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Hydrologic Evaluation of a Hypothetical Coal-mining Site near Chrisney, Spencer County, Indiana

Open-file Report 80-1107

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

HYDROLOGIC EVALUATION OF A HYPOTHETICAL COAL-MINING SITE NEAR CHRISNEY, SPENCER COUNTY, INDIANA

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FACTORS FOR CONVERTING INCH-POUND UNITS TO THE INTERNATIONAL SYSTEM OF METRIC UNITS (SI)

Multiply inch-pound unit	By	To obtain SI unit
acre	0.4047	hectare (ha)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.0109	cubic meter per second per square kilometer [(m^3/s)/km^2]
foot (ft)	0.3048	meter (m)
inch (in.)	2.540	centimeter (cm)
mile (mi)	1.609	kilometer (km)
million gallons per day (Mgal/d)	3,785	cubic meter per day (m^3/d)
pound (lb)	0.4540	kilogram
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
ton	0.9072	megagram (Mg)
ton per square mile (ton/mi^2)	0.3503	megagram per square kilometer (Mg/km^2)
ton per year per square mile [(ton/yr)/mi^2]	0.3503	megagram per year per square kilometer [(Mg/yr)/km^2]

DATUM USED IN THIS REPORT

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

USE OF TRADE NAMES

Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

ABBREVIATIONS

acre-ft	Acre foot.
Alk	Alkalinity.
BOD_5	Five-day, biochemical-oxygen demand.
BTM	Stream bottom.
Btu	British thermal unit.
°C	Degree Celsius.
$CaCO_3$	Calcium carbonate.
diss. (Diss.)	Dissolved.
DNR	Indiana Department of Natural Resources.
DO	Dissolved oxygen.
E.	East.
E	Estimate.
°F	Degree Fahrenheit.
fil	Filtered.
ft	Foot.
ft/mi	Foot per mile.
ft^3/s	Cubic foot per second.
$(ft^3/s)/d$	Cubic foot per second per day.
$(ft^3/s)/mi^2$	Cubic foot per second per square mile.
gal/min	Gallon per minute.
h	Hour.
Ho	Hosmer soil series.
IGS	Indiana Geological Survey.
in.	Inch.
in./h	Inch per hour.
in./yr	Inch per year.
inst.	Instantaneous.
ISBH	Indiana State Board of Health.
lab	Laboratory.
lb	Pound.
meq/L	Milliequivalent per liter.
mg/L	Milligram per liter.
mi	Mile.
mi^2	Square mile.
μg/g	Microgram per gram.
μg/L	Microgram per liter.
μmho/cm	Micromho per centimeter, at 25° C.
Mgal/d	Million gallons per day.
mL	Milliliter.
mm	Millimeter.
N.	North.
N/A	Not available.
ND	Not determined.
NE	Northeast.
NF	No flow.

NGVD of 1929	National Geodetic Vertical Datum of 1929.
NOAA	National Oceanic and Atmospheric Administration.
noncarb.	Noncarbonate.
nonfil	Not filtered.
NPDES	National Pollution Discharge Elimination System.
NW	Northwest.
OSM	Office of Surface Mining, U.S. Department of Interior.
P	Phosphorus.
PDR	Planning Development Region.
Q7,10	Average low flow over a 7-day period with a recurrence interval of 10 years.
R.	Range.
S.	South.
s	Second.
SAR	Sodium-adsorption-ratio.
SE	Southeast.
SMCRA	Surface Mining Control and Reclamation Act.
Sn	Stendal soil series.
Spec. conduc.	Specific conductance.
SPSA	Indiana State Planning Services Agency.
STP	Sewage-treatment plant.
susp.	Suspended.
SW	Southwest.
T.	Township.
temp.	Temperature.
ton/mi^2	Ton per square mile.
$(ton/yr)/mi^2$	Ton per year per square mile.
tot. (Tot.)	Total.
tr	Trace concentration, <0.1 mg/L.
USDA, SCS	U.S. Department of Agriculture, Soil Conservation Service.
USGS	U.S. Geological Survey.
W.	West.
WRD	Water Resources Division (USGS).
yr	Year.
Za	Zanesville soil series.

GLOSSARY. Part 1.

Allochthonous means material in a stream that is produced within the watershed and brought to the stream in various forms of organic matter.

Backfilling means the process of refilling an excavation.

Btu (British thermal unit) means the quantity of heat required to raise the temperature of 1 pound of water 1 degree Farenheit.

Coal recovery area means that part of the permit area from which coal is extracted.

Deep mining means underground mining, usually in a shaft mine, as opposed to mining on the land surface.

Diel means a 24-hour period that usually includes a day and the adjoining night.

Harmonic temperature function means a sine function of the annual variation of surface-water temperatures.

High wall means the unexcavated face of exposed overburden and coal in a surface mine or the face or bank on the uphill side of a contour strip mine.

Hyperbolic subsoiler means a device used in surface mining to improve subsoil porosity and to correct excess soil compaction.

Hypothetical mining area means the same as permit area in this report.

Last-cut lakes means lakes resulting from unreclaimed surface mines, where the last coal-recovery pit is not backfilled and is allowed to fill with water. Typical of historical mining activities, occasionally practiced today.

Lense means the areal gradation of one lithology into another.

Population pulse means an abrupt increase in population due to environmental conditions.

Scarification means a process whereby the hard compacted surface of the land is broken up and loosened after strip mining to promote revegetation and reclamation.

Shaft mine means a mine where the coal seam is reached by a tunnel extending underground.

Soil amendments means fertilizers and soil stabilizers added to the soil of the reclaimed mining site to improve productivity and to retard erosion.

Soil reconstruction means the replacement of segregated topsoil and subsoil in mined areas in an effort to reproduce premining conditions.

Spoil banks means areas created by the deposited overburden material before backfilling. Also called cast overburden.

Study basin means the area defined by East Fork Little Pigeon Creek watershed, including subsurface hydrology and geology.

Surface mining means a mining method whereby the overlying materials are removed to expose the mineral for extraction.

Unconsolidated overburden means overburden material in a form of loose aggregation.

GLOSSARY. Part 2. Terms defined in the Final Regulatory Program of the Surface Mining Control and Reclamation Act

(Quoted from Federal Register, 1979, p. 15314-15322, 15349)

Acid drainage means water with a pH of less than 6.0 and in which total acidity exceeds total alkalinity, discharged from an active, inactive or abandoned surface coal mine and reclamation operation or from an area affected by surface coal mining and reclamation operations.

Acid-forming materials means earth materials that contain sulfide minerals or other materials which, if exposed to air, water, or weathering processes, form acids that may create acid drainage.

Adjacent area means land located outside the affected area, permit area, or mine plan area, depending on the context in which adjacent area is used, where air, surface or ground water, fish, wildlife, vegetation or other resources protected by the Act may be adversely impacted by surface coal mining and reclamation operations.

Affected area means, with respect to surface mining activities, any land or water upon or in which those activities are conducted or located. With respect to underground mining activities, affected area means: (i) any water or surface land upon or in which those activities are conducted or located; and (ii) land or water which is located above underground mine workings.

Application means the documents and other information filed with the regulatory authority under this Subchapter and the regulatory program for the issuance of exploration approval or a permit.

Approximate original contour means that surface configuration achieved by backfilling and grading of the mined areas so that the reclaimed area, including any terracing or access roads, closely resembles the general surface configuration of the land prior to mining and blends into and complements the drainage pattern of the surrounding terrain, with all highwalls, spoil piles and coal refuse piles eliminated. Permanent water impoundments may be permitted where the regulatory authority has determined that they comply with 30 CFR 816.49 and 816.56, 816.133 or 817.49, 817.56, and 817.133.

Aquifer means a zone, stratum, or group of strata that can store and transmit water in sufficient quantities for a specific use.

Class I Road means a road that is utilized for transportation of coal.

Coal exploration means the field gathering of: (a) surface or subsurface geologic, physical, or chemical data by mapping, trenching, drilling, geophysical, or other techniques necessary to determine the quality and quantity of overburden and coal of an area; or (b) the gathering of environmental data to establish the conditions of an area before beginning surface coal mining and reclamation operations under the requirements of this chapter.

Compaction means increasing the density of a material by reducing the voids between the particles and is generally accomplished by controlled placement and mechanical effort such as from repeated application of wheel, track, or roller loads from heavy equipment.

Cropland means land used for the production of adapted crops for harvest, alone or in a rotation with grasses and legumes, and includes row crops, small grain crops, hay crops, nursery crops, orchard crops, and other similar specialty crops.

Disturbed area means an area where vegetation, topsoil, or overburden is removed or upon which topsoil, spoil, coal processing waste, underground development waste, or noncoal waste is placed by surface coal mining operations. Those areas are classified as disturbed until reclamation is complete and the performance bond or other assurance of performance required by Subchapter J of this Chapter is released.

Diversion means a channel, embankment, or other manmade structure constructed to divert water from one area to another.

Embankment means an artificial deposit of material that is raised above the natural surface of the land and used to contain, divert, or store water, support roads or railways, or for other similar purposes.

Ephemeral stream means a stream which flows only in direct response to precipitation in the immediate watershed or in response to the melting of a cover of snow and ice, and which has a channel bottom that is always above the local water table.

Existing structure means a structure or facility used in connection with or to facilitate surface coal mining and reclamation operations for which construction begins prior to the approval of a State program or implementation of a Federal program or Federal lands program, whichever occurs first.

General area means, with respect to hydrology, the topographic and ground water basin surrounding a mine plan area which is of sufficient size, including areal extent and depth, to include one or more watersheds containing perennial streams and ground water zones and to allow assessment of the probable cumulative impacts on the quality and quantity of surface and ground water systems in the basins.

Ground water means subsurface water that fills available openings in rock or soil materials to the extent that they are considered water saturated.

Highwall means the face of exposed overburden and coal in an open cut of a surface coal mining activity or for entry to underground mining activities.

Hydrologic balance means the relationship between the quality and quantity of water inflow to, water outflow from, and water storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, lake, or reservoir. It encompassses the dynamic relationships among precipitation, runoff, evaporation, and changes in ground and surface water storage.

Hydrologic regime means the entire state of water movement in a given area. It is a function of the climate and includes the phenomena by which water first occurs as atmospheric water vapor, passes into a liquid or solid form, falls as precipitation, moves along or into the ground surface, and returns to the atmosphere as vapor by means of evaporation and transpiration.

Impoundment means a closed basin, naturally formed or artificially built, which is dammed or excavated for the retention of water, sediment, or waste.

Intermittent stream means--(a) A stream or reach of a stream that drains a watershed of at least 1 mi^2, or (b) a stream or reach of a stream that is below the local water table for at least some part of the year, and obtains its flow from both surface runoof and ground-water discharge.

Land use means specific uses or management-related activities, rather than the vegetation or cover of the land. Land uses may be identified in combination when joint or seasonal uses occur. Changes of land use or uses from one of the following categories to another shall be considered as a change to an alternative land use which is subject to approval by the regulatory authority.

Mine plan area means the area of land and water within the boundaries of all permit areas during the entire life of the surface coal mining and reclamation operations. At a minimum, it includes all areas which are or will be affected during the entire life of those operations. Other terms defined in this Section which relate closely to mine plan area are: (1) permit area, which will always be within or the same as the mine plan area; (2) affected area, which will always be within or the same as the permit area; and (3) adjacent area, which may surround or extend beyond the affected area, permit area, or mine plan area.

Moist bulk density means the weight of soil (oven dry) per unit volume. Volume is measured when the soil is at field moisture capacity (1/3 bar moisture tension). Weight is determined after drying the soil at 105° C.

Mulch means vegetation residues or other suitable materials that aid in soil stabilization and soil moisture conservation, thus providing microclimatic conditions suitable for germination and growth.

Operator means any person engaged in coal mining who removes or intends to remove more than 250 tons of coal from the earth or from coal refuse piles by mining within 12 consecutive calendar months in any one location.

Overburden means material of any nature, consolidated or unconsolidated, that overlies a coal deposit, excluding topsoil.

Perennial stream means a stream or part of a stream that flows continuously during all of the calendar year as a result of ground-water discharge or surface runoff. The term does not include intermittent or ephemeral stream.

Permanent diversion means a diversion remaining after surface coal mining and reclamation operations are completed which has been approved for retention by the regulatory authority and other appropriate State and Federal agencies.

Permit means a permit to conduct surface coal mining and reclamation operations issued by the State regulatory authority pursuant to a State program or by the Secretary pursuant to a Federal program. For purposes of the Federal lands program, permit means the document issued authorizing surface coal miing and reclamation operations on Federal lands, after approval of a mining plan by the Secretary, and, where a cooperative agreeement pursuant to Section 523 of the Act has been executed, the State regulatory authority.

Permit area means the area of land and water within the boundaries of the permit which are designated on the permit application maps, as approved by the regulatory authority. This area shall include, at a minimum, all areas which are or will be affected by the surface coal mining and reclamation operations during the term of the permit.

Precipitation event means a quantity of water resulting from drizzle, rain, snow, sleet, or hail in a limited period of time. It may be expressed in terms of recurrence interval. As used in these regulations, precipitation event also includes that quantity of water emanating from snow cover as snowmelt in a limited period of time.

Prime farmland means those lands which are defined by the Secretary of Agriculture in 7 CFR 657 (Federal Register Vol.4 No.21) and which have historically been used for cropland as that phrase is defined above.

Recharge capacity means the ability of the soils and underlying materials to allow precipitation and runoff to infiltrate and reach the zone of saturation.

Reclamation means those actions taken to restore mined land as required by this Chapter to a postmining land use approved by the regulatory authority.

Recurrence interval means the interval of time in which a precipitation event is expected to occur once, on the average. For example, the 10-year 24-hour precipitation event would be that 24-hour precipitation event expected to occur on the average once in 10 years.

Reference area means a land unit maintained under appropriate management for the purpose of measuring vegetation ground cover, productivity and plant species diversity that are produced naturally or by crop production methods approved by the regulatory authority. Reference areas must be representative of geology, soil, slope, and vegetation in the permit area.

Regulatory authority means the department or agency in each State which has primary responsibility at the State level for administering the Act in the initial program, or the State regulatory authority where the State is administering the Act under a State regulatory program, or the Secretary in the initial or permanent program where the Secretary is administering the Act, or the Secretary when administering a Federal program or Federal lands program or when enforcing a State program pursuant to Section 521(b) of the Act.

Sedimentation pond means a primary sediment control structure designed, constructed and maintained in accordance with 30 CFR 816.46 and including but not limited to a barrier, dam, or excavated depression which retards surface runoff to allow sediment to settle out. A sedimentation pond shall not include secondary sedimentation control structures, such as straw dikes, riprap, check dams, mulches, dugouts and other measures that reduce overland flow velocity, reduce runoff volume or trap sediment, to the extent that such secondary sedimentation structures drain to a sedimentation pond.

Slope means average inclination of a surface, measured from the horizontal, generally expressed as the ratio of a unit of vertical distance to a given number of units of horizontal distance (e.g., 1v: 5h). It may also be expressed as a percent or in degrees.

Soil horizons mean contrasting layers of soil parallel or nearly parallel to the land surface. Soil horizons are differentiated on the basis of field characteristics and laboratory data. The three major soil horizons are:

(a) A horizon. The uppermost mineral layer, often called the surface soil. It is the part of the soil in which organic matter is most abundant, and leaching of soluble or suspended particles is typically the greatest.

(b) B horizon. The layer that typically is immediately beneath the A horizon and often called the subsoil. This middle layer commonly contains more clay, iron, or aluminum than the A or C horizons.

(c) C horizon. The deepest layer of soil profile. It consists of loose material or weathered rock that is relatively unaffected by biologic activity.

Soil survey means a field and other investigation, resulting in a map showing the geographic distribution of different kinds of soils and an accompanying report that describes, classifies, and interprets such soils for use. Soil surveys must meet the standards of the National Cooperative Soil Survey as incorporated by reference in 30 CFR 785.17(b)(1).

