.02	0.13	18.10	19.91
26AUG77	77238	30.35	15.71	0.95	18.55	19.98
16SEP77	77259	31.19	15.64	5.17	18.66	20.79
21SEP77	77264	30.19	15.71	0.97	20.48	19.51
6OCT77	77279	30.16	15.63	0.95	18.15	19.64
12OCT77	77285	30.44	15.65	0.99	18.62	20.04
28OCT77	77301	30.71	21.75	1.13	18.71	19.89
11NOV77	77315	30.76	15.34	2.89	18.61	19.57
18NOV77	77322	29.77	15.32	1.04	18.71	19.24
3DEC77	77337	30.70	15.45	7.32	18.89	20.29
14FEB78	78045	31.10	15.69	1.52	19.36	20.39
25FEB78	78056	30.21	15.95	1.00	19.19	19.41
7MAR78	78066	30.99	15.85	0.28	18.80	19.27
1APR78	78091	30.27	17.09	4.83	18.43	19.50
25APR78	78115	30.85	17.42	0.99	18.13	19.33
13MAY78	78133	30.96	15.69	5.09	17.59	20.65
26MAY78	78146	30.70	15.54	0.89	18.44	19.41
2JUN78	78153	30.43	14.96	0.79	17.71	19.13
13JUN78	78164	30.68	15.58	2.39	17.50	19.34
20JUL78	78201	30.58	15.22	0.96	17.29	19.59
21AUG78	78233	30.52	15.15	0.99	16.14	----
19SEP78	78262	30.68	15.43	1.17	16.31	----
5OCT78	78278	30.75	15.45	1.06	16.62	----
31OCT78	78304	30.22	15.35	0.00	16.79	----
29JAN79	79029	30.35	24.19	5.79	17.48	----
3MAR79	79062	30.96	24.25	7.77	17.49	----
3MAY79	79123	31.11	22.75	5.93	13.08	----
19MAY79	79139	30.39	14.50	3.60	17.46	----
2JUN79	79153	30.97	15.02	3.14	17.19	----
14JUL79	79195	31.17	23.17	5.12	12.12	----
25AUG79	79237	29.26	14.15	0.00	15.28	----

APPENDIX C

SATURATED ZONE CROSS SECTION AREAS

SATURATED ZONE CROSS SECTION AREAS

Models for Saturated Zone Cross Section

Qualitative evaluation of the hydrologic data for individual wells at the two study spoil banks has to be made when constructing their saturated zone cross sections. At the Indian Fork Study Spoil Bank all wells sufficiently penetrated the spoil to fully characterize fluctuations of the phreatic surface. As a result, only two cross sections were constructed. The first, Area 1, considers the bank profile from the highwall to the F4 well. It is defined by the impermeable layer and groundwater elevations observed in the bench pond (F1), F2, F3, and F4 wells. The second Indian Fork cross section, Area 2, extends from the highwall to the extreme edge of the toe at the F8 well. It is defined by the impermeable layer and by groundwater elevations at the F1, F2, F3, F4, F6, and F8 wells. As described in the text, interpolated values, linked to hydrologic condition at upgradient wells, were used at the F6 and F8 wells for the first 2-1/2 years of the hydrologic record. Only the Indian Fork Area 2 is referred to in the Results and Discussion chapters of the text.

Because both the Bills Branch B1 and B5 wells failed to fully penetrate the spoil to the impermeable layer, the use of their data must be qualified. In addition, the extent of the seepage area, B6, at the base of the spoil is known to vary, at times going completely dry but generally extending 6 to 8 feet up the toe embankment. Based upon these observations, four cross sections were constructed for the Bills

Branch Study Spoil Bank. All consider the entire profile from highwall to toe.

Bills Branch Area 1 is defined by the impermeable layer, the upper limit of saturation at the toe, and groundwater elevations at the B2, B3, and B5 wells. It is not considered in the text. Area 2 is defined by the impermeable layer, the upper limit of saturation at the toe, and groundwater elevations at all the wells including B1. Bills Branch Area 2 is taken to represent the maximum extent of saturation at the study bank and is only valid for dates when the phreatic surface rises significantly above the bottom of the B1 and B5 wells. Area 3 is constructed to represent minimum conditions when the phreatic surface is below the bottom of the B1 and B5 wells and the toe is dry. It is defined by the impermeable layer, the base of the toe embankment, and groundwater elevations in the B2 and B3 wells. Median saturated zone conditions are defined by Area 4. Here, the upper limit of saturation at the toe embankment and groundwater elevations at the B2 and B3 wells are considered. This cross section corresponds to field observations that a large saturated area generally remains at the toe embankment even though the B1 and B5 wells may be dry.

Area values for the cross sections described above are presented in Tables C-1 and C-2.

Table C-1. Indian Fork Study Spoil Bank Saturated Zone Cross Section Areas (Sq. Ft.)

CALENDAY	JULIAN	AREA 1	AREA 2
8APR75	75098	3816.35	4363.97
15APR75	75105	3957.66	4509.03
22APR75	75112	4036.69	4648.81
29APR75	75119	4114.47	4674.59
6MAY75	75126	4032.43	4595.80
13MAY75	75133	4061.21	4621.58
20MAY75	75140	3878.13	4434.75
27MAY75	75147	3922.45	4489.82
3JUN75	75154	3966.85	4530.47
20JUN75	75171	4015.23	4574.34
27JUN75	75178	4001.38	4556.00
7JUL75	75188	3914.33	4466.45
14JUL75	75195	3744.82	4294.69
21JUL75	75202	3679.87	4235.49
28JUL75	75209	3611.73	4165.35
5AUG75	75217	3423.81	3977.43
13AUG75	75225	3443.46	3997.08
20AUG75	75232	3548.72	4102.34
27AUG75	75239	3445.73	3999.35
4SEP75	75247	3133.43	3677.05
9SEP75	75252	3069.42	3608.03
16SEP75	75259	3055.26	3593.88
22SEP75	75265	3259.74	3813.35
29SEP75	75272	3730.77	4297.89
9OCT75	75282	3825.45	4690.78
14OCT75	75287	3900.40	4770.73
31OCT75	75304	3904.39	4775.97
7NOV75	75311	4095.66	5020.99
14NOV75	75318	4156.83	5102.16
21NOV75	75325	4134.09	5019.42
1DEC75	75335	4204.11	5090.19
8DEC75	75342	4268.27	5172.35
15DEC75	75349	4389.80	5281.12
22DEC75	75356	4207.96	5110.78
31DEC75	75365	4365.71	5185.29
5JAN76	76005	4483.66	5371.99
15JAN76	76015	4879.14	5767.47
22JAN76	76022	3955.49	4523.36
30JAN76	76030	4530.34	5391.42
5FEB76	76036	4259.94	5117.02
12FEB76	76043	4634.10	5196.96
19FEB76	76050	4672.20	5531.28
26FEB76	76057	4360.55	4923.41
4MAR76	76064	3913.53	4474.15
11MAR76	76071	4420.25	5001.87

Table C-1. (Continued)

CALENDAY	JULIAN	AREA 1	AREA 2
17MAR76	76077	4103.86	4666.73
25MAR76	76085	4471.31	5080.43
1APR76	76092	4825.46	5740.79
8APR76	76099	4345.29	5028.55
12APR76	76103	4199.68	4804.05
20APR76	76111	4053.17	4627.29
26APR76	76117	4144.96	4816.38
11MAY76	76132	4263.85	5152.19
18MAY76	76139	4964.68	5915.50
25MAY76	76146	4598.64	5318.98
1JUN76	76153	4774.67	5364.53
9JUN76	76161	4645.33	5239.45
15JUN76	76167	4259.00	4817.62
22JUN76	76174	4306.33	4876.94
29JUN76	76181	4275.02	4848.13
6JUL76	76188	4688.58	5328.44
13JUL76	76195	4072.33	4672.75
20JUL76	76202	3802.99	4338.61
27JUL76	76209	4208.00	4764.62
3AUG76	76216	4136.76	4693.38
10AUG76	76223	4059.89	4616.51
17AUG76	76230	4070.59	4627.20
24AUG76	76237	3918.11	4470.48
30AUG76	76243	3900.20	4454.57
7SEP76	76251	3892.07	4452.68
14SEP76	76258	3876.39	4435.01
21SEP76	76265	3887.00	4439.11
18OCT76	76292	4178.84	4726.96
22OCT76	76296	4276.23	4324.34
5NOV76	76310	4281.01	4831.37
18NOV76	76323	4308.83	4873.70
11JAN77	77011	4559.35	5491.43
19JAN77	77019	4544.07	5476.15
5MAY77	77125	4749.34	5754.17
17MAY77	77137	4715.96	5637.04
9JUN77	77160	4345.62	5115.20
23JUN77	77174	5099.53	6122.61
6JUL77	77187	5138.70	6149.78
13JUL77	77194	4777.09	5359.71
20JUL77	77201	4340.54	4923.16
3AUG77	77215	3877.17	4428.04
10AUG77	77222	4041.35	4637.68
18AUG77	77230	4462.30	5231.68
24AUG77	77236	4799.36	5763.92
1SEP77	77244	4230.40	4739.61

Table C-1. (Continued)

CALENDAY	JULIAN	AREA 1	AREA 2
9SEP77	77252	4770.85	5671.20
16SEP77	77259	5297.38	6473.10
21SEP77	77264	4434.95	5105.68
6OCT77	77279	4737.25	5729.42
12OCT77	77285	5255.80	6359.50
28OCT77	77301	4657.65	5814.57
4NOV77	77308	5107.30	6272.81
11NOV77	77315	5167.42	6337.51
18NOV77	77322	5369.79	6572.32
3DEC77	77337	5419.78	6643.72
29JAN78	78029	5353.70	6535.18
14FEB78	78045	5277.73	6395.31
25FEB78	78056	5312.88	6410.41
7MAR78	78066	5401.58	6602.64
1APR78	78091	5101.49	6073.88
25APR78	78115	5177.62	6197.57
13MAY78	78133	5423.31	6570.30
26MAY78	78146	4926.85	5732.15
2JUN78	78153	4693.01	5442.34
13JUN78	78164	4956.96	5861.96
29JUN78	78180	4530.15	5365.48
18JUL78	78199	4545.96	5298.54
21AUG78	78233	4831.95	5586.69
19SEP78	78262	4280.39	4892.27
26SEP78	78269	4164.05	4761.74
5OCT78	78278	4078.14	4665.87
14OCT78	78287	4000.65	4535.93
20OCT78	78293	3793.28	4301.80
31OCT78	78304	3736.10	4223.54
3NOV78	78307	3723.53	4163.26
11NOV78	78315	3317.59	3806.09
30NOV78	78334	4639.21	5530.94
7DEC78	78341	4875.39	5892.54
12DEC78	78346	4820.97	5813.80
29DEC78	78363	4955.67	5889.58
4JAN79	79004	5128.38	6352.81
29JAN79	79029	4945.98	6043.47
3MAR79	79062	5007.13	6156.18
5MAY79	79125	5130.82	6406.24
18MAY79	79138	4966.09	5860.34
2JUN79	79153	5376.90	6606.78
14JUL79	79195	4982.05	6151.51
25AUG79	79237	4439.39	5173.61

Table C-2. Bills Branch Study Spoil Bank Saturated Zone Cross Section Areas (Sq. Ft.)

CALENDAY	JULIAN	AREA 1	AREA 2	AREA 3	AREA 4
1APR76	76092	3628.95	4133.35	2374.18	2908.47
8APR76	76099	2671.24	3574.74	1427.17	2050.53
13APR76	76104	2635.32	3575.40	1490.38	2022.20
20APR76	76111	2604.05	3559.89	1368.22	1990.19
27APR76	76118	2583.73	3544.61	1340.08	1962.50
4MAY76	76125	2547.15	3511.18	1301.49	1924.25
11MAY76	76132	2567.32	3520.63	1324.56	1946.83
18MAY76	76139	3183.06	4191.23	1912.78	2537.41
25MAY76	76146	2756.28	3688.16	1540.44	2158.18
1JUN76	76153	2852.63	3798.38	1641.85	2256.02
8JUN76	76160	2742.27	3679.82	1514.61	2133.47
15JUN76	76167	2936.16	3876.86	1775.53	2384.82
22JUN76	76174	2905.84	3848.44	1739.75	2349.53
29JUN76	76181	2764.28	3825.41	1628.57	2233.66
6JUL76	76188	3222.93	4161.11	2034.93	2638.00
13JUL76	76195	2933.26	3913.02	1918.35	2420.78
20JUL76	76202	2600.03	3560.91	1407.00	2026.31
27JUL76	76209	2660.73	3629.81	1460.97	2078.70
3AUG76	76216	2681.06	3957.83	1496.88	2111.98
10AUG76	76223	2533.18	3483.98	1306.60	1928.42
17AUG76	76230	3629.07	4559.06	2628.86	3212.10
24AUG76	76237	2759.85	3689.21	1567.62	2182.24
31AUG76	76244	3002.04	3929.50	1859.08	2464.96
7SEP76	76251	2575.36	3521.11	1339.94	1960.97
14SEP76	76258	3678.26	4602.58	2672.59	3255.33
21SEP76	76265	2591.97	3521.33	1364.59	1985.14
11OCT76	76285	2894.00	3834.08	1773.09	2382.08
5NOV76	76310	2719.44	3638.71	1516.09	2132.58
19NOV76	76324	3454.69	4408.01	2405.31	2995.85
11JAN77	77011	3691.44	4600.62	2630.20	3263.88
15JUN77	77166	3677.28	4609.16	2498.38	3086.46
23JUN77	77174	4225.89	4925.74	3034.20	3622.72
6JUL77	77187	4492.36	5292.47	3315.34	3904.43
13JUL77	77194	3480.07	4379.16	2432.45	3071.53
20JUL77	77201	3408.91	4326.28	2431.14	3020.56
3AUG77	77215	3505.72	4404.82	2436.93	3027.06
10AUG77	77222	3592.17	4484.33	2527.15	3115.67
18AUG77	77230	3350.52	4352.38	2275.07	2866.22
26AUG77	77238	3533.17	4463.79	2463.24	3052.69
16SEP77	77259	4267.71	4927.85	3148.14	3737.19
21SEP77	77264	3711.19	4640.55	2714.42	3296.64
6OCT77	77279	3468.81	4394.38	2411.84	3002.80
12OCT77	77285	3550.83	4475.14	2478.59	3067.79
28OCT77	77301	3573.00	4873.09	2512.41	3101.27