Spoil means overburden that has been removed during surface coal mining operations.

Stabilize means to control movement of soil, spoil piles, or areas of disturbed earth by modifying the geometry of the mass, or by otherwise modifying physical or chemical properties, such as by providing a protective surface coating.

Surface coal mining operations means--(a) Activities conducted on the surface of lands in connection with a surface coal mine or, subject to the requirements of Section 516 of the Act, surface operations and surface impacts incident to an underground coal mine, the products of which enter commerce or the operations of which directly or indirectly affect interstate commerce. Such activities include excavation for the purpose of obtaining coal, including such common methods as contour, strip, auger, mountaintop removal, box cut, open pit, and area mining, the uses of explosives and blasting, and in situ distillation or retorting, leaching or other chemical or physical processing, and the cleaning, concentrating, or other processing or preparation, loading of coal for interstate commerce at or near the minesite, provided, these activities do not include the extraction of coal incidental to the extraction of other minerals, where coal does not exceed 16 2/3 per centum of the tonnage of minerals removed for purposes of commercial use or sale, or coal exploration subject to Section 512 of the Act; and Provided further, that excavation for the purpose of obtaining coal includes extraction of coal from coal refuse piles; and (b) Areas upon which the activities described in paragraph (a) above occur or where those activities disturb the natural land surface. These areas shall also include any adjacent land the use of which is incidental to any such activities, all lands affected by the construction of new roads or the improvement or use of existing roads to gain access to the site of those activities and for haulage and excavation, workings, impoundments, dams, ventilation shafts, entryways, refuse banks, dumps, stockpiles, overburden piles, spoil banks, culm banks, tailings, holes or depressions, repair areas, storage areas, processing areas, shipping areas, and other areas upon which are sited structures, facilities, or other property or material on the surface, resulting from or incident to those activities.

Surface coal mining and reclamation operations means surface coal mining operations and all activities necessary or incidental to the reclamation of such operations. This term includes the term surface coal mining operations.

Surface mining activities means those surface coal mining and reclamation operations incident to the extraction of coal from the earth by removing the materials over a coal seam, before recovering the coal by auger coal mining, or by recovery of coal from a deposit that is not in its original geologic location.

Suspended solids or nonfilterable residue, expressed as milligrams per liter, means organic or inorganic materials carried or held in suspension in water which are retained by a standard glass fiber filter in the procedure outlined by the Environmental Protection Agency's regulations for waste water and analyses (40 CFR 136).

Temporary diversion means a diversion of a stream or overland flow which is used during coal exploration or surface coal mining and reclamation operations and not approved by the regulatory authority to remain after reclamation as part of the approved postmining land use.

Topsoil means the A soil horizon layer of the three major soil horizons.

Toxic-forming materials means earth materials or wastes which, if acted upon by air, water, weathering, or microbiological processes, are likely to produce chemical or physical conditions in soils or water that are detrimental to biota or uses of water.

Toxic mine drainage means water that is discharged from active or abandoned mines or other areas affected by coal exploration or surface coal mining and reclamation operations, which contains a substance that through chemical action or physical effects are likely to kill, injure, or impair biota commonly present in the area that might be exposed to it.

Water table means the upper surface of a zone of saturation, where the body of ground water is not confined by an overlying impermeable zone.

HYDROLOGIC EVALUATION OF A HYPOTHETICAL COAL-MINING SITE NEAR CHRISNEY, SPENCER COUNTY, INDIANA

By John S. Zogorski, Daniel S. Ramey, Paul W. Lambert, Jeffrey D. Martin, and Robert E. Warner

ABSTRACT

Protecting the water resources of the Nation is a major emphasis of the Surface Mining Control and Reclamation Act, PL 95-87. Permanent regulations established for this Act by the Office of Surface Mining (OSM) require the issuance of a permit before mining begins. An application for a mining permit must include an assessment of the hydrologic characteristics of the mining site and adjacent area, and a projection of the potential impacts of mining activities on surface water and ground water.

OSM's permanent regulations and guidelines provide little insight on the "how to" aspect of making the required hydrologic assessment. This investigation was completed to improve the understanding of the kinds of information needed to make such assessments by: (a) reviewing the regulations to determine what hydrologic information is required; (b) preparing an example hydrologic assessment based on the regulations; and (c) using the experience gained in (a) and (b) to identify areas lacking or needing additional data to make the required assessment.

Hydrologic data for the study area were obtained from published and unpublished reports, maps, aerial photographs, personal interviews with residents in the area of the hypothetical mine site, and discussions with experts in the field. Where data were unavailable, "synthetic" data were generated by extrapolation from proximate or similar watersheds and (or) by assumptions based on experience or theory. Some field data were collected to corroborate and augment information originating from all these sources.

INTRODUCTION

Background

On August 3, 1977, the Surface Mining Control and Reclamation Act, Public Law 95-87 (SMCRA or the Act) was enacted by the 95th Congress (Public Law 95-87, 1977). Some of the purposes of the Act, the Federal government's first attempt to regulate coal-mining activities on a national basis, are:

(1) "to establish a national program to protect society and the environment from the adverse effects of coal mining;

(2) "to prohibit mining where reclamation as required by the Act is not feasible;

(3) "to assure that reclamation occurs as contemporaneously as possible with the mining;

(4) "to strike a balance between protection of the environment and agricultural productivity and the assurance of adequate coal production;

(5) "to assist the States in developing, administering, and enforcing regulatory programs which achieve the purposes of the Act;

(6) "to achieve reclamation of areas previously mined; and

(7) "to provide appropriate procedures for public participation in the development of regulations, standards, and programs under SMCRA" (U.S. Department of the Interior, 1979, p. AII-2).

Section 501(b) of the Act requires the Secretary of the Interior "to promulgate permanent regulatory procedures for surface coal mining and reclamation operations" (U.S. Department of the Interior, 1979, p. AI-1). The intent of the regulatory procedures is the controlling of adverse environmental effects of surface coal mining, underground coal mining, and coal exploration. The regulatory program consists of three major parts:

(1) "regulations concerning environmental and public health and safety performance standards and permit application and bonding requirements for surface coal mining and reclamation operations;

(2) "regulations covering the procedures for preparation and submission of State programs for the Secretary's approval and for the substantive review criteria used for approval; and

(3) "regulations governing the development and implementation of a Federal program for a State" (U.S. Department of the Interior, 1979, p. AII-4).

Protection of the surface-water and ground-water resources of the Nation is a major emphasis of the regulations. Section 507(b)(11) Title V of the Act requires that permit applications for mining include extensive information describing the "probable hydrologic consequences of the mining and reclamation operations, both on and off the mine site, with respect to the hydrologic regime, quantity and quality of water in surface and ground-water systems including the dissolved and suspended solids under seasonal flow conditions and the collection of sufficient data for the mine site and surrounding areas so that an assessment can be made by the regulatory authority of the probable cumulative impacts of all anticipated mining in the area upon the hydrology of the area and particularly on water availability" (Public Law 95-87, 1977). This information will be used to help mitigate adverse hydrologic impacts of surface mining by (a) assessing the impacts of mining before approval of a mine permit, (b) protecting the quantity and quality of water during all phases of mining, (c) preventing the addition of sediment to streams and other waterways by using the best technology available in the design of treatment procedures, and (d) minimizing acid drainage by selective burial of or sealing procedures for toxic substances or by treatment of contaminated waters (U.S. Department of the Interior, 1979, p. AIII-1).

Problem

In terms of hydrology, the regulations only state what should be included in the mining-permit application and rarely specify the method to be used in obtaining or calculating data, or how the information should be used in assessing "probable hydrologic consequences." Also, because of coal producers' general lack of information on or experience in determining "probable hydrologic consequences" of mining, the type and amount of data necessary for an accurate assessment is not easily determined. Without clear guidelines, the hydrologic information presented in permit applications will vary widely in type and quality. This problem is critical for the regulatory agency that must evaluate the permit applications to assess "cumulative impacts of all anticipated mining." Without any consistent format or data base, the regulatory agency may be unable to issue mining permits on a timely basis, and coal production may be adversely affected. Results in this report and OSM guidelines (U.S. Department of the Interior, 1980) for determining the hydrologic consequences of surface mining should aid the operator in preparing a mining permit application and assist the regulatory authority in making the required assessments of cumulative impacts on the hydrologic system.

Objective

The overall objective of this investigation was to develop a better understanding of the type of information needed to assess the hydrologic impacts of proposed mine operations. Toward this objective, three major goals are to (a) review the permanent regulations and determine the kinds of information required, (b) use the permanent regulations as a guideline for preparing an example hydrologic assessment for a potential mine site, and (c) use the experience gained in (a) and (b) to determine where data are nonexistent or inadequate for the completion of the hydrologic assessment. Methods of data collection and data analysis used in this study should be useful to OSM Regional Offices in preparing technical procedures necessary for developing short-term monitoring programs. These methods can be used to obtain the hydrologic information needed by mine operators and regulatory authorities for assessing the impact of proposed surface-mining operations on the hydrologic environment.

Scope and Method of Study

The duration of the study was 3 months (June 1980-August 1980), and the funding was about 25,000 dollars. This level of study is probably the kind that would be made in completing a determination of hydrologic consequences and hydrologic assessments for a small mining operation.

A potential minesite, randomly selected from several sites in the coal region in southwestern Indiana, met the following criteria: (a) an area being mined or that can be mined, (b) an area that has not already been intensively studied as the quantity and type of data available would be atypical of most minesites, and (c) an area where about 100,000 tons of coal per year will be mined as small operators will probably benefit most from the results of this study.

Hydrologic data for the study area were obtained from published reports, unpublished reports, personal interviews with local residents of the study area or hydrologists, topographic maps, and aerial photographs. Where data were unavailable, the authors "synthesized" data by extrapolation from proximate or similar watersheds or by assumptions based on experience and theory. Field data were collected to corroborate and augment information from the preceding sources. Details of the methods used are referenced or are given in appropriate sections of this report.

Pertinent Parts of the Regulatory Program of SMCRA

The parts of the permanent-regulatory program of the Surface Mining Control and Reclamation Act (Federal Register, 1979) that were used in part to prepare the mine plan and to project the impacts caused by a hypothetical mining operation may be conceptually divided into two groups: (a) those relating to information required for a mining-permit application (parts 776, 779, and 780) and (b) those relating to the permanent-performance standards for mining operations (parts 815 and 816). Parts 776, 779, and 780 indicate that the mining-permit application must contain information that describes both the natural and human environment for the permit area and the general area. Moreover, the permit must contain a detailed description of the timing, sequence, and methods of the proposed mining and reclamation. This information must be complete and in sufficient detail to allow the regulatory authority to determine the probable cumulative hydrologic impacts of mining.

Parts 815 and 816 of the permanent-regulatory program contain detailed rules and regulations governing the methods of mining and reclamation. The purpose of the standards is to minimize impacts of a permitted mining activity on the hydrologic balance of the permit area and the general area.

The appropriate sections of the permanent regulations are referenced in the section "Example Hydrologic Assessment." Because many terms have specific legal meanings, as defined by the permanent regulations, a glossary containing these terms has been included.

Acknowledgments

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Acknowledgment is also expressed to professionals at the numerous local, State, and Federal agencies who provided requested information.

The authors thank Donald Carr and the Coal and Industrial Mineral Section of the Indiana Geological Survey for their assistance in the analysis of coal samples and for their contribution of well logs used in this study. The work of Cheryl Metz of the Indiana University Department of Geology in the preparation of coal thin sections is also acknowledged.

EXAMPLE HYDROLOGIC ASSESSMENT

Present Environmental Setting

Part 779 of the permanent regulations specifies minimum requirements for information on environmental resources. The major objective of this part is to ensure that each permit application provides the regulatory authority with a complete and accurate description of the environmental resources that may be impacted or affected by proposed surface-mining activities. Premining environmental resources within the proposed mine-plan area and adjacent areas must be described.

Sections of Part 779 that were considered during the completion of the example hydrologic assessment include:

Section	779.13	Description of hydrology and geology: General requirements
	779.14	Geology description
	779.15	Ground water information
	779.16	Surface water information
	779.17	Alternative water supply information
	779.18	Climatological information
	779.19	Vegetation information
	779.21	Soil resources information
	779.22	Land-use information
	779.24	Maps: General requirements
	779.25	Cross sections, maps, and plans
	779.27	Prime farmland investigations

Location and General Description of Study Basin, General Area, and Permit Area

The hypothetical minesite (permit area) is in the drainage of the East Fork Little Pigeon Creek (study basin)[1] near the town of Chrisney, Spencer County, Ind. (fig. 1). The study basin is primarily in Jackson (T. 5 S., R. 6 W.) and Grass (T. 6 S., R. 6 W.) Townships, but a small part is along the western edges of Clay (T. 5 S., R. 5 W.) and Hammond (T. 6 S., R. 5 W.) Townships. The unmined permit area (fig. 1) is west of previously mined land and is underlain by Buffaloville coal that is economically extractable.

[1]The term, "study basin" is not mentioned in the permanent regulations. In this report, it is used to describe the East Fork Little Pigeon Creek watershed, including subsurface hydrology and geology. The term differs from "general area," defined by the regulatory authority, in that the "study basin" does not contain a perennial stream.

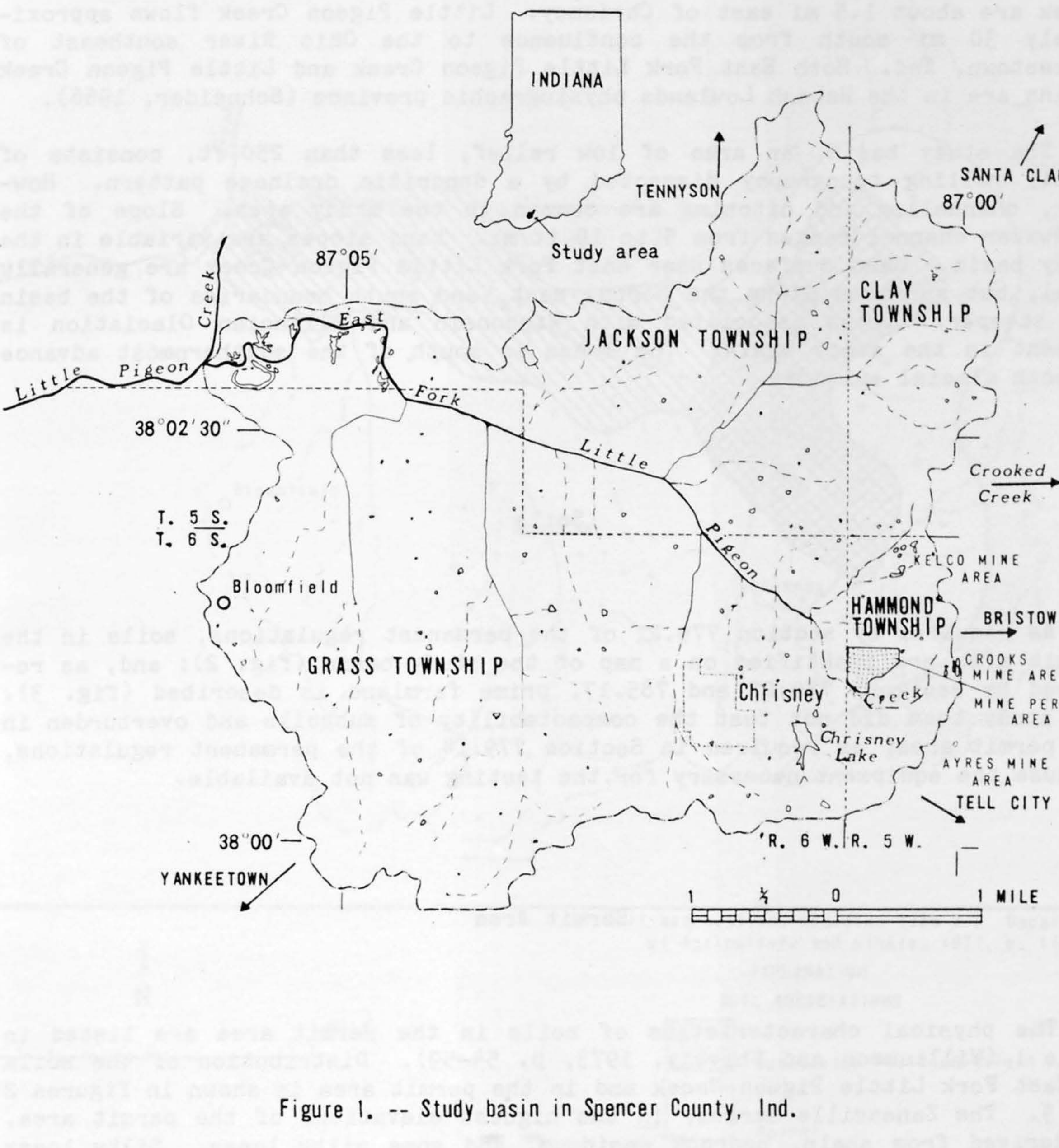


Figure 1. -- Study basin in Spencer County, Ind.