Table C-2. (Continued)

CALENDAY	JULIAN	AREA 1	AREA 2	AREA 3	AREA 4
11NOV77	77315	3821.55	4606.52	2779.31	3368.54
18NOV77	77322	3516.90	4417.25	2498.10	3086.96
3DEC77	77337	4681.22	5162.29	3598.91	4187.10
14FEB78	78045	3736.20	4629.62	2657.92	3244.34
25FEB78	78056	3572.47	4515.07	2553.43	3140.48
7MAR78	78066	3407.59	4339.27	2388.97	2977.39
1APR78	78091	4106.28	4879.28	3064.54	3654.45
25APR78	78115	3453.11	4489.02	2415.63	3006.66
13MAY78	78133	4132.31	4800.64	2997.93	3590.99
26MAY78	78146	3475.30	4398.98	2439.57	3029.44
2JUN78	78153	3363.84	4257.25	2329.87	2922.47
13JUN78	78164	3609.35	4440.98	2557.20	3150.60
20JUL78	78201	3375.81	4274.90	2302.92	2897.10
21AUG78	78233	3265.46	4158.25	2159.91	2758.41
19SEP78	78262	3312.14	4211.23	2210.37	2808.22
5OCT78	78278	3327.59	4234.88	2232.72	2829.41
31OCT78	78304	3084.97	4089.36	1993.89	2589.94
29JAN79	79029	4170.80	5330.92	3095.06	3688.53
3MAR79	79062	4486.58	5525.65	3411.07	4004.50
8MAY79	79128	4256.80	5317.30	3194.41	3785.63
19MAY79	79139	3820.57	4507.82	2744.39	3337.94
2JUN79	79153	4513.52	4947.30	3431.33	4025.89
14JUL79	79195	4060.05	5198.10	2983.42	3577.04
25AUG79	79237	2926.13	3854.22	1801.44	2403.16

APPENDIX D

MAJOR CONSTITUENT QUALITY DATA

Table D-1. Spoil Bank, Water Quality Data Base

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: B1	(Bills Branch)									
calendar	NO.									
21APR76	1	Total	6.30	0.01	123.00	6.40	54.00	74.00	-----	-----
28APR76	1	Total	7.80	0.05	94.00	8.10	56.00	82.00	-----	-----
19MAY76	1	Total	6.50	0.12	10.00	11.00	111.00	88.00	809.00	-----
26MAY76	1	Total	7.00	0.15	118.00	9.00	57.00	65.00	524.00	-----
3JUN76	1	Total	7.70	0.07	53.00	9.70	113.00	79.00	494.00	-----
21JUN76	1	Total	6.50	0.14	3.00	9.20	111.00	82.00	511.00	-----
9JUL76	1	Diss	6.30	0.25	7.00	8.10	96.00	82.00	455.00	-----
9JUL76	1	Total			100.00	9.30	108.00	80.00		
12SEP76	1	Diss	6.30	0.20	3.00	8.00	110.00	76.00	448.00	140
12SEP76	1	Total			-----	-----	-----	-----		
12SEP76	2	Diss	6.30	0.17	3.00	7.90	113.00	76.00	448.00	145
12SEP76	2	Total			-----	-----	-----	-----		
12SEP76	3	Diss	6.10	0.16	6.00	7.00	108.00	73.00	448.00	-----
12SEP76	3	Total			-----	-----	-----	-----		
5OCT76	1	Diss	6.40	0.23	9.00	7.20	102.00	70.00	436.00	123
5OCT76	1	Total			185.00	11.00	36.00	82.00		
8MAR77	1	Diss	6.30	0.25	1.10	11.00	120.00	76.00	455.00	320
8MAR77	1	Total			-----	-----	-----	-----		

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: B1 (Bills Branch)										
calendar	NO.									
8MAR77	2	Diss	6.20	0.24	4.60	11.00	125.00	81.00	444.00	325
8MAR77	2	Total			-----	-----	-----	-----		
8MAR77	3	Diss	6.20	0.24	5.40	10.00	120.00	91.00	460.00	335
8MAR77	3	Total			-----	-----	-----	-----		
2OCT77	1	Diss	6.50	0.43	-----	-----	-----	-----	479.00	165
13OCT77	1	Diss	6.40	0.29	-----	-----	-----	-----	495.00	185
3DEC77	1	Diss	6.60	-0.10	-----	-----	-----	-----	463.00	175
18FEB78	1	Diss	7.40	0.23	9.10	10.00	117.00	60.00	550.00	240
7MAR78	1	Diss	6.40	0.18	12.00	13.00	147.00	78.00	531.00	185
1APR78	1	Diss	6.10	0.31	5.20	8.00	62.00	34.00	142.00	160
1APR78	2	Diss	6.20	0.30	8.20	8.10	64.00	35.00	146.00	160
25APR78	1	Diss	6.00	0.35	4.20	11.40	90.00	51.00	202.00	210
25APR78	2	Diss	6.00	0.29	4.70	11.00	87.00	51.00	197.00	205
26MAY78	1	Diss	6.30	0.33	-----	-----	-----	-----	-----	210
13JUN78	1	Diss	6.35	0.23	14.00	8.60	71.00	42.00	150.00	215

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: B2 **(Bills Branch)**										
calendar	NO.									
21APR76	1	Total	-----	-0.10	48.00	-----	40.00	30.00	-----	-----
19MAY76	1	Total	6.30	0.30	16.00	2.40	90.00	85.00	182.00	-----
26MAY76	1	Total	6.50	0.19	16.00	17.00	89.00	82.00	-----	-----
3JUN76	1	Total	6.60	0.26	11.00	1.80	97.00	85.00	334.00	-----
21JUN76	1	Total	6.60	0.15	11.00	2.60	96.00	93.00	341.00	-----
9JUL76	1	Diss	6.30	0.35	0.60	1.20	99.00	91.00	342.00	340
9JUL76	1	Total			7.60	1.20	102.00	95.00		
12SEP76	1	Diss	6.20	0.25	3.00	1.80	182.00	130.00	375.00	-----
12SEP76	1	Total			-----	-----	-----	-----		
12SEP76	2	Diss	6.30	0.20	5.00	2.50	179.00	137.00	375.00	-----
12SEP76	2	Total			-----	-----	-----	-----		
5OCT76	1	Diss	6.50	0.20	7.00	2.10	181.00	122.00	347.00	-----
5OCT76	1	Total			-----	-----	-----	-----		
8MAR77	1	Diss	6.30	0.28	0.30	2.40	84.00	68.00	242.00	275
8MAR77	1	Total			-----	-----	-----	-----		
8MAR77	2	Diss	6.30	0.29	0.40	2.40	86.00	70.00	277.00	300
8MAR77	2	Total			-----	-----	-----	-----		

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: B2 **(Bills Branch)**										
calendar	NO.									
8MAR77	3	Diss	6.20	0.28	0.30	2.50	86.00	70.00	240.00	290
8MAR77	3	Total			-----	-----	-----	-----		
13OCT77	1	Diss	6.50	0.37	-----	-----	-----	-----	389.00	385
3DEC77	1	Diss	6.00	-0.10	-----	-----	-----	-----	136.00	220
3DEC77	2	Diss	6.00	-0.10	-----	-----	-----	-----	138.00	220
18FEB78	1	Diss	6.80	0.26	0.70	0.40	117.00	72.00	394.00	280
7MAR78	1	Diss	6.60	0.42	0.40	0.30	154.00	88.00	449.00	210
7MAR78	2	Diss	6.60	0.29	0.40	0.20	146.00	86.00	452.00	210
1APR78	1	Diss	6.10	0.46	0.40	2.30	90.00	59.00	204.00	210
1APR78	2	Diss	6.10	0.45	0.30	1.80	94.00	60.00	227.00	220
13JUN78	1	Diss	6.40	0.24	0.40	1.20	113.00	68.00	276.00	235
13JUN78	2	Diss	6.20	0.25	0.30	1.20	112.00	67.00	288.00	230
3MAR79	1	Diss	5.00	0.26	0.40	1.00	51.00	46.00	168.00	220
5MAY79	1	Diss	6.00	0.36	-----	-----	-----	-----	288.00	240
2JUN79	1	Diss	5.80	0.50	0.04	0.78	50.00	50.00	172.00	205
14JUL79	1	Diss	6.60	0.50	0.05	0.05	91.00	65.00	275.00	285
14JUL79	1	Total			0.50	-----	94.00	66.00		

Table D-1. (Continued)

	(Bank)	Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: B2 **(Bills Branch)**										
calendar	NO.									
19DEC79	1	Diss	6.20	0.46	0.30	2.10	100.00	73.00	279.00	280
Site: B3										
19MAY76	1	Total	7.70	0.21	9.80	9.20	110.00	47.00	-----	-----
26MAY76	1	Total	7.60	0.14	3.00	9.00	111.00	51.00	394.00	-----
3JUN76	1	Total	6.30	0.31	6.00	9.80	115.00	51.00	425.00	-----
21JUN76	1	Total	6.50	0.20	3.00	11.00	-----	49.00	309.00	-----
9JUL76	1	Diss	6.30	0.26	8.90	11.00	100.00	49.00	396.00	68
9JUL76	1	Total			-----	11.00	98.00	48.00		
12SEP76	1	Diss	6.10	0.10	14.00	13.00	107.00	53.00	420.00	63
12SEP76	1	Total			20.00	13.00	107.00	50.00		
12SEP76	2	Diss	6.10	0.10	22.00	14.00	105.00	52.00	423.00	63
12SEP76	2	Total			26.00	14.00	107.00	54.00		
5OCT76	1	Diss	6.40	0.10	21.00	13.00	97.00	48.00	432.00	46
5OCT76	1	Total			23.00	14.00	101.00	47.00		
8MAR77	1	Diss	6.50	0.19	56.00	18.00	87.00	56.00	526.00	215
8MAR77	1	Total			-----	-----	-----	-----		
13OCT77	1	Diss	6.30	0.27	-----	-----	-----	-----	525.00	65

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: B3	(Bills Branch)									
calendar	NO.									
3DEC77	1	Diss	6.50	-0.10	-----	-----	-----	-----	467.00	50
3DEC77	2	Diss	6.50	-0.10	-----	-----	-----	-----	490.00	25
7MAR78	1	Diss	6.50	0.20	75.00	17.00	83.00	50.00	493.00	40
7MAR78	2	Diss	6.80	0.19	78.00	17.00	83.00	48.00	501.00	50
1APR78	1	Diss	6.35	0.19	55.00	15.00	83.00	48.00	429.00	0
1APR78	2	Diss	6.35	0.19	56.00	15.90	81.00	48.00	442.00	0
25APR78	1	Diss	5.90	0.18	45.00	18.70	76.00	47.00	490.00	0
25APR78	2	Diss	5.90	0.18	47.00	18.30	77.00	48.00	478.00	0
26MAY78	1	Diss	6.10	0.23	41.00	18.70	74.00	46.00	492.00	10
26MAY78	2	Diss	6.20	0.25	42.00	18.60	75.00	48.00	505.00	5
13JUN78	1	Diss	6.50	0.15	39.00	21.40	105.00	46.50	424.00	16
13JUN78	2	Diss	6.50	0.16	38.00	20.90	72.00	44.50	418.00	17
7SEP78	1	Diss	6.60	0.14	37.00	19.40	83.00	43.00	412.00	101
11NOV78	1	Diss	6.00	0.21	-----	-----	-----	-----	403.00	7
3MAR79	1	Diss	6.00	0.20	46.40	18.30	78.00	41.00	478.00	8
5MAY79	1	Diss	6.00	0.22	51.00	18.20	82.00	47.00	456.00	0

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l CaCO3)	Sulfate (mg/l)
Site: B3 (Bills Branch)										
calendar	NO.									
18MAY79	1	Diss	5.90	0.26	58.00	18.00	78.00	46.00	419.00	0
2JUN79	1	Diss	6.10	0.22	48.00	17.60	70.00	53.00	380.00	6
14JUL79	1	Diss	6.80	0.23	40.00	17.00	67.00	46.00	393.00	0
14JUL79	1	Total			-----	17.00	69.00	47.00		
25AUG79	1	Diss	6.40	0.20	42.00	18.80	74.00	44.00	381.00	33
25AUG79	1	Total			44.00	18.80	75.00	44.00		
19DEC79	1	Diss	6.40	0.29	34.50	16.80	60.00	38.00	369.00	33
28JUN80	1	Diss	6.30	0.25	39.00	15.80	70.00	42.00	390.00	0
28JUN80	1	Total			47.50	16.40	70.00	42.00		
Site: B5										
19MAY76	1	Total	7.70	0.29	32.00	-----	110.00	-----	-----	-----
26MAY76	1	Total	-----	-0.10	52.00	23.00	88.00	-----	-----	-----
3JUN76	1	Total	-----	-0.10	67.00	30.00	-----	80.00	-----	-----
21JUN76	1	Total	6.60	0.13	91.00	22.00	96.00	90.00	193.00	-----
9JUL76	1	Diss	6.60	0.11	45.00	15.00	103.00	150.00	254.00	-----
9JUL76	1	Total			49.00	12.00	103.00	154.00		

Table D-1. (Continued)

Site: B5 **(Bills Branch)**

calendar NO.

	(Bank)	Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
12SEP76	1	Diss	6.10	0.09	29.00	34.00	95.00	78.00	-----	-----
12SEP76	1	Total			-----	-----	-----	-----		
5OCT76	1	Diss	6.80	0.13	25.00	27.00	107.00	88.00	-----	-----
5OCT76	1	Total			-----	-----	-----	-----		
2OCT77	1	Diss	6.60	0.36	-----	-----	-----	-----	247.00	320
7SEP78	1	Diss	5.80	0.15	4.20	3.10	4.40	7.80	57.40	91
11NOV78	1	Diss	5.30	0.27	-----	-----	-----	-----	18.30	6

Site: B6

	(Bank)	Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
21APR76	1	Total	-----	-0.10	-----	-----	62.00	91.00	-----	-----
28APR76	1	Total	6.10	0.32	0.10	0.20	58.00	92.00	-----	-----
19MAY76	1	Total	6.70	0.32	0.10	1.30	78.00	122.00	110.00	-----
26MAY76	1	Total	7.00	0.29	-----	-----	-----	-----	93.00	-----
3JUN76	1	Total	6.70	0.40	-----	1.20	77.00	106.00	105.00	-----
9JUL76	1	Diss	6.70	0.30	1.70	1.20	70.00	102.00	70.00	460
9JUL76	1	Total			0.10	0.80	67.00	102.00		
8MAR77	1	Diss	6.70	0.18	0.10	0.50	133.00	130.00	107.00	800
8MAR77	1	Total			-----	-----	-----	-----		

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: B6 (Bills Branch)										
calendar	NO.									
3MAR79	1	Diss	4.50	0.33	-----	-----	-----	-----	39.20	1000
Site: B4										
7MAR78	1	Diss	5.60	0.19	7.40	5.90	54.00	32.00	31.30	205
1APR78	1	Diss	6.60	0.22	1.40	2.50	80.00	46.00	198.00	175
25APR78	1	Diss	5.90	0.19	2.60	5.70	67.00	42.00	148.00	165
26MAY78	1	Diss	6.45	0.38	2.30	2.60	63.00	42.00	300.00	160
13JUN78	1	Diss	6.30	0.18	1.40	3.80	68.00	39.00	166.00	170

Table D-1. (Continued)

Site: F1 (Indian Fork)

calendar NO.

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
10JUL75	1	Total	7.10	0.28	1.50	0.05	19.00	7.00	-----	63
15AUG75	1	Total	8.70	-0.10	2.00	0.08	20.00	7.00	-----	66
22AUG75	1	Total	7.90	-0.10	2.20	0.18	18.00	6.00	-----	73
20FEB76	1	Total	7.30	-0.10	2.20	0.10	11.00	8.00	-----	55
1MAR76	1	Total	7.40	-0.10	1.50	0.02	21.00	9.00	-----	58
17MAR76	1	Total	-----	-0.10	1.70	0.00	19.00	9.00	-----	52
26MAR76	1	Total	7.40	-0.10	1.50	0.09	16.00	8.00	-----	48
2APR76	1	Total	7.20	-0.10	0.25	0.22	13.00	8.00	-----	49
21APR76	1	Total	6.00	0.26	0.17	0.04	20.00	11.00	-----	60
28APR76	1	Total	6.60	0.26	0.15	0.03	22.00	11.00	42.00	61
19MAY76	1	Total	7.40	0.29	0.70	0.07	14.00	7.40	21.00	44
26MAY76	1	Total	7.60	0.37	0.30	0.04	19.00	9.50	32.00	51
3JUN76	1	Total	7.00	0.44	0.80	0.06	13.00	6.30	24.00	41

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F1	**(Indian Fork)**									
calendar	NO.									
21JUN76	1	Total	6.50	0.37	1.70	0.07	13.00	6.10	68.00	36
9JUL76	1	Diss	7.00	0.33	0.10	0.07	18.00	8.60	30.00	50
9JUL76	1	Total			0.10	0.80	18.00	8.70		
26JUL76	1	Diss	6.40	0.25	0.10	0.06	21.00	8.90	29.00	48
26JUL76	1	Total			0.10	0.06	20.00	9.00		
26AUG76	1	Diss	6.60	0.26	0.10	0.06	24.00	9.20	47.00	48
26AUG76	1	Total			0.10	0.10	25.00	9.70		
4OCT76	1	Diss	7.70	0.33	0.10	0.01	16.00	5.80	22.00	33
4OCT76	1	Total			0.10	0.03	16.00	6.00		
6MAY77	1	Diss	7.10	0.25	0.10	0.02	22.00	8.00	41.00	58
6MAY77	1	Total			0.50	0.07	22.00	8.00		
23JUN77	1	Diss	-----	0.20	0.06	-----	24.00	7.50	37.00	-----
23JUN77	1	Total			1.30	-----	24.00	7.50		
4AUG77	1	Diss	6.80	0.32	0.04	-----	29.00	10.00	42.00	-----
4AUG77	1	Total			0.12	-----	30.00	10.00		
10AUG77	1	Diss	7.10	0.28	0.08	0.00	21.00	8.80	44.00	46
10AUG77	1	Total			0.50	-----	21.00	9.00		

Table D-1. (Continued)

Site: F1 (Indian Fork)

calendar	NO. (Bank)	Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
16AUG77	1	Diss	-----	-0.10	0.20	-----	24.00	8.50	38.30	47
16AUG77	1	Total			0.40	-----	20.00	8.00		
23AUG77	1	Diss	7.10	0.34	0.20	0.02	19.00	8.30	40.00	48
23AUG77	1	Total			0.20	0.04	20.00	8.50		
1SEP77	1	Diss	7.50	0.45	0.20	0.01	22.00	6.50	26.00	38
1SEP77	1	Total			0.60	0.04	14.00	6.50		
9SEP77	1	Diss	7.30	0.50	0.10	0.08	14.00	6.00	25.00	36
9SEP77	1	Total			1.10	0.14	14.00	6.50		
16SEP77	1	Diss	7.70	0.53	-----	-----	-----	-----	-----	-----
20SEP77	1	Diss	7.90	0.51	0.20	0.08	16.00	9.50	27.00	60
20SEP77	1	Total			1.20	0.12	16.00	9.50		
11OCT77	1	Diss	6.80	0.51	-----	-----	-----	-----	6.20	45
29OCT77	1	Diss	6.00	0.34	0.40	0.08	20.00	9.50	29.00	51
29OCT77	1	Total			1.20	0.11	20.00	9.50		
13NOV77	1	Diss	6.70	0.42	0.10	0.04	23.00	10.00	29.00	62
13NOV77	1	Total			0.20	0.04	23.00	10.00		
8JAN78	1	Diss	6.80	0.28	0.30	0.10	20.00	9.00	24.20	80

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F1 (Indian Fork)										
calendar	NO.									
25FEB78	1	Diss	6.90	0.43	0.07	0.10	27.00	11.00	29.70	49
13JUN78	1	Diss	6.90	0.24	0.04	0.10	21.00	11.00	32.40	70
14JUL79	1	Diss	6.80	0.47	0.04	0.01	26.00	10.00	49.70	65
14JUL79	1	Total			0.60	-----	26.00	10.00		
25AUG79	1	Diss	7.80	0.50	0.02	0.00	29.00	10.00	52.00	81
25AUG79	1	Total			0.40	-----	29.00	10.00		
22OCT79	1	Diss	7.70	0.27	0.02	0.00	30.00	11.00	48.00	73
22OCT79	1	Total			0.30	0.10	31.00	11.00		
28JUN80	1	Diss	8.30	0.43	0.00	0.00	36.00	12.00	69.80	70
28JUN80	1	Total			0.15	0.30	36.00	12.00		
Site: F2										
10JUL75	1	Total	6.50	0.28	5.00	1.00	50.00	15.00	-----	62
10JUL75	2	Total	6.30	0.28	5.00	1.00	50.00	15.00	-----	62
15AUG75	1	Total	6.20	-0.10	4.00	0.60	40.00	13.00	-----	61
22AUG75	1	Total	6.10	-0.10	4.80	0.60	40.00	13.00	-----	62
1MAR76	1	Total	6.40	-0.10	0.40	0.59	48.00	15.00	-----	87
17MAR76	1	Total	-----	-0.10	0.30	0.61	46.00	14.00	-----	80

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F2 (Indian Fork)										
calendar	NO.									
26MAR76	1	Total	6.50	-0.10	0.40	0.30	43.00	13.00	-----	69
2APR76	1	Total	6.70	-0.10	0.10	0.12	30.00	10.00	-----	47
21APR76	1	Total	6.50	0.29	6.80	0.51	26.00	8.60	-----	39
28APR76	1	Total	4.90	0.29	8.00	0.57	29.00	9.30	68.00	46
19MAY76	1	Total	6.50	0.28	0.60	0.29	43.00	15.00	109.00	69
26MAY76	1	Total	6.50	0.35	1.10	0.50	44.00	16.00	120.00	68
3JUN76	1	Total	6.40	0.36	0.40	0.24	42.00	14.00	118.00	60
21JUN76	1	Total	5.90	0.34	6.90	0.58	28.00	9.60	98.00	38
9JUL76	1	Diss	6.30	0.27	5.00	0.50	50.00	15.00	130.00	59
9JUL76	1	Total			6.00	0.50	50.00	15.00		
26JUL76	1	Diss	5.40	0.25	8.00	0.60	29.00	8.90	79.00	36
26JUL76	1	Total			9.00	0.60	28.00	8.70		
26AUG76	1	Diss	5.70	0.24	5.00	0.70	35.00	11.00	161.00	39
26AUG76	1	Total			6.00	0.70	38.00	12.00		
4OCT76	1	Diss	5.70	0.32	4.00	0.80	35.00	11.00	115.00	39
4OCT76	1	Total			4.00	0.80	36.00	11.00		

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F3 (Indian Fork)										
calendar	NO.									
10JUL75	1	Total	4.90	-0.01	96.00	7.80	180.00	40.00	-----	0
22AUG75	1	Total	4.70	-0.10	8.50	10.00	280.00	70.00	-----	-----
20FEB76	1	Total	5.20	-0.10	66.00	6.20	96.00	17.00	-----	8
1MAR76	1	Total	5.40	-0.10	59.00	4.50	66.00	13.00	-----	14
17MAR76	1	Total	-----	-0.10	65.00	4.50	71.00	12.00	-----	9
26MAR76	1	Total	5.40	-0.10	44.00	3.60	36.00	9.00	-----	0
28APR76	1	Total	5.60	0.25	38.00	7.00	54.00	20.00	84.00	165
19MAY76	1	Total	6.10	0.22	29.00	5.40	77.00	32.00	125.00	120
26MAY76	1	Total	6.20	0.27	26.00	7.00	100.00	46.00	270.00	188
3JUN76	1	Total	6.80	0.13	39.00	6.30	76.00	29.00	206.00	135
21JUN76	1	Total	6.10	0.21	121.00	6.20	68.00	26.00	249.00	180
9JUL76	1	Diss	5.80	0.19	46.00	5.80	64.00	25.00	65.00	125
9JUL76	1	Total			108.00	9.90	219.00	64.00		
26JUL76	1	Diss	5.50	0.19	39.00	5.60	67.00	26.00	83.00	125
26JUL76	1	Total			80.00	13.00	284.00	94.00		

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F3 (Indian Fork)										
calendar	NO.									
26AUG76	1	Diss	4.90	0.17	102.00	7.50	100.00	40.00	30.00	125
26AUG76	1	Total			168.00	12.00	256.00	69.00		
26AUG76	2	Diss	-----	-0.10	60.00	6.00	57.00	27.00	-----	-----
26AUG76	3	Diss	-----	-0.10	35.00	5.50	54.00	26.00	-----	-----
4OCT76	1	Diss	4.80	0.19	123.00	7.70	57.00	27.00	100.00	125
4OCT76	1	Total			142.00	11.00	172.00	47.00		
6MAY77	1	Diss	5.40	0.07	-----	-----	-----	-----	356.00	100
6MAY77	1	Total			45.00	2.00	98.00	39.00		
6MAY77	2	Diss	6.60	0.07	8.10	0.70	112.00	39.00	344.00	120
6MAY77	2	Total			8.90	0.60	109.00	38.00		
6MAY77	3	Diss	6.60	0.11	7.10	0.60	115.00	40.00	360.00	120
6MAY77	3	Total			-----	-----	-----	-----		
23JUN77	1	Diss	4.70	0.06	13.00	2.10	86.00	29.00	-----	-----
23JUN77	1	Total			19.00	2.20	84.00	30.00		
23JUN77	2	Diss	6.50	0.02	8.00	0.90	35.00	11.00	100.00	125
23JUN77	2	Total			13.00	0.90	40.00	12.00		
23JUN77	3	Diss	6.20	0.07	-----	-----	-----	-----	118.00	-----
23JUN77	3	Total			48.00	1.70	52.00	18.00		
4AUG77	1	Diss	5.50	0.06	52.00	3.40	95.00	37.00	-----	-----
4AUG77	1	Total			74.00	3.90	77.00	38.00		
4AUG77	2	Diss	6.80	0.10	-----	2.10	88.00	33.00	262.00	-----
4AUG77	2	Total			70.00	2.60	96.00	37.00		

Table D-1. (Continued)