East Fork Little Pigeon Creek, whose surface drainage area is approximately 24 mi^2, flows approximately 7 mi west-northwest from its headwaters to the confluence with Little Pigeon Creek near Tennyson. The headwaters of the creek are about 1.5 mi east of Chrisney. Little Pigeon Creek flows approximately 30 mi south from the confluence to the Ohio River southeast of Yankeetown, Ind. Both East Fork Little Pigeon Creek and Little Pigeon Creek basins are in the Wabash Lowlands physiographic province (Schneider, 1966).

The study basin, an area of low relief, less than 250 ft, consists of gently rolling topography dissected by a dendritic drainage pattern. However, channeling and ditching are common in the study area. Slope of the headwater channel ranges from 5 to 10 ft/mi. Land slopes are variable in the study basin. Land surfaces near East Fork Little Pigeon Creek are generally level, but surfaces along the north, east, and south boundaries of the basin are steeper. Loess associated with Wisconsin and Illinoian Glaciation is present in the study basin. The loess is south of the southernmost advance of both glacial episodes.

Soils

As required by section 779.21 of the permanent regulations, soils in the permit area are identified on a map of the study basin (fig. 2); and, as required by sections 779.27 and 785.17, prime farmland is described (fig. 3). The study team did not test the compactability of subsoils and overburden in the permit area, as required in Section 779.14 of the permanent regulations, because the equipment necessary for the testing was not available.

Permit Area

The physical characteristics of soils in the permit area are listed in table 1 (Williamson and Shively, 1973, p. 54-59). Distribution of the soils in East Fork Little Pigeon Creek and in the permit area is shown in figures 2 and 3. The Zanesville series, in the highest elevations of the permit area, is derived from shale, bedrock residuum, and some silty loess. Silty loess is the parent material of the Hosmer series, directly downslope from the Zanesville series. The Stendal series, along the swale within the permit area, is a mixture of alluvial deposits whose predominant component is silt.

The data in table 1 indicate that the permeability of the soils is low and the erodibility is high. Percolation data provided by the Spencer County Health Officer also shows that the low permeability of soils in the vicinity

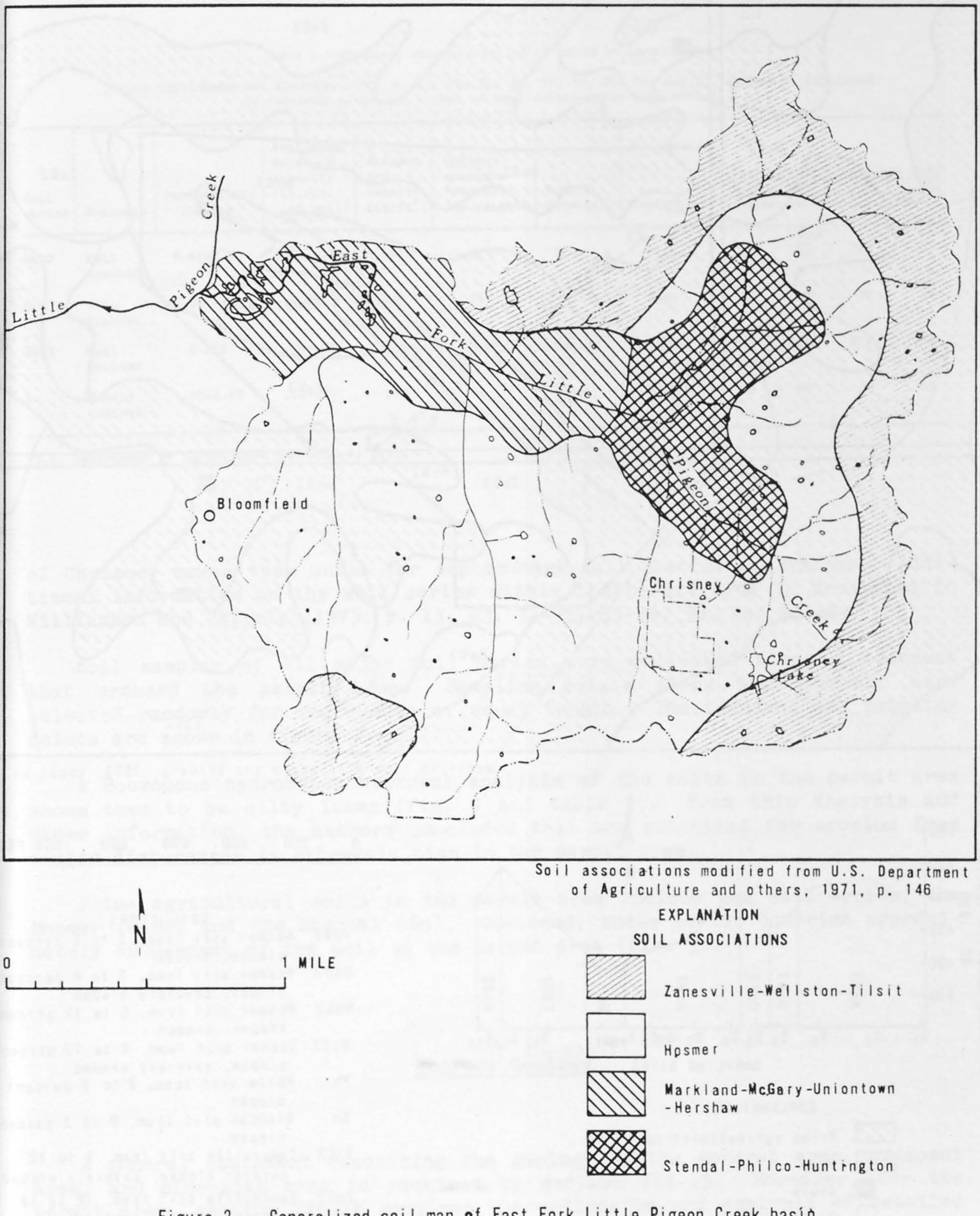


Figure 2.-- Generalized soil map of East Fork Little Pigeon Creek basin, Spencer County, Ind.

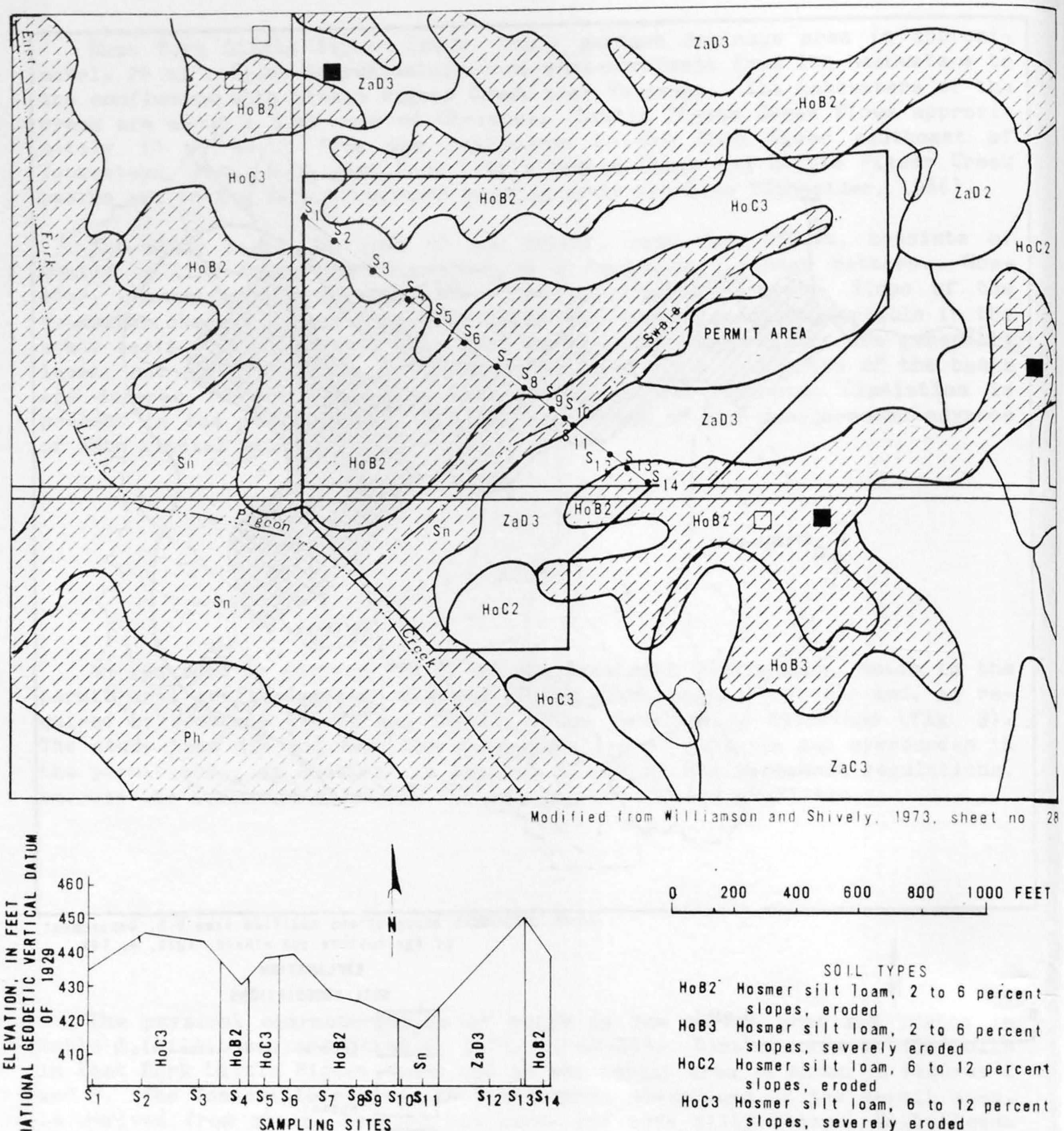


Figure 3.-- Soil series in the vicinity of the mine-permit area.

Table 1.--Physical characteristics of soils in permit area

[After Williamson and Shively, 1973, p. 13, 23, 31, 32, 54, 55, 57, 59, and 61, except as indicated by footnote 1; in./in., inch of soil moisture per inch of soil]

Soil series	Drainage	Permeability (in./h)	Available moisture capacity (in./in. of soil)	Maximum dry density (lb/ft^3)	Optimum moisture (percent by weight)	Runoff potential	Erodibility	Particle-size analysis (mm) (percent smaller than) 0.05	0.02	0.005	0.002
HoB2	Well drained	0.63-2.00	0.18-0.23	101	21	Slow	High	94	63	25	17
HoC3	Well drained	<.06	.04	102	20	Rapid	High	98	69	32	26
ZaD3	Well drained	.2-.63	.19-.21	N/A	N/A	Rapid	High	N/A	N/A	N/A	N/A
Sn	Poorly drained	.63-2.00	.18-.23	107	16	Slow	Slight[1]	91	66	25	18

[1]U.S. Department of Agriculture and others, 1971.

of Chrisney makes them unfit for septic tank-soil absorption systems. Additional information on the soil series within the permit area is presented in Williamson and Shively (1973, p. 13, 23, 31-32, 35-36, 38, and 43-44).

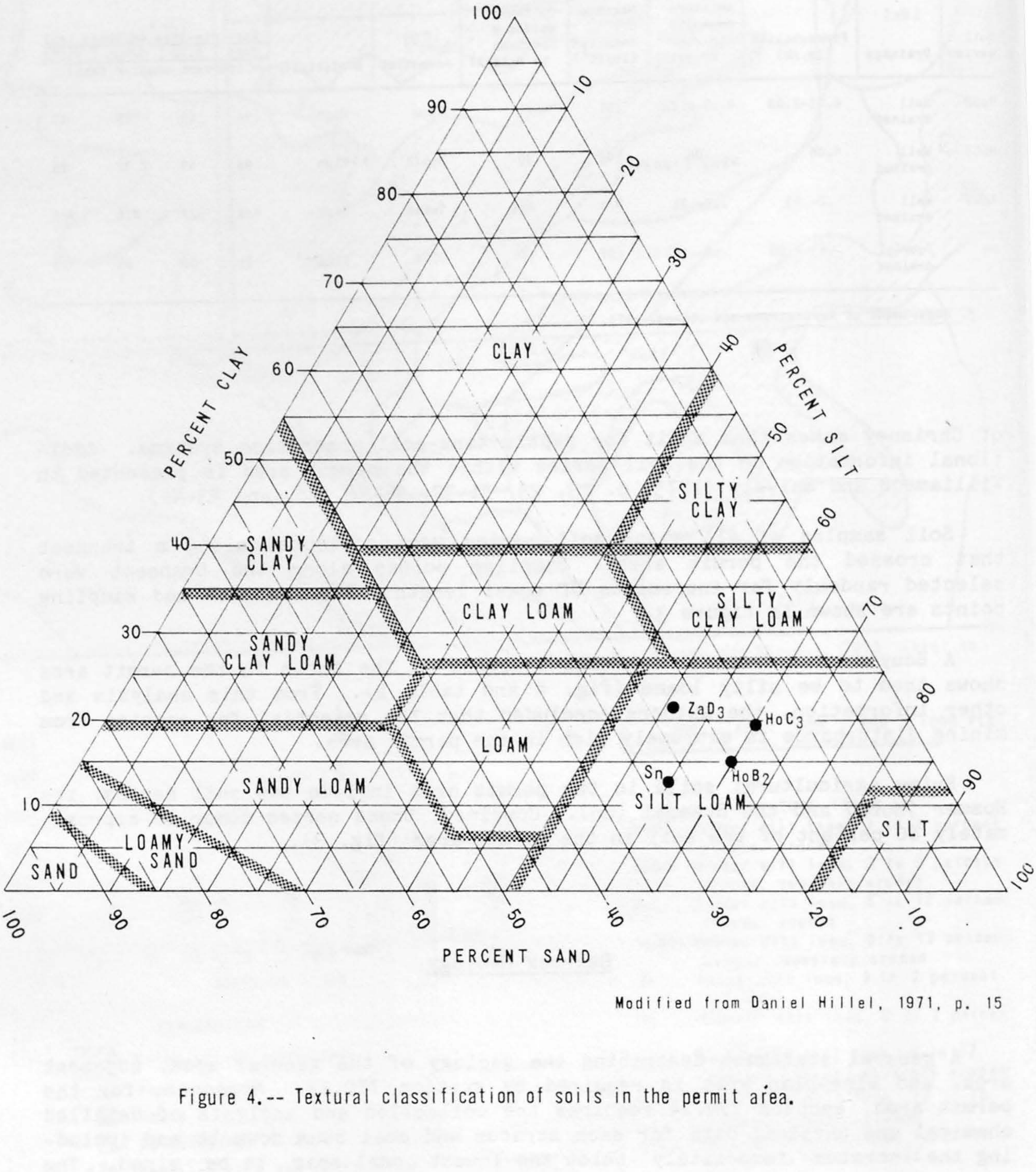
Soil samples of all major soil series were collected along a transect that crossed the permit area. Sampling points along the transect were selected randomly for increments of equal length. The transect and sampling points are shown in figure 3.