	(Bank)	Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F3 (Indian Fork)										
calendar	NO.									
4AUG77	3	Diss	6.90	0.11	18.00	2.00	77.00	27.00	214.00	125
4AUG77	3	Total			51.00	1.80	-----	28.00		
10AUG77	1	Diss	5.00	0.16	33.00	3.00	72.00	29.00	225.00	132
10AUG77	1	Total			70.00	3.80	88.00	37.00		
10AUG77	2	Diss	5.40	0.18	-----	-----	-----	-----	161.00	125
10AUG77	2	Total			112.00	3.90	68.00	34.00		
10AUG77	3	Total	-----	-0.10	-----	3.90	63.00	27.00	-----	-----
16AUG77	1	Diss	-----	-0.10	2.20	4.90	72.00	41.00	95.90	210
16AUG77	1	Total			128.00	6.10	168.00	50.00		
16AUG77	2	Diss	-----	-0.10	2.00	2.60	48.00	22.00	96.30	185
16AUG77	2	Total			38.00	3.10	64.00	25.00		
16AUG77	3	Total	-----	-0.10	94.00	-----	-----	-----	-----	-----
23AUG77	1	Diss	6.10	0.37	29.00	3.30	73.00	35.00	234.00	215
23AUG77	1	Total			40.00	3.80	86.00	39.00		
23AUG77	2	Diss	5.20	0.12	-----	-----	-----	-----	150.00	225
23AUG77	2	Total			74.00	4.50	76.00	37.00		
1SEP77	1	Diss	5.30	0.15	70.00	3.50	84.00	39.00	212.00	175
1SEP77	1	Total			92.00	4.40	88.00	42.00		
1SEP77	2	Diss	5.90	0.11	54.00	3.40	98.00	43.00	281.00	170
1SEP77	2	Total			74.00	3.70	106.00	45.00		
9SEP77	1	Diss	4.90	0.16	50.00	2.90	120.00	54.60	299.00	150
9SEP77	1	Total			94.00	4.80	82.00	43.00		

Table D-1. (Continued)

	(Bank)	Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F3 (Indian Fork)										
calendar	NO.									
9SEP77	2	Diss	5.40	0.10	11.00	1.20	134.00	57.00	412.00	240
9SEP77	2	Total			16.00	1.30	150.00	59.00		
16SEP77	1	Diss	5.90	0.17	-----	-----	-----	-----	-----	-----
16SEP77	2	Diss	6.70	0.21	-----	-----	-----	-----	-----	-----
20SEP77	1	Diss	6.30	0.19	36.00	2.20	122.00	54.00	347.00	195
20SEP77	1	Total			51.00	2.80	116.00	52.00		
20SEP77	2	Diss	6.80	0.19	17.00	1.20	140.00	57.00	455.00	245
20SEP77	2	Total			21.00	1.40	146.00	52.00		
11OCT77	1	Diss	5.60	0.14	-----	-----	-----	-----	387.00	25
11OCT77	2	Diss	6.20	0.09	-----	-----	-----	-----	330.00	120
29OCT77	1	Diss	5.60	0.14	17.00	2.40	128.00	49.00	440.00	20
29OCT77	1	Total			28.00	2.90	123.00	48.00		
29OCT77	2	Diss	6.20	0.11	9.00	1.80	147.00	51.00	458.00	145
29OCT77	2	Total			11.00	1.90	151.00	53.00		
13NOV77	1	Diss	5.50	0.18	13.00	2.40	126.00	49.00	178.00	90
13NOV77	1	Total			24.00	3.00	114.00	50.00		
13NOV77	2	Diss	6.10	0.20	6.00	1.60	138.00	50.00	241.00	180
13NOV77	2	Total			10.00	2.00	139.00	51.00		
8JAN78	1	Diss	5.40	-0.01	8.20	1.70	103.00	38.00	296.00	160
8JAN78	2	Diss	6.30	0.04	2.00	1.10	100.00	35.00	184.00	170

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F3 (Indian Fork)										
calendar	NO.									
25FEB78	1	Diss	5.60	0.03	2.40	2.00	113.00	42.00	332.00	120
25FEB78	2	Diss	6.40	0.11	5.10	1.20	117.00	40.00	328.00	135
13JUN78	1	Diss	6.10	0.12	0.90	2.12	85.00	36.00	153.00	70
13JUN78	2	Diss	6.60	0.12	0.70	0.70	68.00	22.50	211.00	90
13JUN78	3	Diss	6.80	0.15	0.20	0.35	45.00	15.00	131.00	85
7SEP78	1	Diss	6.20	0.09	1.00	1.10	124.00	44.00	390.00	145
7OCT78	1	Diss	5.90	0.28	-----	-----	-----	-----	-----	-----
11NOV78	1	Diss	4.40	0.23	-----	-----	-----	-----	-----	-----
7DEC78	1	Diss	6.40	0.23	-----	-----	-----	-----	416.00	-----
3MAR79	1	Diss	6.50	0.32	9.40	1.10	82.00	36.00	268.00	125
5MAY79	1	Diss	6.10	0.20	3.30	0.70	74.00	23.00	211.00	75
18MAY79	1	Diss	6.20	0.34	3.50	0.70	83.00	24.00	220.00	87
2JUN79	1	Diss	6.40	0.35	4.20	0.52	62.00	23.00	188.00	76
14JUL79	1	Diss	6.70	0.37	6.40	1.00	87.00	29.00	285.00	75
14JUL79	1	Total			8.70	1.00	88.00	29.00		

Table D-1. (Continued)

	(Bank)	Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F3 (Indian Fork)										
calendar	NO.									
25AUG79	1	Diss	6.40	0.26	3.60	0.80	78.00	22.00	209.00	71
25AUG79	1	Total			5.80	0.80	78.00	22.00		
22OCT79	1	Diss	6.70	0.02	1.80	1.30	135.00	38.00	323.00	146
22OCT79	1	Total			2.20	1.30	136.00	38.00		
19DEC79	1	Diss	6.40	0.35	1.40	1.00	80.00	24.00	201.00	94
Site: F5										
10JUL75	1	Total	6.90	0.29	8.20	1.10	70.00	22.00	-----	200
10JUL75	2	Total	6.40	0.29	8.20	1.10	70.00	22.00	-----	200
20FEB76	1	Total	7.10	-0.10	0.80	0.28	43.00	13.00	-----	82
1MAR76	1	Total	6.70	-0.10	0.10	0.22	38.00	12.00	-----	59
17MAR76	1	Total	-----	-0.10	0.30	0.50	42.00	12.00	-----	52
26MAR76	1	Total	6.70	-0.10	0.20	0.38	44.00	12.00	-----	52
2APR76	1	Total	6.90	-0.10	0.15	0.47	33.00	11.00	-----	45
21APR76	1	Total	5.30	0.33	2.00	2.50	50.00	18.00	-----	59
28APR76	1	Total	6.30	0.32	0.05	1.40	51.00	18.00	137.00	67
19MAY76	1	Total	6.80	0.32	0.40	0.18	47.00	15.00	280.00	52

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F4	(Indian Fork)									
calendar	NO.									
26MAY76	1	Total	6.40	0.35	2.50	2.00	55.00	17.00	151.00	48
3JUN76	1	Total	6.70	0.38	0.80	0.67	49.00	16.00	147.00	49
21JUN76	1	Total	6.60	0.32	3.60	3.30	50.00	16.00	180.00	47
9JUL76	1	Diss	6.40	0.26	7.00	6.80	57.00	17.00	174.00	37
9JUL76	1	Total			28.00	9.90	49.00	17.00		
26JUL76	1	Diss	6.10	0.17	27.00	16.00	87.00	24.00	244.00	57
26JUL76	1	Total			37.00	19.00	66.00	25.00		
26AUG76	1	Diss	5.80	0.15	43.00	24.00	66.00	23.00	325.00	50
26AUG76	1	Total			54.00	28.00	81.00	29.00		
4OCT76	1	Diss	6.10	0.21	2.00	3.70	64.00	20.00	166.00	80
4OCT76	1	Total			2.00	3.80	65.00	21.00		
4OCT76	2	Total	6.10	0.21	1.00	3.10	65.00	21.00	166.00	80
6MAY77	1	Diss	6.60	0.22	0.10	0.40	50.00	14.00	150.00	51
6MAY77	1	Total			2.20	0.60	49.00	14.00		
6MAY77	2	Diss	6.70	0.21	0.10	0.30	42.00	13.00	140.00	48
6MAY77	2	Total			1.40	0.40	50.00	14.00		
23JUN77	1	Diss	6.30	0.17	-----	0.40	56.00	20.00	200.00	-----
23JUN77	1	Total			8.00	0.50	78.00	21.00		

Table D-1. (Continued)

Site: F4 (Indian Fork)

calendar NO.

	(Bank)	Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
10AUG77	1	Diss	5.80	0.12	2.70	3.80	48.00	17.00	153.00	145
10AUG77	1	Total			7.40	5.00	50.00	17.00		
10AUG77	2	Diss	5.50	0.22	1.20	3.50	46.00	16.00	123.00	145
10AUG77	2	Total			3.40	4.20	49.00	17.00		
10AUG77	3	Total	-----	-0.10	0.60	-----	46.00	17.00	-----	-----
16AUG77	1	Diss	-----	-0.10	0.40	4.30	46.00	17.00	-----	115
16AUG77	1	Total			1.10	3.70	49.00	17.00		
16AUG77	2	Diss	-----	-0.10	0.60	2.80	48.00	16.00	162.00	110
16AUG77	2	Total			2.20	2.90	51.00	17.00		
16AUG77	3	Diss	-----	-0.10	0.60	2.20	48.00	17.00	161.00	115
16AUG77	3	Total			1.20	2.30	51.00	17.00		
1SEP77	1	Diss	6.30	0.20	8.00	7.80	46.00	18.00	236.00	60
1SEP77	1	Total			16.00	10.80	48.00	19.00		
1SEP77	2	Diss	6.10	0.19	2.00	5.80	42.00	17.00	179.00	65
1SEP77	2	Total			2.00	6.20	44.00	18.00		
9SEP77	1	Diss	5.80	0.21	0.80	0.50	56.00	21.00	182.00	101
9SEP77	1	Total			1.60	0.70	57.00	22.00		
9SEP77	2	Diss	5.90	0.32	0.60	0.50	57.00	22.00	180.00	110
9SEP77	2	Total			0.40	0.50	56.00	21.00		
20SEP77	1	Diss	7.30	0.35	0.80	0.60	56.00	22.00	178.00	140
20SEP77	1	Total			1.60	0.60	57.00	23.00		

Table D-1. (Continued)

	(Bank)	Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F4	(Indian Fork)									
calendar	NO.									
20SEP77	2	Diss	7.30	0.35	0.60	0.60	57.00	22.00	179.00	140
20SEP77	2	Total			0.40	0.60	58.00	23.00		
11OCT77	1	Diss	6.90	0.37	-----	-----	-----	-----	118.00	55
11OCT77	2	Diss	6.70	0.40	-----	-----	-----	-----	109.00	50
29OCT77	1	Diss	6.60	0.29	0.10	0.20	54.00	16.00	171.00	60
29OCT77	1	Total			1.20	0.30	56.00	16.00		
29OCT77	2	Diss	6.60	0.31	0.10	0.20	53.00	15.00	142.00	70
29OCT77	2	Total			0.30	0.20	56.00	16.00		
13NOV77	1	Diss	6.60	0.43	0.50	0.10	50.00	13.00	67.00	90
13NOV77	1	Total			10.00	1.00	49.00	15.00		
13NOV77	2	Diss	6.60	0.45	0.10	0.10	48.00	13.00	60.00	95
13NOV77	2	Total			1.30	0.20	49.00	13.00		
8JAN78	1	Diss	6.40	0.31	0.10	0.10	44.00	10.00	95.00	55
8JAN78	2	Diss	6.60	0.30	-----	-----	-----	-----	-----	-----
25FEB78	1	Diss	6.10	0.28	0.50	0.80	43.00	12.00	90.10	45
25FEB78	2	Diss	6.80	0.30	0.11	0.10	45.00	11.00	93.60	45
13JUN78	1	Diss	6.60	0.24	-----	-----	-----	-----	136.00	56
13JUN78	2	Diss	6.60	0.26	0.05	0.22	51.00	18.00	137.00	60
7OCT78	1	Diss	6.00	0.21	7.50	11.40	45.00	22.00	182.00	56

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F4 (Indian Fork)										
calendar	NO.									
7DEC78	1	Diss	6.00	0.28	-----	-----	-----	-----	89.60	-----
3MAR79	1	Diss	6.10	0.29	0.40	0.40	38.00	14.00	90.50	100
5MAY79	1	Diss	6.35	0.49	0.02	0.01	44.00	14.00	104.00	74
18MAY79	1	Diss	6.00	0.50	0.02	0.20	59.00	16.00	116.00	89
2JUN79	1	Diss	6.50	0.50	-----	-----	-----	-----	105.00	68
14JUL79	1	Diss	6.70	0.48	0.04	0.04	46.00	15.00	136.00	57
14JUL79	1	Total			0.50	0.20	46.00	15.00		
25AUG79	1	Diss	6.10	0.51	0.20	0.10	54.00	20.00	153.00	0
25AUG79	1	Total			1.90	1.80	63.00	20.00		
22OCT79	1	Diss	6.30	0.44	0.01	0.70	58.00	19.00	139.00	84
22OCT79	1	Total			0.40	0.80	60.00	19.00		
19DEC79	1	Diss	6.70	0.52	0.10	0.10	52.00	17.00	111.00	90
28JUN80	1	Diss	6.30	0.51	0.25	1.60	48.00	17.00	126.00	53
28JUN80	1	Total			2.85	1.90	46.00	18.00		

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F5 (Indian Fork)										
calendar	NO.									
10JUL75	1	Total	6.30	0.16	50.00	7.80	128.00	21.00	-----	62
15AUG75	1	Total	-----	-0.10	2.50	5.50	25.00	12.00	-----	68
20FEB76	1	Total	6.30	-0.10	36.00	8.60	55.00	18.00	-----	79
1MAR76	1	Total	6.30	-0.10	16.00	9.70	59.00	20.00	-----	67
17MAR76	1	Total	-----	-0.10	32.00	7.90	53.00	17.00	-----	62
26MAR76	1	Total	7.00	-0.10	42.00	8.20	52.00	18.00	-----	65
2APR76	1	Total	6.30	-0.10	34.00	9.10	57.00	21.00	-----	68
21APR76	1	Total	6.60	0.14	19.00	11.00	63.00	26.00	-----	68
28APR76	1	Total	6.30	0.17	42.00	11.00	75.00	24.00	236.00	68
19MAY76	1	Total	6.50	0.12	31.00	8.20	52.00	19.00	174.00	61
9JUL76	1	Diss	6.30	0.19	28.00	5.70	41.00	15.00	135.00	38
9JUL76	1	Total			57.00	5.80	41.00	15.00		
26JUL76	1	Diss	6.10	0.11	38.00	7.70	58.00	20.00	198.00	50
26JUL76	1	Total			40.00	7.70	57.00	20.00		