A Bouyoucos hydrometer textural analysis of the soils in the permit area shows them to be silty loams (fig. 4 and table 2). From this analysis and other information, the authors concluded that the potential for erosion from mining disturbance is extremely high in the permit area.

Prime agricultural soils in the permit area include two soil series, the Hosmer (HoB2) and the Stendal (Sn). Combined, these series comprise approximately 60 percent of the soil in the permit area (fig. 3).

Bedrock Geology

A general statement describing the geology of the general area, adjacent area, and mine-plan area is required by section 779.13. Moreover, for the permit area, section 779.14 requires the collection and analysis of detailed chemical and physical data for each stratum and coal seam down to and including the stratum immediately below the lowest coal seam to be mined. The



Modified from Daniel Hillel, 1971, p. 15

Figure 4.-- Textural classification of soils in the permit area.

Table 2.--Textural class analysis of soils in permit area

[Source of data, U.S. Geological Survey]

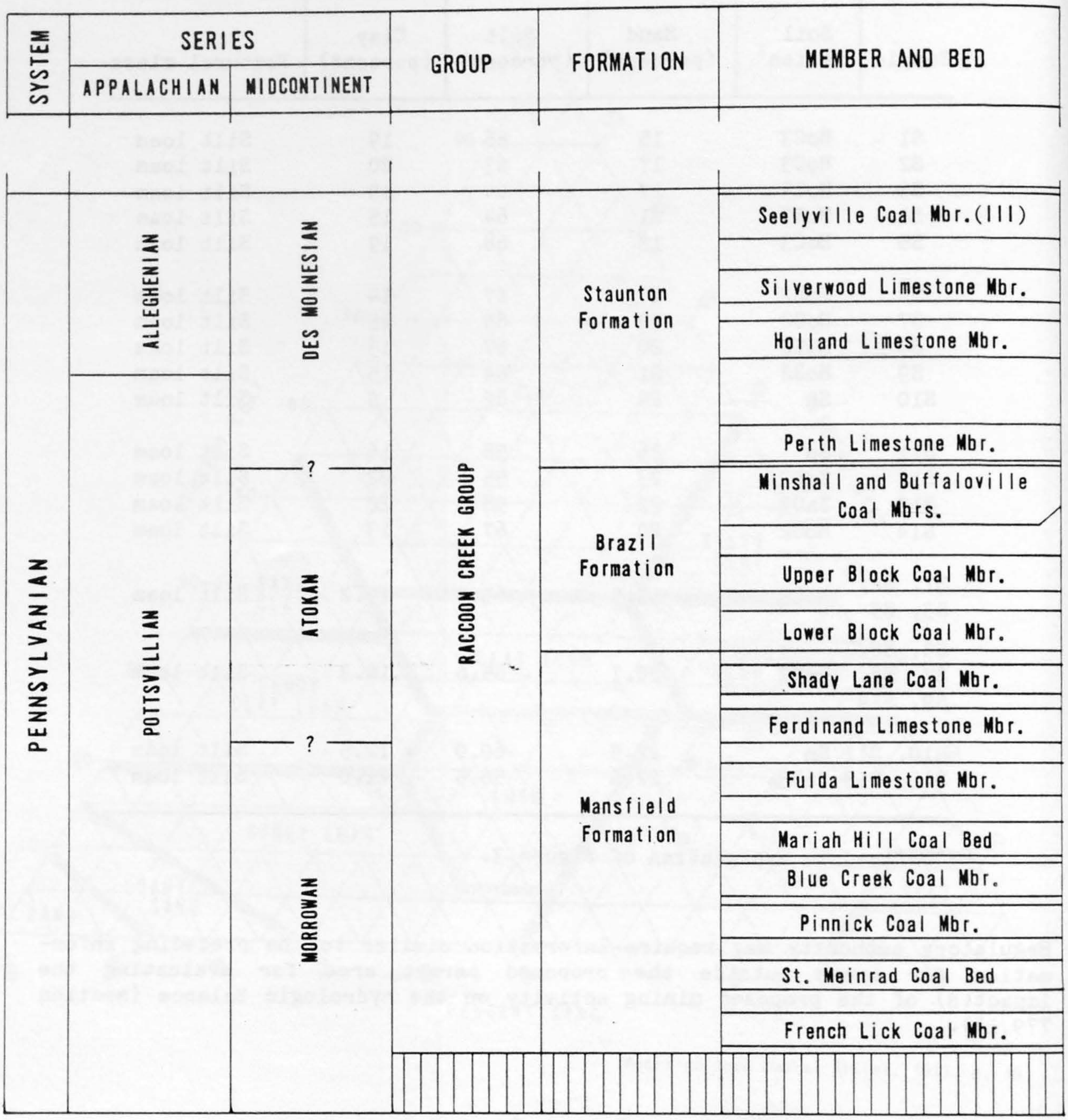
Sample	Soil series[1]	Sand (percent)	Silt (percent)	Clay (percent)	Textural class
S1	HoC3	15	66	19	Silt loam
S2	HoC3	17	63	20	Silt loam
S3	HoC3	17	64	19	Silt loam
S4	HoB2	21	64	15	Silt loam
S5	HoC3	13	68	19	Silt loam
S6	HoB2	19	67	14	Silt loam
S7	HoB2	20	65	15	Silt loam
S8	HoB2	20	67	13	Silt loam
S9	HoB2	21	64	15	Silt loam
S10	Sn	29	62	9	Silt loam
S11	Sn	26	58	16	Silt loam
S12	ZaD3	23	55	22	Silt loam
S13	ZaD3	22	58	20	Silt loam
S14	HoB2	20	67	13	Silt loam
S1, S2, S3, S5	HoC3	15.5	65.3	19.2	Silt loam
S4, S5, S7, S8, S9, S14	HoB2	20.1	65.6	14.3	Silt loam
S10, S11	Sn	27.5	60.0	12.5	Silt loam
S12, S13	ZaD3	22.5	56.5	21.0	Silt loam

[1]Defined in explanation of figure 3.

regulatory authority may require information similar to the preceding information for areas outside the proposed permit area for evaluating the impact(s) of the proposed mining activity on the hydrologic balance (section 779.14).

Spencer County

Spencer County is completely underlain by the Raccoon Creek Group of the Lower and Middle Pennsylvanian Series (fig. 5). This group ranges in thickness from 200 to 400 ft, and formations of the group, the Staunton, Brazil,



Modified from R.H. Shaver and others, 1970, table 3

The geologic names used in this report are accepted by the Indiana Geological Survey and differ somewhat from those accepted by the U.S. Geological Survey

Figure 5. -- Stratigraphic section of Spencer County, Ind.

and Mansfield Formations, crop out throughout the area (Gray, Wayne, and Wier, 1970).

The Staunton Formation consists of 75 to 140 ft of sandstone and shale and contains as many as six coal seams (Hutchison, 1959). The coal seams within the basin are not continuous, are of little areal extent, and are variable in both quality and thickness (Shaver and others, 1970, p. 171).

The Brazil Formation consists of shale, sandstone, coal, and underclay. The thickness of this formation ranges from 0 to 90 ft (Hutchison, 1960), but a typical thickness in the study basin is in the range from 80 to 90 ft. In ascending order, the Brazil Formation consists of the Lower Block Coal Member, the Upper Block Coal Member, and the Buffaloville and Minshall Coal Members (Shaver and others, 1970). The Buffaloville coal seam is the predominantly mined coal within the study basin and in adjacent areas. The type section for the Buffaloville Coal Member is just outside the watershed of East Fork Little Pigeon Creek. The Buffaloville coal is best characterized as a blocky coal underlain with a floor of underclay about 3 ft thick. The roof of this coal seam at the type section is black, sheety, unfossiliferous shale 0.5 ft thick. This shale lense is overlain by a dark-gray, soft, calcareous, fossiliferous, silty shale, which in turn is overlain by a dark-blue to black, fossiliferous limestone as much as 2 ft thick (Shaver and others, 1970, pl. 4).

In general, the Buffaloville coal has an above average moisture content, a below average ash content, and two classes of thermal content--one very low and the other only slightly below average as shown in the table that follows. The Buffaloville coal contains large nodules of pyrite (Neavel, 1961, p. 55).

	Percent moisture	Percent ash	Percent sulfur	Btu per pound
Maximum	32.2	27.6	7.2	13,400
Mean	14.1	12.0	3.1	11,930
Minimum	6.1	4.5	0.7	9,990

The Mansfield Formation mainly consists of thinly stratified, fine-grained, "muddy" sandstones, and cross-stratified, medium-grained sandstones (Gray, 1962). The Mansfield Formation, which crops out on the eastern side of Spencer County, ranges in thickness from 50 to 200 ft.

Study Basin

Appropriate sections of the major coal seams, formations, depths, outcrops, and associated well logs within the study basin are shown in section A-A' (fig. 6), as required by section 779.25 of the permanent regulations. Section B-B', depicted in figure 7, shows the relation between adjacent stripped areas, the permit area, and streams sampled in the study. The section shows that Sandy Creek could be influenced by both direct runoff from mined areas and direct contact with the Buffaloville coal. The unnamed coal seam could also impact East Fork Little Pigeon Creek, Chrisney Lake, and its tributary through direct contact and (or) water transmission through or above the coal seam.

Section C-C' (fig. 8) shows the relation between the unnamed coal and the Buffaloville coal seams in the permit area and adjacent land. Locations of sections A-A', B-B', and C-C' are shown in figure 9.

Permit Area

Published information and discussion with local miners indicate that the bedrock geology in the study basin, and probably within the permit area, is highly variable. Vertical profiles and coal analyses for 15 test holes drilled by Mulzer Crushed Stone Co. on a 20-acre site east of the permit area confirm the noncontinuous and nonuniform nature of the beds within a small area. At the authors' request, an additional test hole was drilled by the Mulzer Crushed Stone Co. at their leased site in the NE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 7, T. 6 S., R. 6 W., approximately 1 mi east of the permit area. A drilling rig with a rotary cone was used, and samples of each stratum in the overburden, coal, and underlier were collected. The test hole was assumed to be representative of the bedrock geology at the permit area, after adjustment for dip and elevation. Application of the test hole's bedrock geology to the permit area, even with the adjustments, is of limited reliability. However, the authors concluded that such an assumption was necessary to allow a complete hydrologic evaluation of the permit area.

The lithology of the strata that were logged during the drilling of the 16th test hole is presented in table 3. Each stratum was analyzed chemically as required by section 779.14. For the analysis, 125 mL of each stratum was placed in separate closed reactors containing 210 mL of de-ionized water. After the slurry was mixed thoroughly once every 6 h during the 48-h test, it was centrifuged, and the supernatant liquid was analyzed (table 4 and fig. 10). Sample 6 (gray shale), sample 7 (thin coal seam), and sample 8 (gray shale) are likely acid-producing layers that may require special consideration during mining. This observation was confirmed in an open-vessel test (table 4). The test was similar to the closed-reactor test except that the slurry was continuously mixed for 48 h in an open container to ensure that sufficient oxygen was available for reaction.

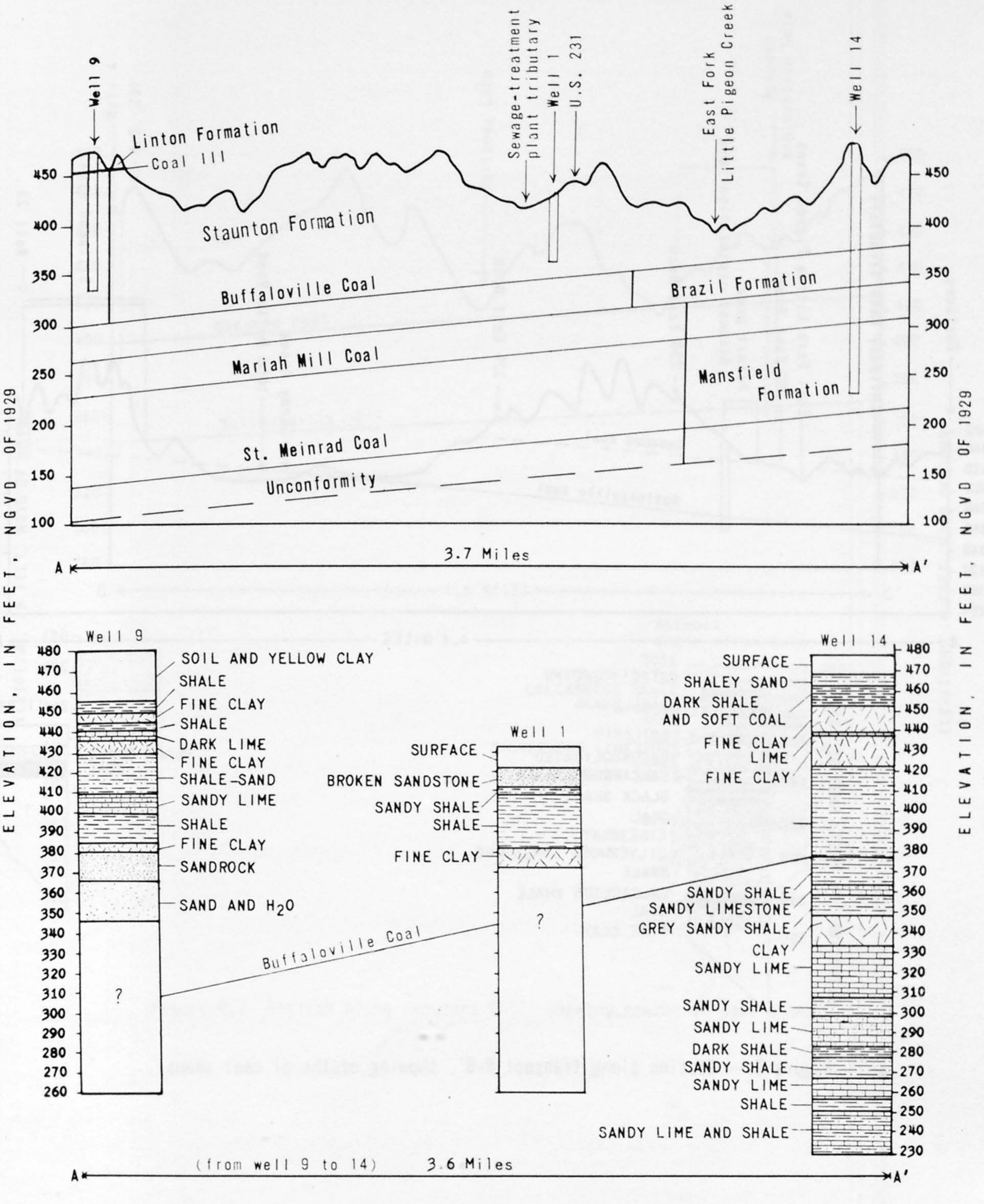


Figure 6. -- Section along transect A-A', showing depths of major coal seams and bedrock units.