Table D-1. (Continued)

	(Bank)	Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F5 (Indian Fork)										
calendar	NO.									
6MAY77	1	Diss	6.30	0.18	35.00	6.70	53.00	16.00	175.00	59
6MAY77	1	Total			36.00	6.80	53.00	16.00		
23JUN77	1	Diss	-----	0.14	15.00	7.10	76.00	21.00	216.00	-----
23JUN77	1	Total			16.00	7.40	77.00	21.00		
9SEP77	1	Diss	5.60	0.43	9.00	9.30	62.00	25.00	245.00	22
9SEP77	1	Total			59.00	9.90	57.00	24.00		
20SEP77	1	Diss	7.20	0.35	25.00	11.20	52.00	23.00	208.00	82
20SEP77	1	Total			66.00	9.30	48.00	22.00		
11OCT77	1	Diss	6.00	0.24	-----	-----	-----	-----	158.00	50
29OCT77	1	Diss	6.40	0.23	30.00	6.30	53.00	17.00	162.00	52
29OCT77	1	Total			50.00	6.50	53.00	17.00		
13NOV77	1	Diss	6.10	0.33	16.00	6.00	46.00	14.00	130.00	56
13NOV77	1	Total			21.00	6.10	47.00	14.00		
25FEB78	1	Diss	6.80	0.26	10.00	3.80	35.00	11.00	84.20	35
13JUN78	1	Diss	6.30	0.20	14.00	3.20	31.00	13.00	99.30	36
14JUL79	1	Diss	6.00	0.22	12.00	3.40	41.00	15.00	132.00	48
14JUL79	1	Total			18.00	3.40	42.00	15.00		

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F6 (Indian Fork)										
calendar	NO.									
10AUG77	1	Diss	5.20	0.19	-----	-----	-----	-----	-----	-----
16AUG77	1	Diss	-----	-0.10	-----	-----	-----	-----	150.00	105
16AUG77	2	Diss	-----	-0.10	-----	-----	-----	-----	121.00	125
16AUG77	3	Diss	-----	-0.10	-----	-----	-----	-----	110.00	110
23AUG77	1	Diss	5.50	0.22	-----	-----	-----	-----	149.00	130
23AUG77	2	Diss	5.40	0.23	-----	-----	-----	-----	160.00	115
1SEP77	1	Diss	5.40	0.28	30.00	8.30	74.00	19.80	271.00	65
9SEP77	1	Diss	5.00	0.26	27.00	10.00	73.00	21.00	280.00	55
9SEP77	2	Diss	5.40	0.25	21.00	11.50	66.00	21.00	204.00	105
20SEP77	1	Diss	6.20	0.16	29.00	10.90	69.00	22.00	300.00	35
11OCT77	1	Diss	5.90	0.11	-----	-----	-----	-----	321.00	-----
29OCT77	1	Diss	5.80	0.11	32.00	10.10	67.00	20.60	306.00	10
13NOV77	1	Diss	5.90	0.11	22.00	11.90	57.00	19.50	159.00	30
25FEB78	1	Diss	6.00	0.18	28.00	18.00	66.00	7.00	195.00	108
13JUN78	1	Diss	5.40	0.11	23.00	9.90	42.00	19.00	150.00	85

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F6	(Indian Fork)									
calendar	NO.									
3MAR79	1	Diss	5.50	0.20	21.70	3.80	33.00	10.70	135.00	52
14JUL79	1	Diss	5.50	0.04	16.00	8.00	46.00	17.00	192.00	32
14JUL79	1	Total			18.00	8.00	45.00	17.00		
25AUG79	1	Diss	5.80	0.03	14.00	8.80	48.00	16.00	180.00	81
25AUG79	1	Total			18.00	8.90	47.00	16.00		
22OCT79	1	Diss	6.00	0.12	15.50	8.70	42.00	16.00	156.00	35
22OCT79	1	Total			18.50	8.80	38.00	16.00		
28JUN80	1	Diss	5.85	0.46	26.50	8.90	41.00	16.00	99.40	94
28JUN80	1	Total			25.00	8.90	48.00	16.00		
Site: F7										
10AUG77	1	Diss	5.30	0.18	-----	-----	-----	-----	25.00	55
16AUG77	1	Diss	-----	-0.10	-----	-----	-----	-----	18.00	95
16AUG77	2	Diss	-----	-0.10	-----	-----	-----	-----	16.00	95
16AUG77	3	Diss	-----	-0.10	-----	-----	-----	-----	16.00	110
23AUG77	1	Diss	6.10	0.23	-----	-----	-----	-----	69.00	95
9SEP77	1	Diss	6.80	0.55	-----	-----	-----	-----	35.00	47
20SEP77	1	Diss	6.20	0.16	0.40	0.20	26.00	8.00	60.30	72

Table D-1. (Continued)

Site: F7 (Indian Fork)

calendar NO.

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
11OCT77	1	Diss	6.20	0.35	-----	-----	-----	-----	81.00	33
29OCT77	1	Diss	6.40	0.33	1.40	4.00	23.00	7.10	57.00	37
13NOV77	1	Diss	6.20	0.32	2.00	2.10	24.00	9.50	28.90	55
25FEB78	1	Diss	7.20	0.28	-----	-----	-----	-----	-----	22
13JUN78	1	Diss	6.70	0.16	1.40	1.00	23.00	8.00	60.80	42
14JUL79	1	Diss	6.40	0.23	0.20	3.30	37.00	14.00	136.00	43
14JUL79	1	Total			-----	7.00	24.00	14.00		

Site: F8

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
1SEP77	1	Diss	6.10	0.29	0.70	4.10	31.00	12.20	82.10	50
9SEP77	1	Diss	6.50	0.45	0.40	0.70	30.00	11.00	60.60	44
20SEP77	1	Diss	7.50	0.23	0.60	0.50	30.00	12.00	61.70	82
11OCT77	1	Diss	6.50	0.29	-----	-----	-----	-----	61.00	35
29OCT77	1	Diss	6.20	0.35	3.70	2.80	26.00	10.00	56.40	48
13NOV77	1	Diss	6.10	0.31	0.30	0.30	23.00	7.00	35.30	46
25FEB78	1	Diss	7.30	0.27	5.40	0.40	24.00	10.00	25.80	58

Table D-1. (Continued)

(Bank)		Type	pH	Eh (Volts)	Iron (mg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Alkalinity (mg/l $CaCO_3$)	Sulfate (mg/l)
Site: F8 (Indian Fork)										
calendar	NO.									
13JUN78	1	Diss	6.30	0.19	2.80	0.55	22.00	14.50	38.80	70
14JUL79	1	Diss	5.60	0.29	0.90	1.80	21.00	12.00	40.00	77
14JUL79	1	Total			4.60	4.10	24.00	12.00		
25AUG79	1	Diss	6.10	0.44	0.50	2.30	38.00	14.00	71.60	77
25AUG79	1	Total			6.00	2.80	37.00	14.00		
22OCT79	1	Diss	6.50	0.55	0.04	2.00	32.00	14.00	56.20	66
22OCT79	1	Total			5.10	2.40	26.00	14.00		
28JUN80	1	Diss	6.40	0.52	0.00	8.80	37.00	15.00	92.00	61
28JUN80	1	Total			37.50	9.90	17.00	14.00		

APPENDIX E

TRACE METAL CONSTITUENT QUALITY DATA

Table E-1. Spoil Bank, Trace Metal Data Base

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: B1	**(Bills Branch)**											
CALENDAR	TYPE											
8MAR76	TOTAL	---	31.4	---	---	---	---	---	---	---	---	---
9JUL76	DISS.	---	14.0	---	---	---	---	---	---	---	---	---
12SEP76	DISS.	---	20.0	---	---	---	---	---	---	---	---	---
5OCT76	DISS.	---	16.0	---	---	---	---	---	---	---	---	---
3DEC77	DISS.	---	500.0	---	---	---	---	---	---	---	---	---
7MAR78	DISS.	0.00	25.5	4.6	1.6	5.4	---	0.1000	1.000	4.90	---	---
1APR78	DISS.	1.80	38.5	0.2	0.0	5.4	---	0.4150	0.030	2.50	---	---
25APR78	DISS.	0.00	42.0	0.8	0.0	5.2	---	0.0000	0.120	2.20	---	---
13JUN78	DISS.	0.90	34.0	3.4	0.0	2.1	---	0.0225	3.450	4.20	---	---
1MAR76	TOTAL	---	31.0	---	---	---	---	0.0250	---	---	---	---
8MAR76	TOTAL	---	17.2	---	---	---	---	---	---	---	---	---
21APR76	TOTAL	---	158.0	---	0.0	---	---	---	---	---	---	---
9JUL76	DISS.	---	5.0	---	---	---	---	---	---	---	---	---
12SEP76	DISS.	---	16.8	---	---	---	---	---	---	---	---	---
5OCT76	DISS.	---	14.8	---	---	---	---	---	---	---	---	---

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: B1 **(Bills Branch)**												
CALENDAR	TYPE											
3DEC77	DISS.	---	34.5	---	---	---	---	---	---	---	---	---
7MAR78	DISS.	0.80	2.5	0.0	1.6	5.0	---	0.0000	0.100	0.00	---	---
1APR78	DISS.	0.40	13.5	0.4	0.0	5.5	---	0.0000	0.050	2.20	---	---
13JUN78	DISS.	0.60	8.5	1.0	0.0	1.8	---	0.0000	0.090	0.00	---	---
3MAR79	DISS.	0.40	8.4	0.0	0.0	1.3	---	0.0400	0.125	1.38	---	---
5MAY79	DISS.	41.30	0.0	0.8	0.0	3.0	---	0.0500	0.034	1.38	---	---

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: B2	**(Bills Branch)**											
CALENDAR	TYPE											
1MAR76	TOTAL	---	55.0	---	---	---	---	0.0200	2.500	---	---	---
8MAR76	TOTAL	---	50.5	---	---	---	---	---	---	---	---	---
9JUL76	DISS.	---	19.8	---	---	---	---	---	---	---	---	---
12SEP76	DISS.	---	40.2	---	---	---	---	---	---	---	---	---
5OCT76	DISS.	---	55.5	---	---	---	---	---	---	---	---	---
3DEC77	DISS.	---	26.0	---	---	---	---	---	---	---	---	---
7MAR78	DISS.	0.00	1.4	1.0	0.0	2.5	---	0.0000	0.030	4.20	---	---
1APR78	DISS.	0.00	7.0	0.2	0.0	6.4	---	0.0000	0.030	4.60	---	---
25APR78	DISS.	0.00	9.0	1.8	0.0	4.7	---	0.0000	0.420	4.20	---	---
13JUN78	DISS.	0.30	7.0	1.8	0.0	1.7	---	0.0000	0.240	2.50	---	---
7SEP78	DISS.	---	14.8	1.2	0.0	3.2	---	0.0300	0.094	---	---	---
3MAR79	DISS.	0.60	8.4	1.4	3.4	3.9	---	0.0500	0.375	2.77	---	---
5MAY79	DISS.	33.10	7.7	1.6	9.6	5.7	---	0.0400	0.306	3.07	---	---
28JUN80	DISS.	0.42	4.6	1.3	1.8	2.9	---	---	0.000	---	---	---
28JUN80	TOTAL	0.70	7.4	9.0	---	2.9	---	---	0.000	---	---	---

Table E-1. (Continued)

SITE: B3 **(Bills Branch)**

(Bank) CALENDAR	TYPE	CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
21APR76	TOTAL	---	53.0	---	72.0	---	---	---	23.700	---	---	---
9JUL76	DISS.	---	44.0	---	---	---	---	---	---	---	---	---
12SEP76	DISS.	---	10.0	---	---	---	---	---	---	---	---	---
5OCT76	DISS.	---	12.5	---	---	---	---	---	---	---	---	---
8MAR76	TOTAL	---	3.5	---	---	---	---	---	---	---	---	---
2APR76	TOTAL	---	---	---	---	---	---	---	1.700	---	---	---
21APR76	TOTAL	---	---	---	---	---	---	---	0.000	---	---	---
28APR76	TOTAL	---	2.3	---	0.9	---	---	---	---	---	---	---
9JUL76	DISS.	---	5.5	---	---	---	---	---	---	---	---	---
3MAR79	DISS.	1.40	20.5	1.4	0.0	14.9	---	0.1700	0.940	3.39	---	---
3DEC77	DISS.	---	24.0	---	---	---	---	---	---	---	---	---
7MAR78	DISS.	1.60	46.5	1.6	0.0	2.3	---	0.0000	1.100	2.50	---	---
1APR78	DISS.	0.00	14.0	1.4	0.0	2.8	---	0.0000	0.030	0.00	---	---
25APR78	DISS.	0.00	41.5	1.0	0.0	4.7	---	0.0000	0.620	1.20	---	---
13JUN78	DISS.	2.10	17.0	0.9	0.0	1.6	---	0.0000	0.130	0.80	---	---