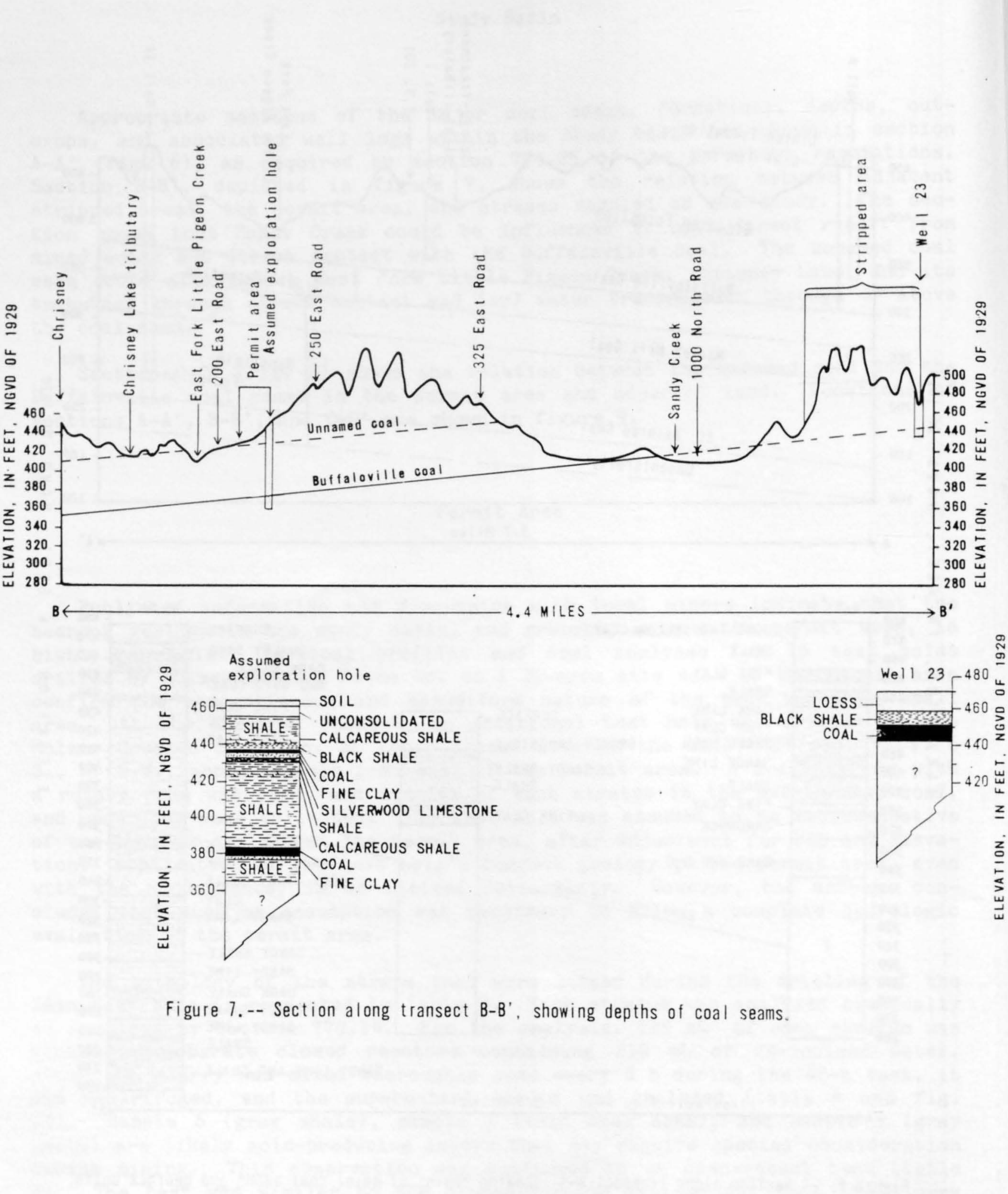


Figure 7.-- Section along transect B-B', showing depths of coal seams.

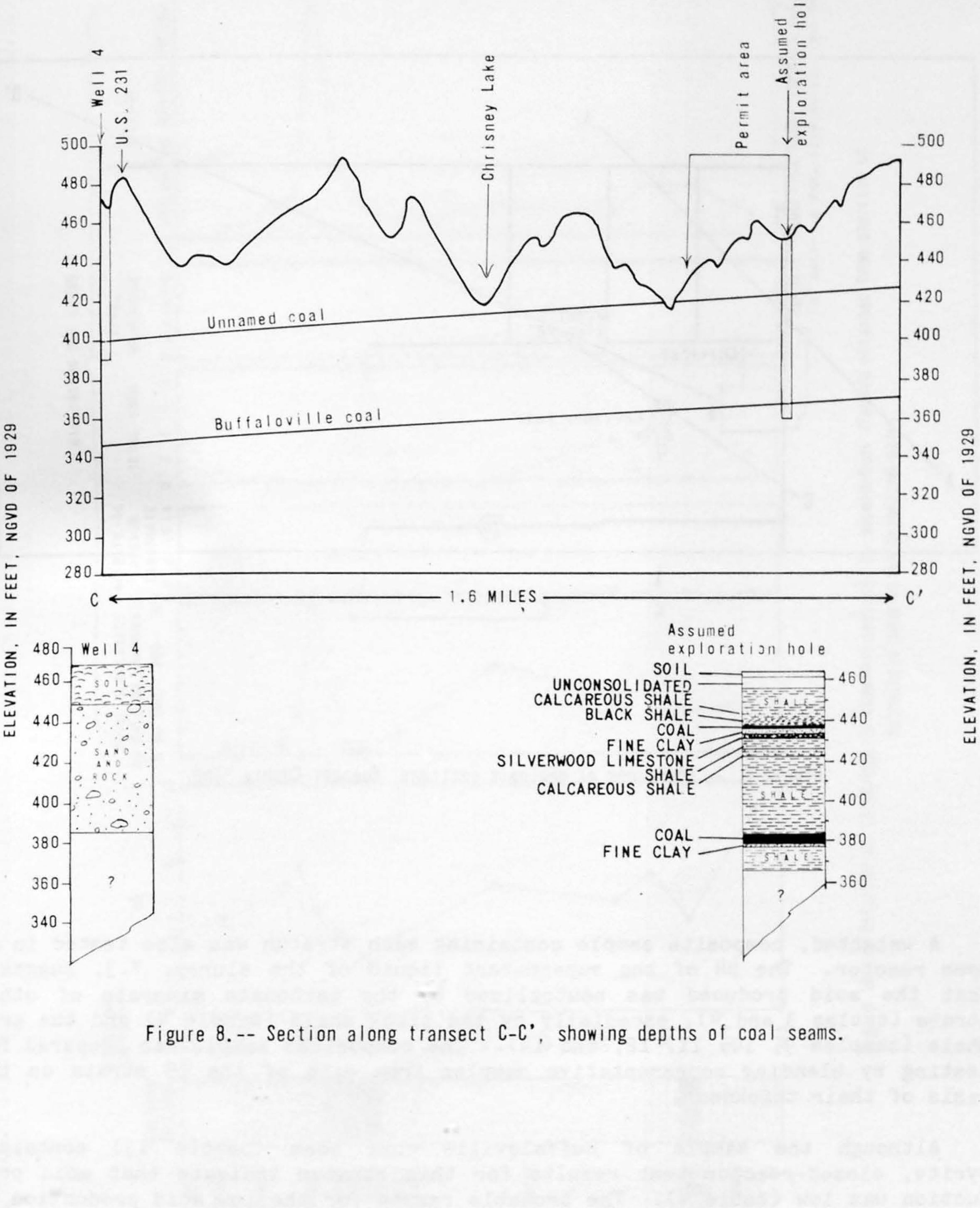


Figure 8.-- Section along transect C-C', showing depths of coal seams.

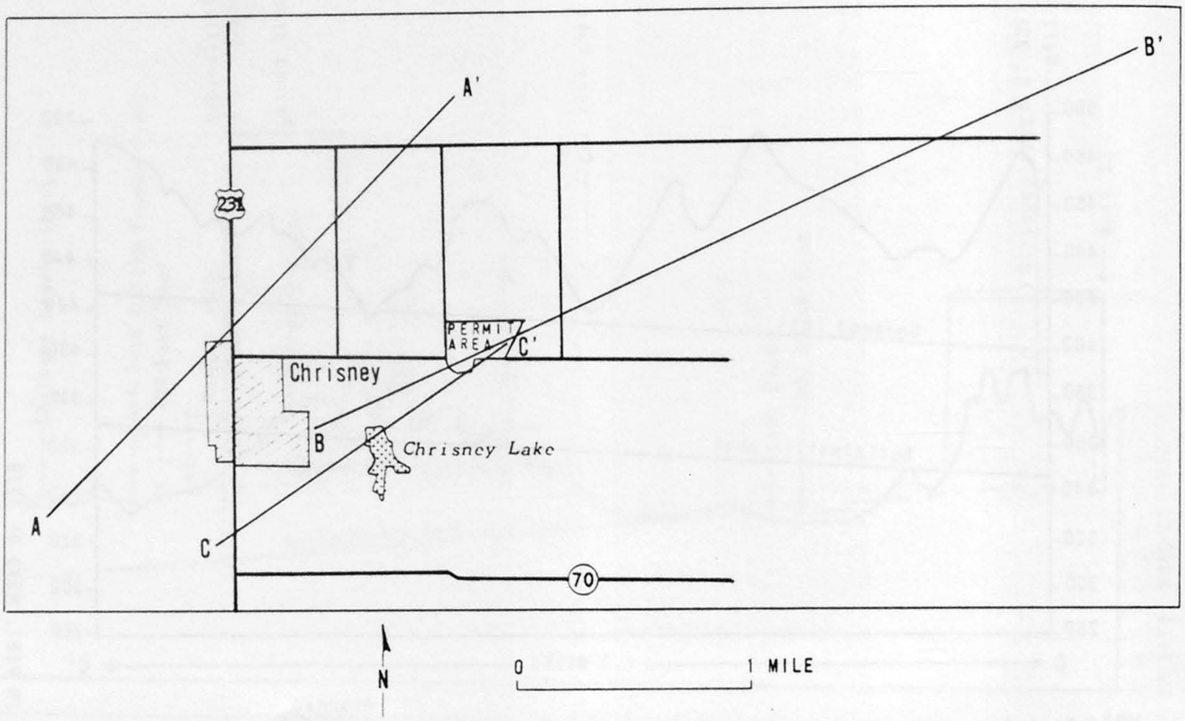


Figure 9. -- Locations of geologic sections, Spencer County, Ind.

A weighted, composite sample containing each stratum was also tested in an open reactor. The pH of the supernatant liquid of the slurry, 7.3, suggests that the acid produced was neutralized by the carbonate minerals of other strata (tables 3 and 4), especially by the black shale (sample 4) and the gray shale (samples 9, 10, 11, 12, and 14). The composited sample was prepared for testing by blending representative samples from each of the 15 strata on the basis of their thickness.

Although the sample of Buffaloville coal seam (sample 13) contained pyrite, closed-reactor test results for this stratum indicate that acid production was low (table 4). The probable reason for the low acid production is that the pyrite is predominantly euhedrial form, which has been shown to be less reactive than the more common framboidal form (Caruccio, 1970, 1972; Caruccio and Ferm, 1974).

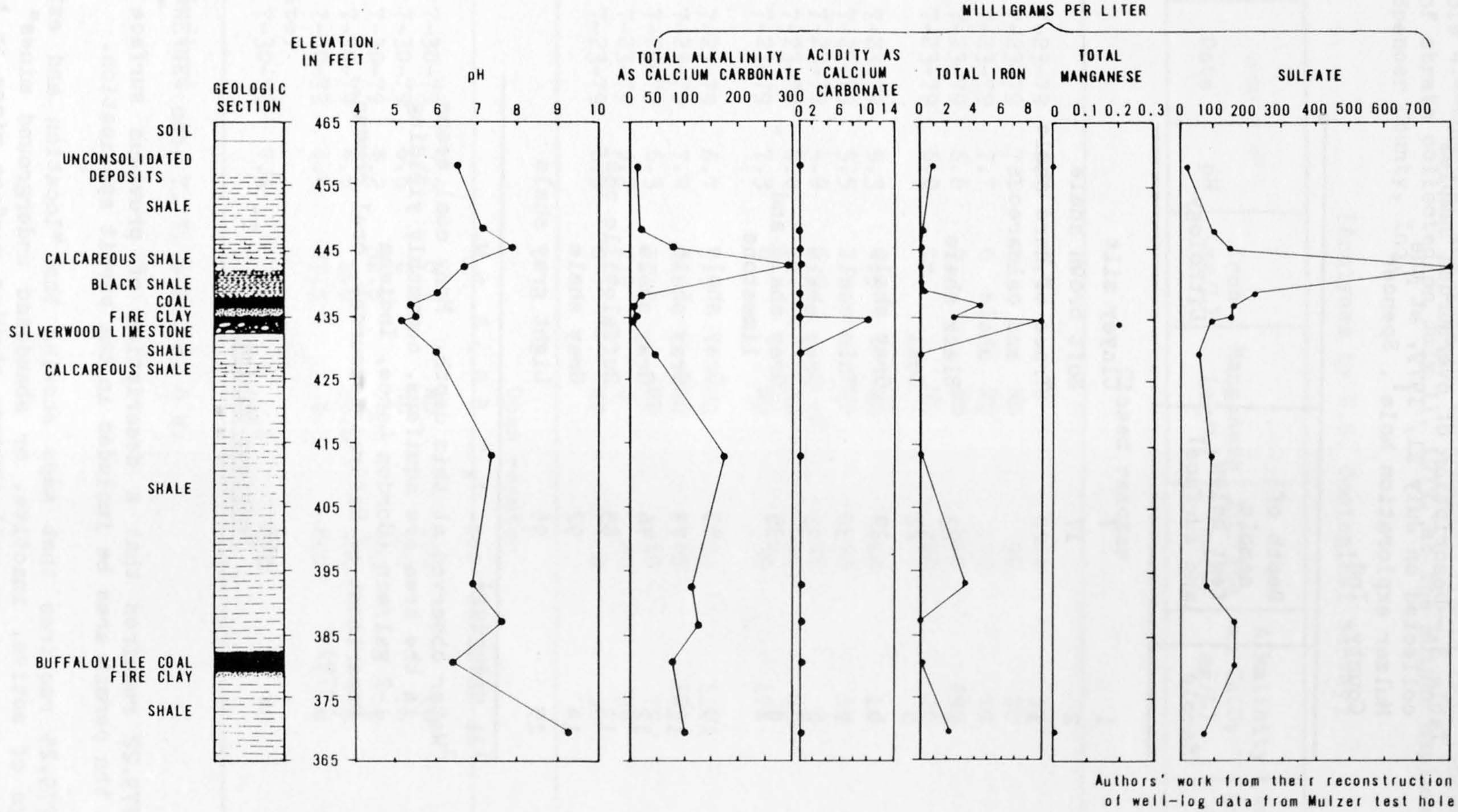


Figure 10. -- Relation of lithology to chemical analyses of supernatant liquids obtained from slurries of lithologic samples in deionized water.

Table 3.--Description of overburden samples collected on July 11, 1979, at the Mulzer exploration hole[1], Spencer County, Ind.

Sample	Depth of sample (feet below land surface)	Lithology
1	7	Clayey silt
2	17	Soft brown shale
3	20	Trace of hard shale and calcareous shale
4	23	Black shale
5	[2]27	Coal
6	29	Gray shale
7	30	Thin coal
8	31	Gray shale
9	35	Gray shale and limestone
10	53	Gray shale
11	73	Gray shale
12	76	Gray shale
13	85	Buffaloville coal
14	92	Gray shale
15	96	Light gray shale

[1]At NE¼NE¼NE¼ sec. 7, T. 6 S., R. 6 W.

[2]Water observed at this depth. Many coal seams in the area are aquifers, commmonly yielding 1-2 gal/min (Gordon Lance, Indiana Department of Natural Resources, oral commun., 1979).

Previous Mining

Section 779.22 requires that a description of previous surface mining activities in the permit area be included in the permit application.

Section 779.25 requires that maps showing the "location and extent of known workings of active, inactive, or abandoned underground mines" in the permit and adjacent areas, as well as maps showing surface mines in the permit area, be included in the permit application.

Table 4.--Chemical analyses of supernatant liquid from laboratory tests of strata collected on July 11, 1979, at the Mulzer exploration hole, Spencer County, Ind.[1]

[Analyses by U.S. Geological Survey]

Sample	Date	pH	Iron (mg/L)	Manganese (mg/L)	Sulfate (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Acidity as $CaCO_3$ (mg/L)	Depth (ft)
				Closed reactor				
1	7-23-79	6.7	0.9	0	20	10	0	7
2	7-23-79	7.1	tr	ND	90	20	0	17
3	7-23-79	7.7	0	ND	140	70	0	20
4	7-23-79	6.6	0	ND	800	290	0	23
5	7-23-79	6.0	tr	ND	220	20	0	27
6	7-23-79	5.3	4.5	ND	160	10	0	29
7	7-23-79	5.5	2.5	ND	150	10	0	30
8	7-23-79	4.9	9.0	.2	90	0	10	31
9	7-23-79	6.0	tr	ND	60	40	0	35
10	7-23-79	7.3	0	ND	90	170	0	53
11	7-23-79	6.7	3.5	ND	80	110	0	73
12	7-23-79	7.4	0	ND	160	120	0	76
13	7-23-79	6.3	tr	ND	160	70	0	85
15	7-23-79	9.2	2.2	0	60	90	0	96
Blank	7-23-79	6.5	0	ND	0	10	0	--
				Open reactor				
4	7-30-79	7.2	0	ND	200	40	0	23
5	7-30-79	6.6	0	ND	300	10	0	27
6	7-30-79	4.2	32.5	5.0	320	0	160	29
7	7-30-79	4.5	6.0	10.0	900	0	30	30
8	7-30-79	4.4	27.5	6.0	600	0	80	31
Composite:								
	7-30-79	7.3	.3	.4	880	40	0	--

[1]At NE¼NE¼NE¼ sec. 7, T. 6 S., R. 6 W.

Study Basin and Vicinity

At least 10 coal-mining operations can be identified near the permit area. The authors believe that an appraisal of the long-term adverse impacts of mining in the area of the hypothetical minesite is impossible without a consideration of all past surface-mining operations in the adjacent area. Therefore, a summary of historical surface and underground mining in the permit and adjacent areas follows. The locations of former surface and deep mines in the vicinity of Chrisney, Ind., are identified by numbers in figure 11. The mines are described in paragraphs that follow.

Kelco Bright Star Mine[1,2] (number 1 in fig. 11). A 65-acre surface operation mining a 3-ft Buffaloville coal seam under 55 to 85 ft of overburden. The mine was active during the last half of 1978 and was inactive and unreclaimed at the time of site visitation (June 1979). Graded and ungraded spoil banks lack vegetative cover. The pit area is filled with approximately 35 ft of water. Surface drainage from the sediment pond enters a tributary of the East Fork Little Pigeon Creek. The future status of this mine is uncertain.

Unidentified Mine[2] (number 2 in fig. 11). A 25-acre surface mine that was active in late 1977. The site was reclaimed and revegetated with wheat at the time of site visitation (July 1979). The mine is on the drainage divide of the study basin. The spoil was graded so that most of the surface runoff collects in a 1.5-acre pond in the center of the mine area. There is only a minimal contribution of surface runoff to the East Fork Little Pigeon Creek.

Crooks Mullen Pit[1,2] (number 3 in fig. 11). A 25-acre surface mine on the drainage divide of the study basin. The Crooks operation mined two seams of coal. The first seam was an unnamed 1.5-ft coal seam under 6-15 ft of unconsolidated overburden. Below the unnamed seam was a 4-ft Buffaloville coal seam under 55 ft of gray-shale overburden. The mine was active in 1977 and was inactive and unreclaimed at the time of site visitation (July 1979). The upper and lower pits have 5 and 30 ft of impounded water, respectively. Surface runoff from a sediment pond enters the headwaters of the East Fork Little Pigeon Creek. Surface runoff from the upper and lower pits does not enter the study basin.

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[1]Information obtained from permit applications, Indiana Department of Natural Resources, Division of Reclamation, Jasonville, Ind.

[2]Information obtained from site visitation, aerial photographs by USGS EROS Data Center, Sioux Falls, S. Dak., and Hutchison (1959).

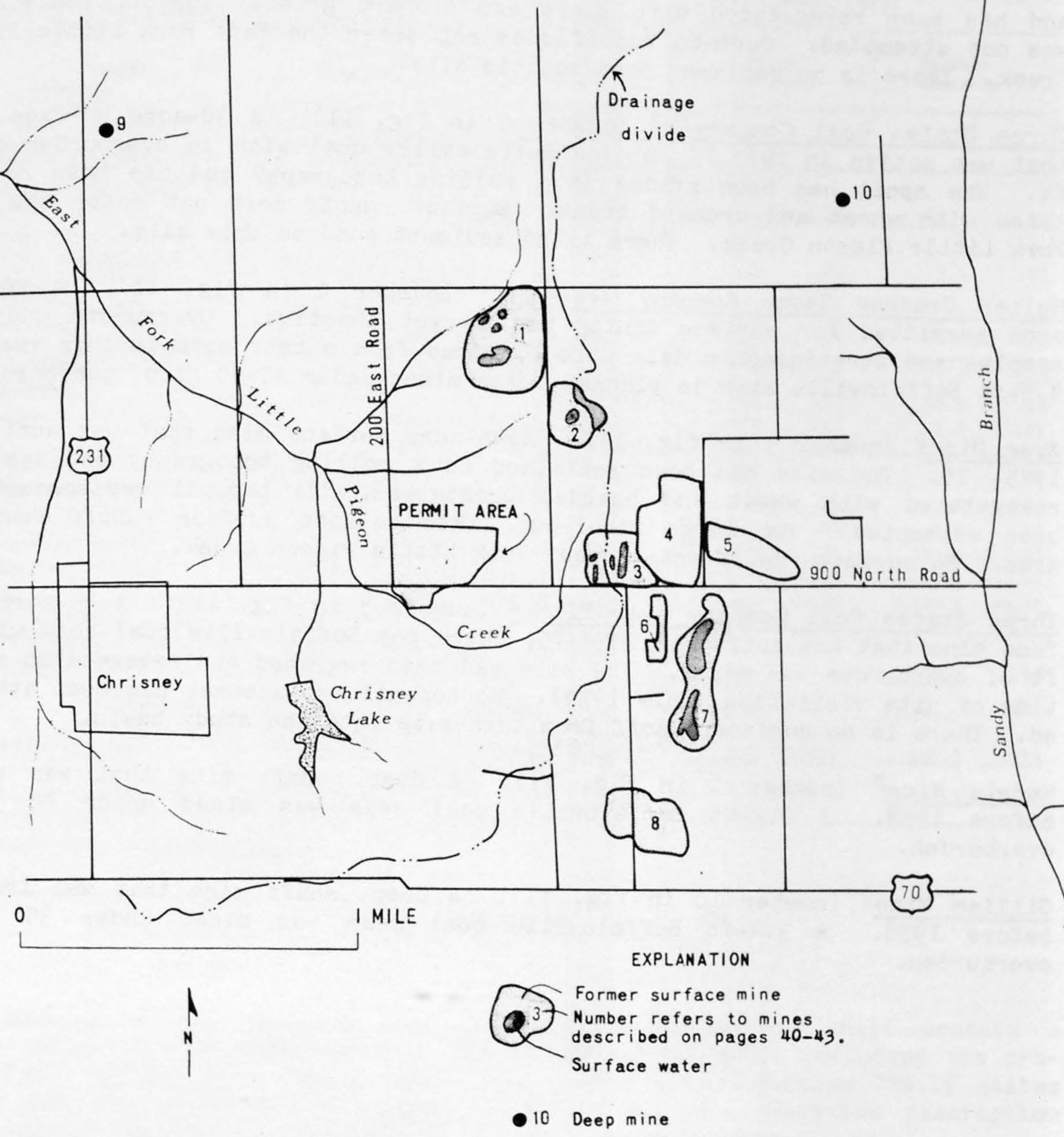

Figure 11.-- Surface and deep mines and the permit area in the vicinity of Chrisney, Ind.

Three States Coal Company[1,2] (number 4 in fig. 11). A 40-acre surface mine that was active between 1973 and 1975. A 4-ft Buffaloville coal seam under 40 ft of overburden was mined. The spoil has been graded to a rolling topography and has been revegetated with wheat and orchard grass. Topsoil replacement was not attempted. Surface runoff does not enter the East Fork Little Pigeon Creek. There is no sediment pond on this site.

Three States Coal Company[1,2] (number 5 in fig. 11). A 30-acre surface mine that was active in 1973-75, mining Buffaloville coal with an overburden of 35 ft. The spoil has been graded to a rolling topography and has been revegetated with wheat and orchard grass. Surface runoff does not enter the East Fork Little Pigeon Creek. There is no sediment pond on this site.

Mulzer Crushed Stone Company Ayer Pit[1] (number 6 in fig. 11). A 20-acre area permitted for surface mining and as yet inactive. Overburden and coal samples and stratigraphic data were obtained from a test hole in this area. A 4.5-ft Buffaloville seam is planned to be mined under 40-90 ft of overburden.

Ayer Mine[2] (number 7 in fig. 11). A 45-acre surface mine that was active in 1975- 76. The site has been reclaimed to a rolling topography and has been revegetated with wheat and bearded wheatgrass. No topsoil replacement has been attempted. Two large final-cut lakes collect surface runoff from the area. No surface runoff enters East Fork Little Pigeon Creek.

Three States Coal Company Ayer Pit[1,2] (number 8 in fig. 11). A 35-acre surface mine that was active in 1974-75, where the Buffaloville coal seam with 35 ft of overburden was mined. The site had been regraded and revegetated at the time of site visitation (July 1979). No topsoil replacement has been attempted. There is no surface runoff from this site into the study basin.

Harris Mine[2] (number 9 in fig. 11). A deep, shaft mine that was active before 1958. A 2.2-ft Buffaloville coal seam was mined under 40 ft of overburden.

Gilliam Mine[2] (number 10 in fig. 11). A deep, shaft mine that was inactive before 1958. A 3.4-ft Buffaloville coal seam was mined under 35 ft of overburden.

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[1]Information obtained from permit applications, Indiana Department of Natural Resources, Division of Reclamation, Jasonville, Ind.

[2]Information obtained from site visitation, aerial photographs by USGS EROS Data Center, Sioux Falls, S. Dak., and Hutchison(1959).

Table 5.--Summary of 1976 land use in townships in the study basin

[Data from Indiana Regional Planning Commission 15, written commun., 1979]

Land use	Clay Township		Grass Township		Hammond Township		Jackson Township	
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Vacant or agricultural land[1]	9,596.0	41.19	24,362.0	82.93	19,960.6	74.79	6,894.3	49.64
Intensive agriculture	19.5	.08	19.1	.07	14.3	.05	.9	.01
Junk and dumping areas	2.0	.01	3.1	.01	.8	.01	3.9	.03
Residential:								
Residence (farm)	62.0	.27	143.0	.49	109.0	.41	36.0	.26
Residence (nonfarm)	55.5	.24	87.5	.30	75.0	.28	46.0	.33
Mobile home (farm)	--------	------	--------	------	--------	------	--------	------
Mobile home (nonfarm)	4.0	.02	8.0	.03	10.8	.04	9.0	.06
Commercial	2.0	.01	3.2	.01	1.6	.01	26.9	.19
Industrial	7.7	.03	11.2	.03	47.5	.18	1.8	.01
Public	.2	.01	30.0	.10	22.4	.08	--------	------
Semipublic	9.4	.04	2.8	.01	9.4	.04	5.3	.04
Private utility	1.5	.01	2.9	.01	2.3	.01	.5	.01
Cemetery	8.1	.03	11.3	.03	14.1	.05	4.6	.03
Park and recreation	--------	------	22.1	.08	.9	.01	151.1	1.09
Mineral extraction	801.0	3.43	4.6	.02	546.5	2.04	--------	------
Forest	7,218.3	30.99	3,950.0	13.45	5,149.8	19.30	5,640.4	40.62
State and (or) federally-owned land	1,800.4	7.73	--------	------	--------	------	155.5	1.12
Railroads	1,265.0	5.43	529.0	1.80	--------	------	667.0	4.80
SUBTOTAL	20,852.6		29,189.8		25,964.9		13,643.2	
Incorporated areas	2,443.4	10.48	186.2	.63	723.1	2.70	244.8	1.76
TOTAL	23,296.0	100.00	29,376.0	100.00	26,688.0	100.00	13,888.0	100.00

[1]Includes water areas and roadways.

Land Use

Section 779.22 requires that the permit application shall contain a description of the premining land use of the permit area, including the productivity of the land, and a map of the permit area. Section 779.19 states that the regulatory authority may require a map and narrative description delineating vegetative types and describing vegetative communities.

Study Basin and Vicinity

The major land uses in the study basin and vicinity are agriculture and forest (table 5).

Permit Area

At present (1979), land use in the permit area is almost entirely agricultural (fig. 12). The land is in a corn-soybean rotation series; soybeans was the growing crop during the site visitations in July 1979. A woodlot of upland tree species, including red oak (Quercus rubra), white oak (Quercus alba), shingle oak (Quercus imbricata), black cherry (Prunus serotina), black walnut (Juglans nigra), shagbark hickory (Carya ovata), sycamore (Platanus occidentalis), and tulip poplar (Liriodendron tulipifera), occupies the northeast corner of the drainage area. This woodlot has been logged in the past 20 years and has been used recently as a pasture lot for beef cattle.

Lowland tree species along East Fork Little Pigeon Creek south of the permit area include poplar (Populus grandidentata), cottonwood (Populus deltoides), soft maple (Acer saccharinum, Acer negundo), sycamore (Platanus occidentalis), tulip poplar (Liriodendron tulipifera) and river birch (Betula nigra). Cropland extends to within 75 ft of the creek, so that only a narrow band of trees now exists. The topography and drainage of the permit area is discussed in the section "Location and General Description of Study Basin, General Area, and Permit Area."

Alternative Water-Supply and Related Information

Section 779.17 requires that the application for a permit identify the extent of contamination, diminution, or interruption of underground or surface sources of water that the proposed mining may cause in the permit area or adjacent area. If the proposed mining will impact sources of water, the mine operator is required to identify alternative sources of water.

Spencer County

Nine public water-supply systems in Spencer County use water pumped primarily from the Ohio River's alluvial deposits (Gordon Lance, Indiana Department of Natural Resources, oral commun., 1979). These systems account for a water use of 315 million gallons per year by about 3,000 people (Governor's Water Resources Study Commission, 1978). Regionally, there is an increasing shift from individual water supplies to small, public water systems. Nearly all the rural area of Spencer County will probably be served by these small water utilities within the next 10 years (Gordon Lance, Indiana Department of Natural Resources, oral commun., 1979).