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE:	B5 **(Bills Branch)**											
CALENDAR	TYPE											
21MAR75	TOTAL	0.10	0.0	0.0	0.2	0.0	---	0.0550	---	---	---	---
22MAR75	TOTAL	0.05	0.0	2.8	1.0	4.7	---	0.0630	---	---	---	---
26APR75	TOTAL	0.08	---	2.0	0.9	0.9	---	0.0100	---	---	0.9	2.4
7MAY75	TOTAL	0.13	0.0	0.0	---	2.9	9.5	0.0200	---	---	1.0	2.2
21MAY75	TOTAL	0.05	---	4.3	0.2	---	3.5	0.0100	---	---	0.9	1.8
10JUL75	TOTAL	0.10	2.5	7.0	8.5	8.5	6.0	0.0450	---	---	0.9	4.8
15AUG75	TOTAL	0.20	2.0	3.0	---	7.8	6.0	0.0100	---	---	0.8	4.6
22AUG75	TOTAL	0.80	5.0	---	3.0	11.0	10.0	0.0250	---	---	1.1	6.6
20FEB76	TOTAL	---	3.0	---	---	---	6.0	0.0190	---	---	---	3.6

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE:	F1 (Indian Fork)											
CALENDAR	TYPE											
1MAR76	TOTAL	---	1.0	---	---	---	---	0.0040	---	---	---	2.4
17MAR76	TOTAL	---	1.0	---	---	---	---	---	---	---	---	2.4
26MAR76	TOTAL	---	2.0	---	---	---	---	---	---	---	---	3.1
2APR76	TOTAL	---	4.0	---	---	---	---	---	---	---	---	2.1
21APR76	TOTAL	---	1.6	---	---	---	5.2	---	---	---	---	3.0
28APR76	TOTAL	---	---	---	0.8	---	8.3	---	---	---	---	3.1
19MAY76	TOTAL	---	---	---	---	---	---	---	---	---	---	2.5
26MAY76	TOTAL	---	---	---	---	---	---	---	---	---	---	2.5
3JUN76	TOTAL	---	---	---	---	---	---	---	---	---	---	3.1
9JUL76	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
26JUL76	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
26AUG76	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
4OCT76	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
6MAY77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
23JUN77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F1	(Indian Fork)											
CALENDAR	TYPE											
4AUG77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
10AUG77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
23AUG77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
1SEP77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
9SEP77	DISS.	---	3.0	---	---	---	---	---	---	---	---	---
20SEP77	DISS.	---	5.0	---	---	---	---	---	---	---	---	---
29OCT77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
13NOV77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
8JAN78	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
25FEB78	DISS.	0.20	2.5	0.4	0.0	2.9	---	0.0000	0.130	2.20	---	---
13JUN78	DISS.	0.00	0.0	1.8	0.0	4.8	---	0.0000	0.090	1.20	---	---
28JUN80	DISS.	0.00	0.0	1.1	0.0	0.6	---	---	0.000	---	---	---
28JUN80	TOTAL	0.00	0.2	1.4	0.0	1.1	2.0	---	0.000	---	---	---

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F2	**(Indian Fork)**											
CALENDAR	TYPE											
21MAR75	TOTAL	0.58	---	2.0	1.2	5.0	3.2	0.6862	---	---	1.2	4.4
26APR75	TOTAL	0.52	---	1.1	0.5	0.6	3.5	0.7700	---	---	1.2	4.4
7MAY75	TOTAL	0.82	4.8	0.0	1.8	2.9	9.2	3.5490	---	---	1.2	4.8
21MAY75	TOTAL	0.70	---	0.6	2.0	4.0	3.0	1.4925	---	---	1.1	4.6
10JUL75	TOTAL	0.90	18.0	6.7	---	12.0	13.0	0.9750	---	---	1.6	6.6
15AUG75	TOTAL	0.40	8.0	2.8	---	7.8	7.0	0.5000	---	---	1.4	6.1
22AUG75	TOTAL	0.30	9.0	---	---	5.3	13.0	0.3300	---	---	1.5	6.1
1MAR76	TOTAL	---	3.0	---	---	---	---	0.2600	---	---	---	7.5
17MAR76	TOTAL	---	3.0	---	---	---	---	---	---	---	---	4.9
26MAR76	TOTAL	---	1.0	---	---	---	---	---	---	---	---	4.5
2APR76	TOTAL	---	---	---	---	---	---	---	---	---	---	3.9
21APR76	TOTAL	---	8.4	---	14.8	---	9.4	---	---	---	---	3.9
28APR76	TOTAL	---	8.8	---	15.2	---	---	---	---	---	---	3.8
19MAY76	TOTAL	---	---	---	---	---	---	---	---	---	---	5.4
22MAY76	TOTAL	---	---	---	---	---	---	---	---	---	---	5.6

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F2	**(Indian Fork)**											
CALENDAR	TYPE											
3JUN76	TOTAL	---	---	---	---	---	---	---	---	---	---	5.3
9JUL76	DISS.	---	3.0	---	---	---	---	---	---	---	---	---
26JUL76	DISS.	---	9.0	---	---	---	---	---	---	---	---	---
26AUG76	DISS.	---	5.8	---	---	---	---	---	---	---	---	---
4OCT76	DISS.	---	12.5	---	---	---	---	---	---	---	---	---

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F3 (Indian Fork)												
CALENDAR	TYPE											
21MAR75	TOTAL	0.10	115.8	0.6	5.7	4.0	29.2	0.0451	---	---	2.0	---
26APR75	TOTAL	0.26	67.0	1.8	2.4	1.2	23.2	0.0252	---	---	1.6	24.0
7MAY75	TOTAL	0.24	64.5	2.9	8.2	3.1	36.5	0.2275	---	---	1.6	27.2
21MAY75	TOTAL	0.26	69.6	6.6	11.5	12.2	42.5	0.0467	---	---	1.7	---
10JUL75	TOTAL	---	---	---	---	25.0	90.0	0.3800	---	---	---	104.0
22AUG75	TOTAL	0.10	50.5	---	7.0	11.4	120.0	0.0250	---	---	0.3	11.2
20FEB76	TOTAL	---	47.0	---	---	---	28.0	0.0085	---	---	---	15.5
1MAR76	TOTAL	---	34.0	---	---	---	---	0.0180	---	---	---	12.9
17MAR76	TOTAL	---	34.0	---	---	---	---	---	---	---	---	11.5
21MAR76	TOTAL	---	---	---	---	---	---	---	---	---	---	21.6
26MAR76	TOTAL	---	27.0	---	---	---	---	---	---	---	---	8.5
28APR76	TOTAL	---	122.0	---	---	---	---	---	---	---	---	---
19MAY76	TOTAL	---	---	---	---	---	---	---	---	---	---	12.2
21MAY76	TOTAL	---	---	---	---	---	---	---	---	---	---	37.2
26MAY76	TOTAL	---	---	---	---	---	---	---	---	---	---	11.7

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F3 (Indian Fork)												
CALENDAR	TYPE											
3JUN76	TOTAL	---	---	---	---	---	---	---	---	---	---	13.9
9JUL76	DISS.	---	47.5	---	---	---	---	---	---	---	---	---
26JUL76	DISS.	---	39.5	---	---	---	---	---	---	---	---	---
26AUG76	DISS.	---	32.3	---	---	---	---	---	---	---	---	---
4OCT76	DISS.	---	34.5	---	---	---	---	---	---	---	---	---
6MAY77	DISS.	---	3.6	---	---	---	---	---	---	---	---	---
23JUN77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
4AUG77	DISS.	---	14.3	---	---	---	---	---	---	---	---	---
10AUG77	DISS.	---	36.5	---	---	---	---	---	---	---	---	---
16AUG77	DISS.	---	55.0	---	---	---	---	---	---	---	---	---
1SEP77	DISS.	---	25.0	---	---	---	---	---	---	---	---	---
9SEP77	DISS.	---	7.5	---	---	---	---	---	---	---	---	---
20SEP77	DISS.	---	3.5	---	---	---	---	---	---	---	---	---
29OCT77	DISS.	---	5.0	---	---	---	---	---	---	---	---	---
13NOV77	DISS.	---	4.0	---	---	---	---	---	---	---	---	---

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F3 **(Indian Fork)**												
CALENDAR	TYPE											
8JAN78	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
25FEB78	DISS.	0.20	2.0	0.6	0.0	5.7	---	0.0000	0.070	2.95	---	---
13JUN78	DISS.	0.66	1.0	1.0	1.3	3.2	---	0.0500	0.100	1.20	---	---
7SEP78	DISS.	0.10	6.0	0.9	0.0	2.5	---	0.0000	0.121	2.48	---	---
3MAR79	DISS.	0.90	1.4	0.0	1.8	1.3	---	0.0000	0.048	1.91	---	---
5MAY79	DISS.	1.00	2.0	0.7	1.9	1.4	---	0.0000	0.042	1.91	---	---

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F4 **(Indian Fork)**												
CALENDAR	TYPE											
21MAR75	TOTAL	0.20	0.0	3.9	7.0	8.6	3.0	0.0300	---	---	1.4	4.8
26APR75	TOTAL	0.28	---	1.0	0.4	0.5	---	0.0076	---	---	1.2	5.9
7MAY75	TOTAL	0.16	3.4	1.2	0.4	2.6	8.8	0.0752	---	---	1.3	6.5
21MAY75	TOTAL	1.90	2.6	2.4	10.0	9.0	4.2	0.0202	---	---	1.2	6.8
10JUL75	TOTAL	0.10	39.5	62.0	71.0	30.0	35.0	0.1450	---	---	2.4	16.8
20FEB76	TOTAL	---	3.5	---	---	---	5.0	0.0090	---	---	---	5.1
1MAR76	TOTAL	---	2.0	---	---	---	---	0.0040	---	---	---	4.6
17MAR76	TOTAL	---	3.0	---	---	---	---	---	---	---	---	4.0
26MAR76	TOTAL	---	2.0	---	---	---	---	---	---	---	---	4.4
2APR76	TOTAL	---	2.0	---	---	---	---	---	---	---	---	4.3
21APR76	TOTAL	---	11.2	---	2.6	---	10.0	---	---	---	---	6.6
28APR76	TOTAL	---	6.0	---	1.3	---	---	---	---	---	---	13.3
19MAY76	TOTAL	---	---	---	---	---	---	---	---	---	---	5.8
26MAY76	TOTAL	---	---	---	---	---	---	---	---	---	---	7.4
3JUN76	TOTAL	---	---	---	---	---	---	---	---	---	---	6.3

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F4	**(Indian Fork)**											
CALENDAR	TYPE											
9JUL76	DISS.	---	29.5	---	---	---	---	---	---	---	---	---
26AUG76	DISS.	---	79.5	---	---	---	---	---	---	---	---	---
4OCT76	DISS.	---	18.5	---	---	---	---	---	---	---	---	---
6MAY77	DISS.	---	2.5	---	---	---	---	---	---	---	---	---
23JUN77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
10AUG77	DISS.	---	27.0	---	---	---	---	---	---	---	---	---
16AUG77	DISS.	---	20.0	---	---	---	---	---	---	---	---	---
1SEP77	DISS.	---	42.5	---	---	---	---	---	---	---	---	---
9SEP77	DISS.	---	3.0	---	---	---	---	---	---	---	---	---
20SEP77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
29OCT77	DISS.	---	4.0	---	---	---	---	---	---	---	---	---
13NOV77	DISS.	---	14.0	---	---	---	---	---	---	---	---	---
8JAN78	DISS.	---	3.0	---	---	---	---	---	---	---	---	---
25FEB78	DISS.	0.20	9.0	0.6	0.0	4.7	---	0.0000	0.090	2.00	---	---
13JUN78	DISS.	7.20	1.0	0.8	0.0	3.4	---	0.0000	0.200	1.60	---	---

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F4 **(Indian Fork)**												
CALENDAR	TYPE											
3MAR79	DISS.	1.40	0.0	0.0	0.0	1.3	---	0.0200	0.040	0.00	---	---
5MAY79	DISS.	0.30	0.0	0.0	0.0	1.2	---	0.0000	0.040	0.00	---	---
28JUN80	DISS.	0.88	3.7	1.0	0.5	1.6	---	---	0.500	---	---	---
28JUN80	TOTAL	0.67	9.5	---	2.5	6.6	7.9	---	4.000	---	---	---

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F5 **(Indian Fork)**												
CALENDAR	TYPE											
21MAR75	TOTAL	0.04	0.0	2.1	0.6	3.7	---	0.0080	---	---	---	---
22MAR75	TOTAL	0.04	0.0	0.0	0.3	4.5	---	0.0035	---	---	---	---
26APR75	TOTAL	12.60	---	1.4	0.0	0.0	---	0.0023	---	---	---	---
27APR75	TOTAL	0.05	22.0	---	---	---	---	---	---	---	---	---
7MAY75	TOTAL	0.04	38.0	1.4	---	1.0	14.0	0.0415	---	---	1.9	5.8
21MAY75	TOTAL	0.02	---	---	0.0	3.4	4.8	---	---	---	1.8	5.9
22MAY75	TOTAL	---	---	5.8	0.5	---	---	---	---	---	---	---
10JUL75	TOTAL	0.20	33.0	6.8	---	7.8	4.0	0.0265	---	---	2.2	7.9
15AUG75	TOTAL	0.05	54.0	0.0	---	1.0	11.0	0.0050	---	---	1.1	1.8
20FEB76	TOTAL	---	38.0	---	---	---	4.0	0.0010	---	---	---	5.4
1MAR76	TOTAL	---	30.0	---	---	---	---	0.0020	---	---	---	5.4
17MAR76	TOTAL	---	29.0	---	---	---	---	---	---	---	---	4.8
26MAR76	TOTAL	---	33.0	---	---	---	---	---	---	---	---	4.8
2APR76	TOTAL	---	37.0	---	---	---	---	---	---	---	---	5.3
21APR76	TOTAL	---	16.0	---	73.0	---	---	---	---	---	---	6.1

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F5 **(Indian Fork)**												
CALENDAR	TYPE											
28APR76	TOTAL	---	---	---	0.0	---	---	---	1.000	---	---	5.8
19MAY76	TOTAL	---	---	---	---	---	---	---	---	---	---	5.4
3JUN76	TOTAL	---	---	---	---	---	---	---	---	---	---	4.1
9JUL76	DISS.	---	24.6	---	---	---	---	---	---	---	---	---
26JUL76	DISS.	---	17.2	---	---	---	---	---	---	---	---	---
6MAY77	DISS.	---	21.5	---	---	---	---	---	---	---	---	---
9SEP77	DISS.	---	26.0	---	---	---	---	---	---	---	---	---
20SEP77	DISS.	---	32.0	---	---	---	---	---	---	---	---	---
29OCT77	DISS.	---	18.0	---	---	---	---	---	---	---	---	---
13NOV77	DISS.	---	18.0	---	---	---	---	---	---	---	---	---
8JAN78	DISS.	---	40.0	---	---	---	---	---	---	---	---	---
25FEB78	DISS.	0.20	20.0	0.0	0.2	1.7	---	0.0000	0.050	2.20	---	---
13JUN78	DISS.	0.00	15.5	0.8	0.0	1.8	---	0.0000	0.050	2.00	---	---

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F6	**(Indian Fork)**											
CALENDAR	TYPE											
16AUG77	DISS.	---	70.3	---	---	---	---	---	---	---	---	---
23AUG77	DISS.	---	100.0	---	---	---	---	---	---	---	---	---
1SEP77	DISS.	---	77.0	---	---	---	---	---	---	---	---	---
9SEP77	DISS.	---	137.5	---	---	---	---	---	---	---	---	---
20SEP77	DISS.	---	66.0	---	---	---	---	---	---	---	---	---
13NOV77	DISS.	---	6.0	---	---	---	---	---	---	---	---	---
8JAN78	DISS.	---	32.0	---	---	---	---	---	---	---	---	---
25FEB78	DISS.	0.30	76.0	0.4	1.0	2.3	---	0.0000	0.190	2.20	---	---
13JUN78	DISS.	0.00	16.5	1.2	0.0	2.9	---	0.0000	0.130	4.40	---	---
3MAR79	DISS.	0.10	47.8	0.5	0.0	0.4	---	0.0000	0.114	1.38	---	---
28JUN80	DISS.	0.46	50.0	0.5	0.5	0.8	---	---	0.000	---	---	---
23AUG77	DISS.	---	37.0	---	---	---	---	---	---	---	---	---
9SEP77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
20SEP77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
29OCT77	DISS.	---	5.0	---	---	---	---	---	---	---	---	---

Table E-1. (Continued)

(Bank)		CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
SITE: F6 **(Indian Fork)**												
CALENDAR	TYPE											
13NOV77	DISS.	---	15.0	---	---	---	---	---	---	---	---	---
8JAN78	DISS.	---	53.0	---	---	---	---	---	---	---	---	---
25FEB78	DISS.	0.00	0.0	0.8	1.6	9.7	---	0.0000	4.500	4.20	---	---
13JUN78	DISS.	0.70	4.0	2.2	1.2	4.8	---	0.0000	1.700	9.20	---	---

Table E-1. (Continued)

SITE: F8 **(Indian Fork)**

(Bank) CALENDAR	TYPE	CD UG/L	CO UG/L	CR UG/L	PB UG/L	CU UG/L	NI UG/L	ZN MG/L	AL MG/L	SI MG/L	NA MG/L	K MG/L
1SEP77	DISS.	---	36.0	---	---	---	---	---	---	---	---	---
9SEP77	DISS.	---	8.0	---	---	---	---	---	---	---	---	---
20SEP77	DISS.	---	3.0	---	---	---	---	---	---	---	---	---
29OCT77	DISS.	---	10.0	---	---	---	---	---	---	---	---	---
13NOV77	DISS.	---	6.0	---	---	---	---	---	---	---	---	---
8JAN78	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
25FEB78	DISS.	0.20	2.0	0.6	1.0	5.6	---	0.0000	0.240	2.00	---	---
13JUN78	DISS.	0.40	2.5	0.4	0.0	8.4	---	0.0000	0.130	1.20	---	---
28JUN80	DISS.	0.40	13.0	3.2	0.6	0.8	---	---	0.000	---	---	---
20SEP77	DISS.	---	3.0	---	---	---	---	---	---	---	---	---
13NOV77	DISS.	---	0.0	---	---	---	---	---	---	---	---	---
8JAN78	DISS.	---	10.0	---	---	---	---	---	---	---	---	---
25FEB78	DISS.	0.20	1.0	0.8	0.0	5.8	---	0.0000	0.320	2.20	---	---

APPENDIX F

OBSERVATION WELL, PERMANENT BENCH POND, AND SEEPAGE SAMPLE DATA

Table F-1. Observation Wells, pH, Eh (mv), and Wet Chemical Constituent Data (mg/l)

Well	pH	Eh	Alkalinity as $CaCO_3$	Sulfate
Obs #1	6.0	+280	76.4	2100
Obs #2	6.15	+230	158	1075
Obs #4	6.6	+515	192	75
Obs #6	5.85	+490	125	80
Obs #7	6.7	+485	314	28
Obs #9	6.0	+350	390	115
Obs #10	5.7	+320	116	110
Obs #12	5.55	+340	31.5	265
Obs #13	5.3	+325	21.4	145
Obs #14	6.5	+545	158	100
Obs #15	6.7	+500	--	35

Table F-2. Observation Wells, Major Metal Constituent Data (mg/l)

Well		Fe	Mn	Ca	Mg
Obs #1	Total	1.6	0.4	520	190
	Dissolved	0.2	DL	510	190
Obs #2	Total	42	2.3	210	76
	Dissolved	40	2.2	210	78
Obs #4	Total	Solids	4.5	26	21
	Dissolved	34	3.1	79	20
Obs #6	Total	35	0.6	49	16
	Dissolved	2.8	0.4	47	16
Obs #7	Total	Solids	18.0	34	29
	Dissolved	DL	14.9	82	30
Obs #9	Total	7.9	5.6	128	29
	Dissolved	0.2	4.7	132	31
Obs #10	Total	13	5.6	46	13
	Dissolved	1.8	5.4	45	13
Obs #12	Total	10.8	8.1	75	63
	Dissolved	5.5	9.8	62	54
Obs #13	Total	15.6	1.2	20	23
	Dissolved	0.5	1.0	26	25
Obs #14	Total	10	1.4	45	34
	Dissolved	0.3	1.0	55	34
Obs #15	Dissolved	DL	3.4	42	19

"Solids" indicates excessive total solids, interference with analytical determination.

"DL" indicates values below analytical detection limits.

Table F-3. Observation Wells, Trace Metal Data (μg/l)

Well		Cd	Co	Cu	Pb	Cu	Ni	Al	Zn	Si(mg/l)
Obs #1	Total									
	Dissolved	1.3	1.4	0.5	2.1	8.9		126	80	3.71
Obs #2	Total									
	Dissolved									
Obs #4	Total	4.90	215	Solids	Solids	Solids	370	Solids		
	Dissolved	0.42	20	6.6	0.6	2.2	18	DL		
Obs #6	Total									
	Dissolved	1.5	1.5	0.5	DL	1.3		51.3	6	1.64
Obs #7	Total	6.8	640	Solids	Solids	Solids		Solids		
	Dissolved	0.39	39	1.7	0.8	3.1	17	DL		
Obs #9	Total									
	Dissolved									
Obs #10	Total									
	Dissolved									
Obs #12	Total									
	Dissolved	3.7	48.3	1.2	1.9	7.3		350	280	1.64
Obs #13	Total									
	Dissolved	19.1	27.6	1.4	27.7	93.3		412	510	4.03
Obs #14	Total	1.05	12	Solids	2.2	11.1	57	17		
	Dissolved	0.68	1.6	4.0	DL	0.8	5.3	DL		
Obs #15	Dissolved	23	21	2.4	0.7	3.6		DL		

"Solids" indicates excessive total solids interference in analytical determination.

"DL" indicates values below analytical detection limits

Table F-4. Ponds, pH, Eh (mv), and Wet Chemical Constituent Data (mg/l)

Pond	pH	Eh	Alkalinity as $CaCO_3$	Sulfate
Pond #2	6.6	+430	12.5	285
Pond #6	6.9	+440	78.5	32
Pond #7	6.2	+340	30.5	47
	6.5	+400	45.4	25
Pond #8	6.4	+380	53.0	61
Pond #9	5.5	+240	25.0	22

Table F-5. Ponds, Major Metal Constituent Data (mg/l)

Pond		Fe	Mn	Ca	Mg
Pond #2	Total	DL	DL	58	36
	Dissolved	DL	DL	58	34
Pond #6	Total	0.90	DL	28	6.4
	Dissolved	DL	DL	28	6.3
Pond #7	Total	0.90	DL	20	5.0
	Dissolved	DL	DL	20	6.0
	Total	1.65	DL	15	3.6
	Dissolved	DL	DL	14	3.6
Pond #8	Total	0.40	DL	20	9.1
	Dissolved	DL	DL	20	9.1
Pond #9	Total	1.00	DL	9.5	2.9
	Dissolved	DL	DL	10	3.0

"DL indicates values below analytical detection limits

Table F-6. Ponds, Trace Metal Data (μg/l)

Pond		Cd	Co	Cr	Pb
Pond #2	Total				
	Dissolved				
Pond #6	Total				
	Dissolved				
Pond #7	Total				
	Dissolved				
	Total	0.1	1.4	6.1	2.3
	Dissolved	0.8	DL	DL	DL
Pond #8	Total				
	Dissolved				
Pond #9	Total	0.1	0.8	1.0	DL
	Dissolved	5.9	DL	0.5	DL

Pond		Cu	Ni	Al	Zn	Si(mg/l)
Pond #2	Total					
	Dissolved					
Pond #6	Total					
	Dissolved					
Pond #7	Total					
	Dissolved					
	Total	1.9		5930	DL	16.1
	Dissolved	0.3		130	DL	DL
Pond #8	Total					
	Dissolved					
Pond #9	Total	2.0		4500	30	14.5
	Dissolved	1.1		43.8	DL	1.1

"DL" indicates values below analytical detection limits

Table F-7. Undisturbed Seepages, pH, Eh (mv), and Wet Chemical Constituent Data (mg/l)

Seepage	pH	Eh	Alkalinity as $CaCO_3$	Acidity as $CaCO_3$	Sulfate
Seep #1	3.8	+490	--	21.5	10
Seep #2	5.0	+400	4.33	10.5	12
Seep #3	4.9	+380	1.78	7.02	12
Seep #4	6.5	+355	5.36	2.34	12
Seep #5	6.4	+390	--	--	31
Seep #6	5.0	+420	1.78	6.79	12
Seep #7	6.5	+415	6.38	3.04	16

Table F-8. Undistrubed Seepages, Major Metal Constituent Data (mg/l)

Seepage		Fe	Mn	Ca	Mg
Seep #1	Total	DL	DL	0.1	0.5
	Dissolved	DL	DL	0.1	0.5
Seep #2	Total	DL	DL	1.7	1.4
	Dissolved	DL	DL	1.7	1.4
Seep #3	Total	DL	DL	1.5	1.5
	Dissolved	DL	DL	1.5	1.5
Seep #4	Total	0.10	DL	1.7	1.4
	Dissolved	DL	DL	1.7	1.4
Seep #5	Total	0.15	DL	4.9	3.0
	Dissolved	DL	DL	4.8	3.0
Seep #6	Total	DL	DL	0.5	1.5
	Dissolved	DL	DL	0.5	1.5
Seep #7	Total	0.30	DL	1.7	2.2
	Dissolved	DL	DL	1.7	2.2

"DL" indicates values below analytical detection limits

Table F-9. Undistrubed Seepages, Trace Metal Data (μg/l)

Seepage		Cd	Co	Cr	Pb
Seep #1	Total				
	Dissolved				
Seep #2	Total				
	Dissolved	0.2	DL	DL	DL
Seep #3	Total				
	Dissolved				
Seep #4	Total				
	Dissolved	0.5	DL	DL	DL
Seep #5	Total				
	Dissolved				
Seep #6	Total				
	Dissolved	0.5	3.3	DL	DL
Seep #7	Total				
	Dissolved	0.4	DL	DL	DL

Seepage		Cu	Ni	Al	Zn	Si(mg/l)
Seep #1	Total					
	Dissolved					
Seep #2	Total					
	Dissolved	0.7		24	DL	2.19
Seep #3	Total					
	Dissolved					
Seep #4	Total					
	Dissolved	0.3		45	DL	1.13
Seep #5	Total					
	Dissolved					
Seep #6	Total					
	Dissolved	0.4		89	DL	2.19
Seep #7	Total					
	Dissolved	0.5		76	DL	0.65

"DL" indicates values below analytical detection limits

APPENDIX G

ADDITIONAL QUALITY DATA

Table G-1. pH, Eh, and Total Subsurface Carbon Concentrations (mg/l)

Site, Sampling Data	pH	Eh	Total Organic Carbon	Total Inorganic Carbon	Alkalinity As Carbon
INDIAN FORK					
F3					
11 Nov 78	4.4	+230	3000	16	0
30 Nov 78	--	--	226	69	30.8
7 Dec 78	6.4	+230	336	89	49.9
29 Jan 79	6.0	--	42	178	45.1
2 Mar 79	6.5	+320	20	78	32.2
F4					
7 Dec 78	6.0	+270	23	22	10.8
29 Jan 79	6.3	--	6	30	9.8
2 Mar 79	6.1	+290	2	18	10.9
F6					
30 Nov 78	--	--	32	43	21.1
29 Jan 79	5.4	--	41	125	13.2
2 Mar 79	5.5	+195	6	21	16.2
BILLS BRANCH					
B2					
2 Mar 79	5.0	+260	2	33	20.2
B3					
11 Nov 78	6.0	+215	55	103	48.4
2 Mar 79	6.0	+200	22	92	57.4
B5					
11 Nov 78	5.3	+270	22	16	2.2
30 Nov 78	--	--	27	13	4.2

The 11 Nov 78 samples represent extreme drought conditions. All other dates represent normally recharged spoil bank. Detection limit for organic carbon is 2.0 mg/l.