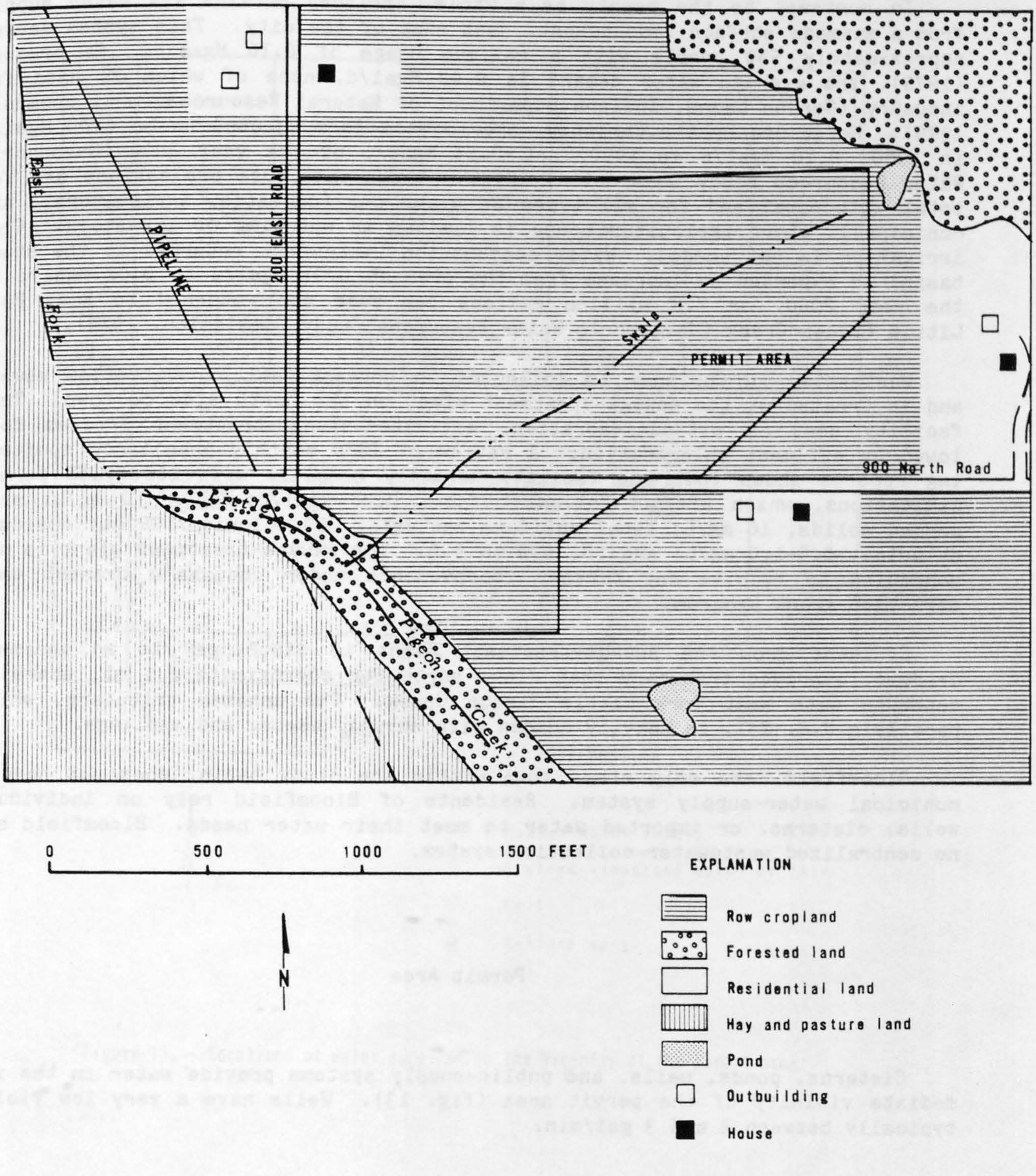


Figure 12. -- Land use in the vicinity of the permit area.

In contrast to the county as a whole. Chrisney obtains its water supply from a manmade surface impoundment. just east of the city. This system serves approximately 550 people with a maximum usage of 0.16 Mgal/d. At present (1979). the average water demand is 0.08 Mgal/d. none of which is used for industry (Gordon Lance. Indiana Department of Natural Resources. oral commun., 1979). Water use by the Chrisney water system is projected to be 0.08 Mgal/d in 1980. 0.10 Mgal/d in 1990. and 0.13 Mgal/d by the year 2000 (Governor's Water Resources Study Commission, 1978). These water-use projections are for total withdrawal and for all types of water use (domestic. agricultural. and municipal). where agricultural use is limited to watering of livestock. Crop irrigation is not needed. Water consumption (water not returned to the study basin) is expected to increase from the present 0.01 Mgal/d to 0.02 Mgal/d by the year 2000. or 7.8 million gallons per year not returned to East Fork Little Pigeon Creek (Governor's Water Resources Study Commission. 1978).

Wastewater in Chrisney is collected in conventional. gravity-flow sewers and is treated at the sewage-treatment plant on the north side of town. This facility uses an extended-aeration. activated-sludge-treatment process followed by effluent chlorination. A review of ISBH monthly compliance monitoring reports shows that the facility normally complies with its NPDES permit limitations. which are as follows: flow. 0.08 Mgal/d; BOD_5. 10 mg/L; suspended solids. 10 mg/L; fecal coliform bacteria. 200 colonies/100 mL; residual chlorine. 0.5-1.0 mg/L; and pH. 6.0 to 9.0. The sewage-treatment plant is not scheduled to receive any further improvements under Indiana's present construction-grant program.

Effluent from the sewage-treatment plant is discharged to an unnamed. dredged. improved tributary that flows north for approximately 1 mi. where it connects with East Fork Little Pigeon Creek. The unnamed tributary, which parallels U.S. 231, is heavily shaded with shrubs. weeds. and saplings.

Bloomfield. the only other town within the study basin. does not have a municipal water-supply system. Residents of Bloomfield rely on individual wells. cisterns. or imported water to meet their water needs. Bloomfield has no centralized wastewater-collection system.

Permit Area

Cisterns. ponds. wells. and public-supply systems provide water in the immediate vicinity of the permit area (fig. 13). Wells have a very low yield. typically between 2 and 3 gal/min.

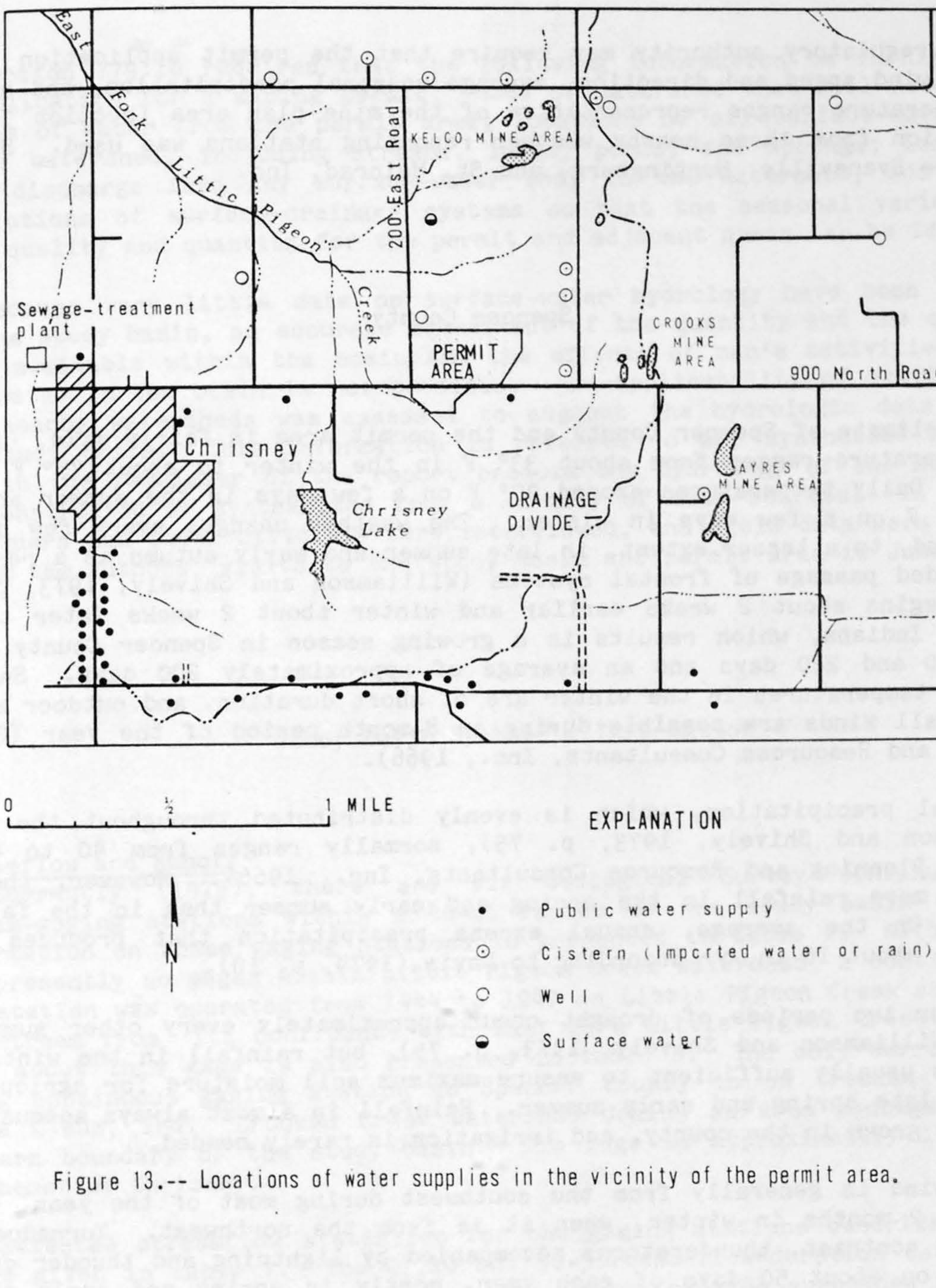


Figure 13.-- Locations of water supplies in the vicinity of the permit area.

Climatology

The regulatory authority may require that the permit application include average wind speed and direction, average seasonal precipitation, and seasonal air-temperature ranges representative of the mine plan area (section 779.18). Information from three nearby weather reporting stations was used. Stations used were Evansville, Huntingburg, and St. Meinrad, Ind.

Spencer County

The climate of Spencer County and the permit area is fairly mild. Average air temperature ranges from about 33° F in the winter to about 75° F in the summer. Daily temperatures exceed 90° F on a few days in the summer and drop below 0° F on a few days in winter. The weather changes every few days in spring and, to a lesser extent, in late summer and early autumn as a result of the speeded passage of frontal systems (Williamson and Shively, 1973, p. 75). Spring begins about 2 weeks earlier and winter about 2 weeks later than in northern Indiana, which results in a growing season in Spencer County of between 180 and 220 days and an average of approximately 200 days. Snow and freezing temperatures in the winter are of short duration, and outdoor activities of all kinds are possible during an 8-month period of the year (General Planning and Resources Consultants, Inc., 1966).

Annual precipitation, which is evenly distributed throughout the county (Williamson and Shively, 1973, p. 75), normally ranges from 40 to 44 in. (General Planning and Resource Consultants, Inc., 1966). However, there is commonly more rainfall in the spring and early summer than in the fall and winter. On the average, annual excess precipitation that produces flood events is about 16 in./yr according to Davis (1974, p. 10).

One or two periods of drought occur approximately every other summer or autumn (Williamson and Shively, 1973, p. 75), but rainfall in the winter and spring is usually sufficient to ensure maximum soil moisture for agricultural needs in late spring and early summer. Rainfall is almost always adequate for the crops grown in the county, and irrigation is rarely needed.

The wind is generally from the southwest during most of the year, except for 1 or 2 months in winter, when it is from the northwest. Tornadoes are rare. In contrast, thunderstorms accompanied by lightning and thunder commonly occur on about 50 days of each year, mostly in spring and early summer. The thunderstorms rarely harm property, crops, or people (Williamson and Shively, 1973, p. 75).

Surface-Water Information

Section 779.16 requires that the following information be furnished with an application for a mining permit: name of watershed that will receive discharges of water from the permit area; locations of all surface-water bodies in the watershed, including streams, lakes, ponds, and springs; location of water discharge into any surface-water body in the watershed; and detailed descriptions of surface-drainage systems so that the seasonal variations in water quality and quantity for the permit and adjacent areas can be identified.

Because very little data on surface-water hydrology have been collected for the study basin, an accurate assessment of the quantity and the quality of water available within the basin and the effects of man's activities on surface water in the basin is not possible. The applicability of available data from nearby watersheds was assessed to augment the hydrologic data base for the study basin. This information is referred to as "synthetic" hydrologic data in the remainder of the report because the hydrology of the study basin was constructed or synthesized from a variety of data sources. In addition, landowners and local officials were interviewed, and field data were collected during the authors' visits to the study basin and permit area in June and July 1979.

Study Basin Synthetic Information

Streamflow and Runoff

Currently (1979), there are six Geological Survey continuous-record stream-gaging stations within a 40-mi radius of the study basin (fig. 14). Information on these gaging stations is presented in table 6. Although there are presently no gages within Little Pigeon Creek watershed, a continuous gaging station was operated from 1944 to 1947 on Little Pigeon Creek about 1.5 mi downstream from its confluence with East Fork Little Pigeon Creek. Information about this gage is also presented in table 6. The only currently operating continuous gaging station in Spencer County is on Crooked Creek near Santa Claus, Ind. Crooked Creek watershed drains an area contiguous to the eastern boundary of the study basin. The gage is approximately 10 mi east-northeast of Chrisney.

Selected streamflow statistics for the gaging stations described in table 6 are given in table 7. The Q7,10 and 90-percent-flow-duration data indicate that ground-water aquifers in the region do not provide sustained streamflows during dry periods. An exception is station 03376350, South Fork Patoka River near Spurgeon, which has a Q7,10 value of 0.5 ft^3/s and a 90-percent flow duration value of 5.6 ft^3/s. These locally high-sustained flows may be due to coal washing and historical strip mining in South Fork Patoka River basin (U.S. Geological Survey, 1973, p. 262).

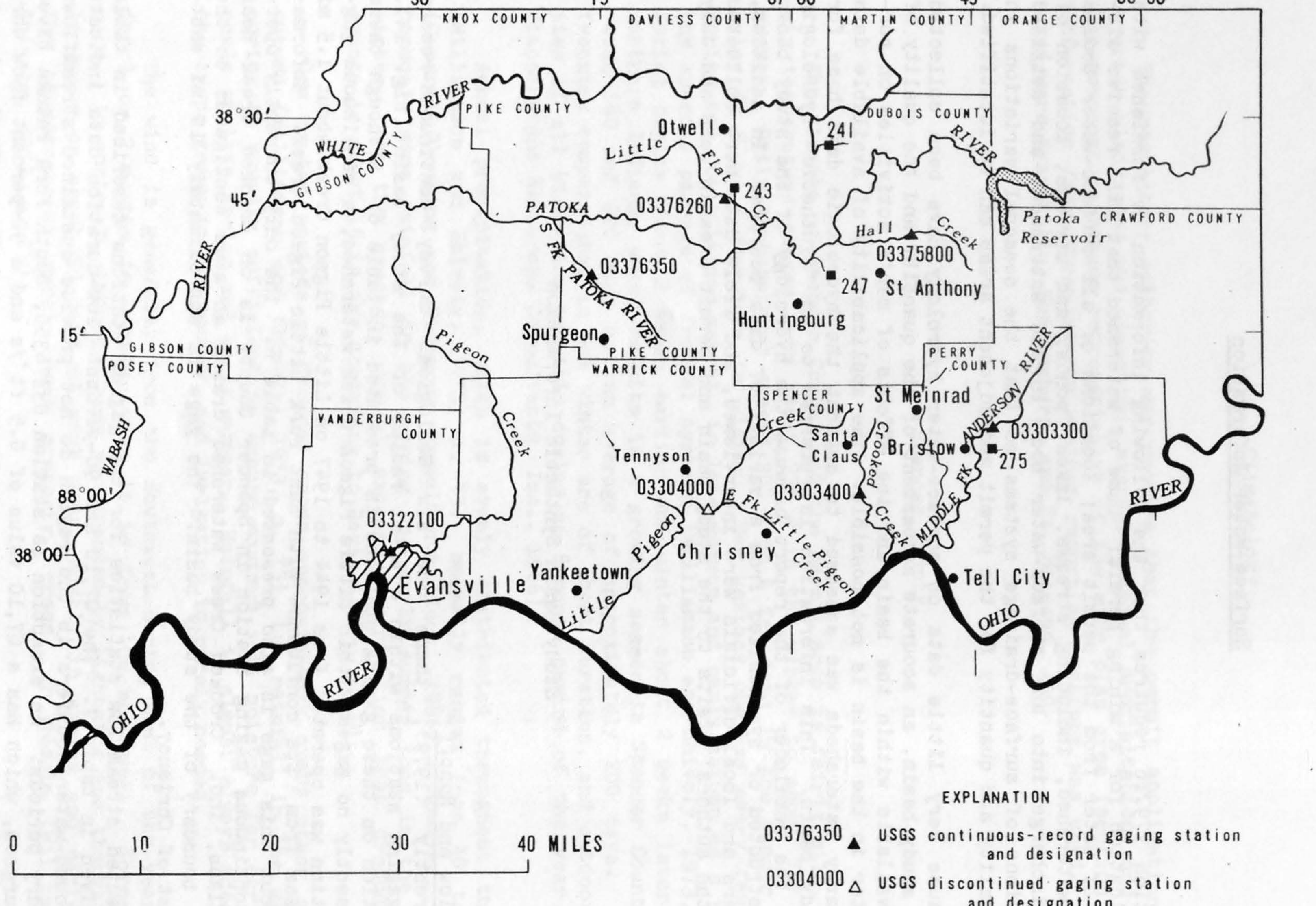


Figure 14.-- Locations of gaging stations in the vicinity of East Fork Little Pigeon Creek basin.