Table G-2. pH, Eh, and Dissolved Subsurface Carbon Concentrations (mg/l)

Site, Sampling Date	pH	Eh	Dissolved Organic Carbon	Dissolved Total Inorganic Carbon	Alkalinity As Carbon
INDIAN FORK					
F3					
11 Nov 78	4.4	+230	3000	15	0
30 Nov 78	--	--	66	78	30.8
7 Dec 78	6.4	+230	40	85	49.9
29 Jan 79	6.0	--	43	157	45.1
2 Mar 79	6.5	+320	9	58	32.2
18 May 79	6.2	+340	10	48	26.4
2 Jun 79	6.4	+350	D.L.	18	22.6
F4					
7 Dec 78	6.0	+270	18	27	10.8
29 Jan 79	6.3	--	6	28	9.8
2 Mar 79	6.1	+290	3	18	10.9
18 May 79	6.0	+500	4	30	13.9
2 Jun 79	6.5	+500	D.L.	12	12.6
28 Jun 80	6.3	+510	8	19	15.1
F6					
30 Nov 78	--	--	24	61	21.1
29 Jan 79	5.4	--	20	105	13.2
2 Mar 79	5.5	+195	9	20	16.2
28 Jun 80	5.0	+460	6	14	11.9
BILLS BRANCH					
B2					
2 Mar 79	5.0	+260	5	30	20.2
2 Jun 79	5.8	+495	D.L.	25	20.6
B3					
11 Nov 78	6.0	+215	51	104	48.4
2 Mar 79	6.0	+200	24	88	57.4
18 May 79	5.9	+260	21	90	50.3
2 Jun 79	6.1	+220	11	39	45.6
28 Jun 80	6.3	+250	26	43	46.8
B5					
11 Nov 78	5.3	+270	15	15	2.2
30 Nov 78	--	--	12	23	4.2

The 11 Nov 78 samples represent extreme drought conditions. All other dates represent the normally recharged spoil bank. Detection limit for organic carbon is 2.0 mg/l.

Table G-3. pH, Eh and Dissolved Iron Concentrations (mg/l)

Site, Sampling Date	pH	Eh	Ferrous Iron	Total Iron
INDIAN FORK				
F3				
7 Sep 78	6.8	+ 90	1.0	1.0
5 May 79	6.1	+280	5.0	5.0
18 May 79	6.2	+340	3.4	3.6
2 Jun 79	6.4	+350	4.0	4.1
F4				
5 May 79	6.4	+490	D.L.	D.L.
18 May 79	6.0	+500	D.L.	D.L.
2 Jun 79	6.5	+500	D.L.	D.L.
BILLS BRANCH				
B2				
5 May 79	6.0	+510	D.L.	D.L.
2 Jun 79	5.8	+495	D.L.	D.L.
B3				
7 Sep 78	6.6	+140	23.0	37.0
5 May 79	6.0	+220	58.0	59.0
18 May 79	5.9	+260	53.0	58.0
2 Jun 79	6.1	+220	45.0	46.0
B5				
7 Sep 78	5.8	+150	2.1	4.2

7 Sep 78 samples represent drought conditions in the spoil bank.
The remaining dates represent normal recharged conditions.
Detection Limit for Ferrous & Total Iron, 0.05 mg/l.

Table G-4. pH, Eh and Dissolved Sulfur Concentrations (mg/l)

			Sulfide		
Site, Sampling Date	pH	Eh	as$[S^{-2}]$	as $[HS^{-}]$	Sulfate
INDIAN FORK					
F3					
7 Sep 78	6.2	+ 90	1.18	1.22	145
7 Oct 78	5.9	+280	2.76	2.84	90
5 May 79	6.1	+280	1.12	1.14	75
18 May 79	6.2	+340	D.L.	D.L.	76
2 Jun 79	6.4	+350	D.L.	D.L.	76
F4					
7 Oct 78	6.0	+210	0.70	0.72	56
18 May 79	6.0	+500	D.L.	D.L.	89
2 Jun 79	6.5	+500	D.L.	D.L.	68
BILLS BRANCH					
B2					
5 May 79	6.0	+510	D.L.	D.L.	240
2 Jun 79	5.8	+495	D.L.	D.L.	205
B3					
7 Sep 78	6.6	+140	0.34	0.34	101
5 May 79	6.0	+220	D.L.	D.L.	D.L.
18 May 79	5.9	+260	D.L.	D.L.	D.L.
2 Jun 79	6.1	+220	D.L.	D.L.	6

Detection Limits: For S^{-2} 0.05 mg/l
For SO_4 2.0

7 Sep & 7 Oct 78 samples represent drought conditions in the spoil bank. The remaining dates represent normal recharged conditions.

Table G-5. pH, Eh and Total Nitrate Concentrations (mg/l)

Site, Sampling Date	pH	Eh	$[NO_3^-]$
INDIAN FORK			
F3			
18 May 79	6.2	+340	1.6
2 Jun 79	6.4	+350	3.3
F4			
18 May 79	6.0	+500	1.6
2 Jun 79	6.5	+500	3.9
28 Jun 80	6.3	+510	1.6
F6			
28 Jun 80	5.9	+460	1.7
BILLS BRANCH			
B2			
2 Jun 79	5.8	+495	3.8
B3			
18 May 79	5.9	+260	5.0
2 Jun 79	6.1	+220	5.3
28 Jun 80	6.3	+250	2.1

Table G-6. pH, Eh and Total Dissolved Phosphate Concentrations (mg/l as P) on Sampling Date 28 Jun 80

Site	pH	Eh	Phosphate
INDIAN FORK			
F4	6.3	+510	0.039
F6	5.8	+460	0.039
F8	6.4	+520	0.009
OBS #7	6.7	+485	0.030
BILLS BRANCH			
B3	6.3	+250	0.055
OBS #14	6.5	+545	0.012

APPENDIX H

SOIL SAMPLING DATA

Table H-1. Indian Fork Study Spoil Bank, In-situ Soil Samples

Sample Sampling Date Depth (ft) Soil Condition	Toe #1 14 Nov 81 2.0 unsaturated	Toe #2 14 Nov 81 2.0 unsaturated	Toe #3 24 Jan 82 2.5 unsaturated	Toe #4 24 Jan 82 2.5 unsaturated	Toe #5 24 Jan 82 2.5 unsaturated	Toe #6 14 Nov 81 3.5 saturated	Toe #7 14 Nov 81 4.0 saturated
V_T (ft^3)	0.01425	--->					
W_T (lbs)	1.7350	1.8626	1.9634	1.9707	1.8079	1.8026	1.8435
Dry Field Density (lbs/ft^3)	102.5	109.4	109.7	110.9	104.5	91.0	97.5
ω'avg	0.1882	0.1941	0.2558	0.2467	0.2139	0.3906	0.3272
Specific Gravity	2.63	2.62	2.67	2.67	2.65	2.61	2.73
Porosity, n [a.]	0.3756	0.3305	0.3415	0.3342	0.3680	0.4415	0.4278
Void Ratio, e [b.]	0.6016	0.4936	0.5185	0.5019	0.5822	0.7904	0.7477

a.) $n = 1 - \frac{W_T}{(1+w')\ S.G.\ \gamma_W\ V_T}$

b.) $e = \frac{n}{1-n}$

Table H-2. Bills Branch Study Spoil Bank, In-situ Soil Samples

Sample	Lower Slope #1	Lower Slope #2	Lower Slope #3	Toe #1	Toe #2	Toe #3
Sampling Date	14 Nov 81	14 Nov 81	14 Nov 81	24 Jan 82	24 Jan 82	24 Jan 82
Depth (ft)	3	3	3	2	2	2
Soil Condition	unsaturated	unsaturated	unsaturated	saturated	saturated	saturated
V_T (ft^3)	0.01425	--->				
W_T (lbs)	1.8900	1.8487	1.7987	1.8141	1.8484	1.8518
Dry Field Density (lbs/ft^3)	114.9	112.4	109.4	101.8	102.8	102.4
ω'avg	0.1535	0.1535	0.1535	0.2530	0.2616	0.2701
Specific Gravity	2.73	2.73	2.75	2.71	2.72	2.73
Porosity, n	0.3250	0.3398	0.3623	0.3978	0.3942	0.3995
Void Ratio, e	0.4816	0.5147	0.5682	0.6605	0.6508	0.6650

APPENDIX I

STREAM HYDROLOGY AND QUALITY DATA RELEVANT TO SPOIL RESEARCH

Table I-1. Flow Duration Data by Disturbance Period for the Lowe Branch, Indian Fork, and Bills Branch Study Basins

Basin	Lowe Branch	Indian Fork	Bills Branch
Period	premining	post mining	post mining
Record Length (days)	1573	1076	1827
Basin Area (acres)	588	2765	429
Frequency Exceeded	Area Normalized Flow (cfs/acre)		
100%	0	2.64E-4	0
99	0	2.89E-4	2.33E-5
95	0	4.70E-4	6.99E-5
90	0	5.42E-4	1.40E-4
75	8.50E-5	9.76E-4	5.83E-4
50	5.61E-4	2.01E-3	1.75E-3
25	2.21E-3	4.70E-3	4.20E-3
10	5.71E-3	1.01E-2	9.56E-3
5	1.02E-2	1.45E-2	1.83E-2

Table I-2. Sustained and Low Flow Surface Water Quality, Major Constituents; Lowe Branch, Indian Fork, and Bills Branch Study Basins

Basin	pH^b	Total Dissolved Concentrations[a] (mg/l)				Alkalinity as $CaCO_3$ mg/l	Sulfate mg/l
		Fe	Mn	Ca	Mg		
Lowe Branch (Premining, Low Flow)							
Mean	6.21	0.10	0.003	1.51	1.76	8.64	11.6
Std. Dev.	6.35E-7	0.0418	0.0015	0.4321	0.2117	3.3205	4.305
Median	6.38	DL	DL	1.5	1.7	8.6	11
Maximum	7.10	0.17	0.005	2.25	2.30	19.7	22
Minimum	5.50	DL	DL	0.9	1.40	1.6	3
Fraction DL	0/23	13/22	19/23	0/23	0/23	0/23	0/23
Indian Fork (Post Mining, Sustained Flow)							
Mean	5.96	2.01	2.07	122.7	48.3	15.29	785
Std. Dev.	1.993E-6	3.988	0.8897	17.93	8.959	9.884	294.6
Median	6.45	0.34	1.985	125.8	48.0	11.8	810
Maximum	7.30	14	3.6	144	64	34	1255
Minimum	5.15	0.09	0.7	88	33.5	5.25	355
Fraction DL	0/12	0/12	0/12	0/12	0/12	0/11	0/12
Indian Fork (Post Mining, Low Flow)							
Mean	6.13	1.72	1.68	102.2	40.2	19.44	650
Std. Dev.	1.410E-6	3.185	0.8062	25.91	11.14	13.32	287
Median	6.62	0.36	1.52	94	39	20.57	550
Maximum	7.60	14	3.6	144	64	46.7	1250
Minimum	5.15	DL	0.66	51.8	20	3.8	210
Fraction DL	0/27	2/27	0/27	0/27	0/27	0/27	0/27

Table 1-2. (Continued)

Basin	pH[b]	Total Dissolved Concentrations[a] (mg/l)				Alkalinity as $CaCO_3$ mg/l	Sulfate mg/l
		Fe	Mn	Ca	Mg		
Bills Branch (Post Mining, Sustained Flow)							
Mean	6.72	0.08	0.10	13.4	8.84	25.21	56.1
Std. Dev.	2.898E-7	0.0263	0.0570	1.0586	0.8889	3.0563	4.885
Median	6.90	DL	0.06	13.0	8.95	25.4	58
Maximum	8.30	0.08	0.22	14.9	10.1	30.3	62
Minimum	6.00	DL	DL	11.9	7.4	20	47
Fraction DL	0/10	6/10	3/10	0/10	0/10	0/10	0/9
Bills Branch (Post Mining, Low Flow)							
Mean	6.88	0.08	0.08	12.3	8.13	22.75	53.76
Std. dev.	1.921E-7	0.0273	0.04311	2.355	1.464	4.410	9.320
Median	7.05	DL	0.046	12.7	8.52	22.05	54
Maximum	8.30	0.10	0.22	15.4	10.6	31.9	74
Minimum	6.00	DL	DL	7.10	5.3	14.7	34
Fraction DL	0/26	19/26	11/26	0/25	0/26	0/26	0/25

[a] "DL" indicates values below analytical detection limits

[b] Standard deviation values recorded for pH represent hydrogen ion concentrations

VITA

Paul Shearin Dickens was born in Hartsville, Tennessee on March 23, 1958. He grew up in and around the Nashville, Tennessee area finishing his secondary education in 1976 at Battle Ground Academy in the neighboring town of Franklin. After a summer of mountaineering at the National Outdoor Leadership School of Lander, Wyoming, he entered The University of Tennessee, Knoxville, where in August 1980 he completed a Bachelor of Science in Civil Engineering. While an undergraduate Mr. Dickens found part-time employment as a field and laboratory technician in coal surface mining research conducted by the Department of Civil Engineering. The interests developed in this work led him to pursue a Master's degree in Environmental Engineering which was completed in August, 1982.

The author is a member of Tau Beta Pi and an associate member of the American Society of Civil Engineers. He received certification as an Engineer-in-Training in the spring of 1980. In addition to research, he has participated in student activities at The University of Tennessee, Knoxville, serving as chairman of the University's Recreation Coordinating Committee, vice-president of the Association of Collegiate Engineers, and as a member of the Undergraduate Academic Council and the Cultural Attractions Committee. After graduation Mr. Dickens will be employed with the Georgia Department of Natural Resources.

He is married to the former Martha Hall of Knoxville, Tennessee.