Table 6.--Information on selected continuous-record gaging stations in the vicinity of the study basin

[Data from U.S. Geological Survey, 1978]

Station	Name	County	Drainage area (mi^2)	Years of recorded discharge	Years of recorded sediment discharge	Years of recorded water quality	Remarks
03303300	Middle Fork Anderson River at Bristow	Perry	39.8	1961-78	1964-76 Partial-record only	None noted	Flow regulated since June 1967.
03303400	Crooked Creek near Santa Claus	Spencer	7.86	1969-78	None noted	do.	No flow 10 percent of water year.
03304000	Little Pigeon Creek near Tennyson	Spencer	150	1944-47	do.	do.	Backwater from Ohio River and other tributaries at high flows.
03322100	Pigeon Creek at Evansville	Vanderburgh	323	1960-78	do.	do.	Backwater from Ohio River at high flows.
03375800	Hall Creek near St. Anthony	Dubois	21.8	1970-78	do.	do.	-------------------
03376260	Flat Creek near Otwell	Pike	21.3	1964-78	do.	do.	-------------------
03376350	South Fork Patoka River near Spurgeon	Pike	42.8	1964-78	do.	do.	Flow regulated by coal-washing operation and strip mining upstream from gage.

Table 7.--Summary of streamflow information for selected gaging stations in the vicinity of the study basin

[Data from Horner, 1976]

Station	Drainage area (mi^2)	Period of analysis	Streamflow characteristics: Low-flow frequency: Q 7,10 (ft^3/s)	Duration of daily flow, percent of time discharge was equaled or exceeded: 90 (ft^3/s)	90 [(ft^3/s)/ mi^2)	50 (ft^3/s)	50 [(ft^3/s)/ mi^2]
03303300	39.8	1962-73	0	0.01	0.00025	12	0.30
03303400	7.86	1970-73	0	0	0	2.1	.27
03304000	150	1944-47	0	0	0	14	.09
03322100	323	1962-73	0	5.5	.017	53	.16
03375800	21.8	1971-73	0	.2	.0092	6.5	.30
03376260	21.3	1965-73	0	.05	.0023	3.5	.16
03376350	42.8	1965-73	.5	5.6	.13	19	.44

For the 90-percent flow duration, the range in streamflow between gages (exclusive of station 03376350) is from 0 to 0.017 (ft^3/s)/mi^2 (table 7). Similarly, the unit-area yield for the 50-percent flow duration (median flow) ranges from 0.09 to 0.30 (ft^3/s)/mi^2. This latter range is narrow considering the variable and noncontinuous geology in southwestern Indiana.

Mean average monthly flows for the period of record at five selected gaging stations are plotted both as a unit area yield (cubic foot per second per square mile) and as a percent of average annual flow (fig. 15). A generalized yearly runoff trend is evident--extremely low streamflows in the summer and early autumn followed by a gradual increase in monthly flows through March and April, when maximum average flows are recorded. These months of peak flows are then followed by a rapid transition to the summer and early autumn lowflow period. Some of the streams complete this low-flow phase within 2 months. Because the generalized annual flow pattern seems to be consistent for all nearby gages and variability among the stations is small, the authors assumed that this pattern is representative of seasonal streamflow changes for the study basin.

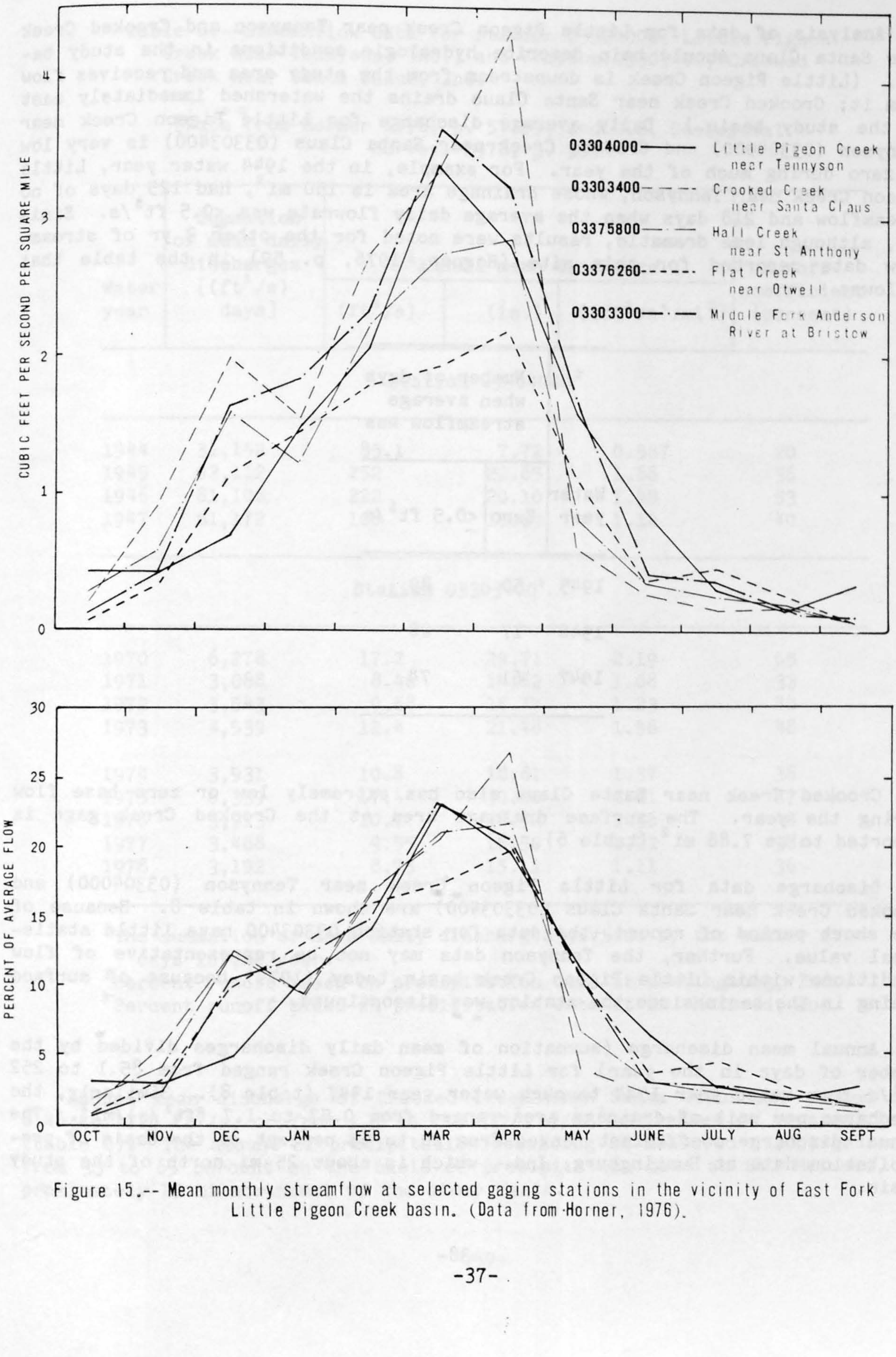


Figure 15.-- Mean monthly streamflow at selected gaging stations in the vicinity of East Fork Little Pigeon Creek basin. (Data from Horner, 1976).

Analysis of data for Little Pigeon Creek near Tennyson and Crooked Creek near Santa Claus should help describe hydrologic conditions in the study basin. (Little Pigeon Creek is downstream from the study area and receives flow from it; Crooked Creek near Santa Claus drains the watershed immediately east of the study basin.) Daily average discharge for Little Pigeon Creek near Tennyson (03304000) and Crooked Creek near Santa Claus (03303400) is very low or zero during much of the year. For example, in the 1944 water year, Little Pigeon Creek near Tennyson, whose drainage area is 150 mi^2, had 125 days of no streamflow and 218 days when the average daily flowrate was $\leq 0.5\ ft^3/s$. Similar, although less dramatic, results were noted for the other 3 yr of streamflow data reported for this site (Horner, 1976, p. 59) in the table that follows:

Water year	Number of days when average streamflow was: Zero	$\leq 0.5\ ft^3/s$
1945	50	89
1946	17	28
1947	61	74

Crooked Creek near Santa Claus also has extremely low or zero base flow during the year. The surface drainage area at the Crooked Creek gage is reported to be 7.86 mi^2 (table 6).

Discharge data for Little Pigeon Creek near Tennyson (03304000) and Crooked Creek near Santa Claus (03303400) are shown in table 8. Because of the short period of record, the data for station 03303400 have little statistical value. Further, the Tennyson data may not be representative of flow conditions within Little Pigeon Creek basin today (1979) because of surface mining in the basin since the station was discontinued.

Annual mean discharge (summation of mean daily discharges divided by the number of days in the year) for Little Pigeon Creek ranged from 85.1 to 252 ft^3/s from water year 1944 through water year 1947 (table 8). Similarly, the discharge per unit of drainage area ranged from 0.57 to 1.7 $(ft^3/s)/mi^2$. The annual discharge coefficient ranged from 20 to 53 percent on the basis of precipitation data at Huntingburg, Ind., which is about 25 mi north of the study basin.

Table 8.--Streamflow data for station 03304000, Little Pigeon Creek near Tennyson, Ind., and station 03303400, Crooked Creek near Santa Claus, Ind.

[Data from Horner 1976, p. 57-59, and U.S. Geological Survey, 1978, p. 58]

Water year	Summation of mean daily discharges [(ft³/s) days]	[1] Annual mean discharge (ft³/s)	(in.)	[(ft³/s)/mi²]	Runoff coefficient (percent)
		Station 03304000[2]			
1944	31,152	85.1	7.72	0.567	20
1945	92,112	252	22.85	1.68	36
1946	81,106	222	20.10	1.48	53
1947	61,172	168	15.69	1.12	40
		Station 03303400[3]			
1970	6,278	17.2	29.71	2.19	65
1971	3,088	8.46	14.62	1.08	33
1972	3,543	9.68	16.77	1.23	40
1973	4,539	12.4	21.48	1.58	48
1974	3,931	10.8	18.61	1.37	36
1975	6,339	17.4	30.00	2.21	57
1976	3,913	10.7	18.52	1.36	44
1977	3,488	9.55	16.50	1.22	38
1978	3,192	8.75	15.11	1.11	36

[1]The summation of mean daily discharges divided by the number of days in the year.
[2]Percent runoff based on precipitation data at Huntingburg, Ind.
[3]Percent runoff based on precipitation data at St. Meinrad, Ind.

Annual mean discharge of Crooked Creek near Santa Claus has ranged from 8.46 to 17.4 ft^3/s, or from 1.1 to 2.2 $(ft^3/s)/mi^2$ expressed on an areal basis (table 8). The amount of precipitation resulting in measured discharge ranged from 33 to 65 percent on the basis of precipitation data at St. Meinrad, approximately 15 mi northeast of the study basin.

Monthly streamflow data for the gages near Tennyson and Santa Claus are presented in table 9. The average monthly flow rates are commonly within a magnitude of 10 to 100 fold. This can be seen more clearly in figure 16, which illustrates the variability in average monthly flows of Crooked Creek near the Santa Claus gaging station. As shown, the range in average monthly flow is greatest during the months from July to October. On the average, 78 percent of the total runoff is recorded between the months of December and April.

Assuming that the areal flow statistics for the Santa Claus gage were applicable to the study basin, the authors synthesized average monthly streamflow data for two sampling sites in the study basin after determining each site's drainage area. Streamflow information was calculated for site 9, which is on East Fork Little Pigeon Creek just downstream from the permit area, and site 18, which is the next-to-last sampling site on the creek (fig. 17) and the last station unaffected by backwater from Little Pigeon Creek. The synthesized data are presented in table 10.

Duration curves were also prepared for the gages near Tennyson and Santa Claus, although the authors recognize that the information for the Tennyson gage may have but little applicability to current conditions in East Fork Little Pigeon Creek. This information is presented in figure 18, in cubic feet per second, and in figure 19 on a unit surface drainage, in cubic feet per second per square mile. Plotted in the two illustrations are the percents of time that the indicated average daily streamflows were equaled or exceeded. The flow duration curve (fig. 18) for Little Pigeon Creek lies above that for Crooked Creek, primarily owing to the larger surface drainage area for the gage near Tennyson. The duration curves align much more closely when the streamflow data are expressed as per unit drainage area (fig. 19). For the Crooked Creek duration curve, the following discharges are indicated:

Flow duration (percent)	Average daily discharge [$(ft^3/s)/mi^2$]
90	0
80	.009
70	.035
60	.12
50	.25
40	.43
30	.75
20	1.4
10	2.5
5	5.9
1	20

These flow statistics are assumed to be representative of the study basin. Using this information and measured drainage areas for sites 9 and 18 in the study basin, the authors synthesized average daily flow duration data (table 11).

Table 9.--Average monthly discharge for station 03304000, Little Pigeon Creek near Tennyson, Ind., water years 1944-47, and for station 03303400, Crooked Creek near Santa Claus, Ind., water years 1970-73

[Data from Horner, 1976, p. 59, and U.S. Geological Survey, 1978, p. 58]

	Average monthly discharge					
	Mean				Range	
Month	(ft /s)	[(ft^3/s)/ mi^2]	(in.)	Percent[1]	(ft^3/s)	(in.)
	Station 03304000					
October	65.8	0.439	0.50	3.00	0-259	0.00-1.99
November	62.6	.417	.46	2.86	.023-210	.00-1.56
December	105.7	.705	.81	4.82	.01-231	.00-1.77
January	223.2	1.488	1.72	10.16	2.7-496	.02-3.81
February	306.7	2.045	2.13	13.99	16.5-661	.12-4.59
March	503.7	3.358	3.87	22.97	103-1,398	.79-10.74
April	421.9	2.813	3.14	19.24	34-645	.25-4.80
May	238.9	1.593	1.78	10.89	80.2-565	.62-4.34
June	132.7	.885	.99	6.05	.297-239	.00-1.78
July	49.9	.333	.38	2.28	.329-139	.00-1.07
August	29.4	.196	.36	1.34	5.74-87.7	.04-.67
September	52.1	.347	.39	2.38	.03-197	.00-1.47
	Station 03303400					
October	2.56	.325	.36	1.82	.034-9.36	.00-1.33
November	10.30	1.310	1.46	7.32	.53-20.0	.08-2.84
December	15.47	1.968	2.20	11.00	.51-28.1	.07-3.99
January	14.96	1.903	2.12	10.63	.058-31.6	.01-4.49
February	21.13	2.688	3.00	14.99	3.20-46.9	.45-6.66
March	29.05	3.696	4.12	20.67	6.55-51.0	.93-7.37
April	28.69	3.650	4.07	20.40	2.27-90.8	.32-12.89
May	6.89	.876	.98	4.91	2.44-20.2	.35-2.87
June	4.63	.589	.66	3.30	.079-16.9	.01-2.40
July	1.34	.170	.19	.95	.001-3.21	.00-.46
August	3.80	.483	.54	2.70	.002-19.4	.00-2.76
September	1.83	.233	.26	1.30	.00-6.28	.00-.87

[1]Percent of average flow. This is the ratio of the mean monthly flow to the mean annual flow. The ratio is computed for the total length of record at each station (Horner, 1976, p. 3).

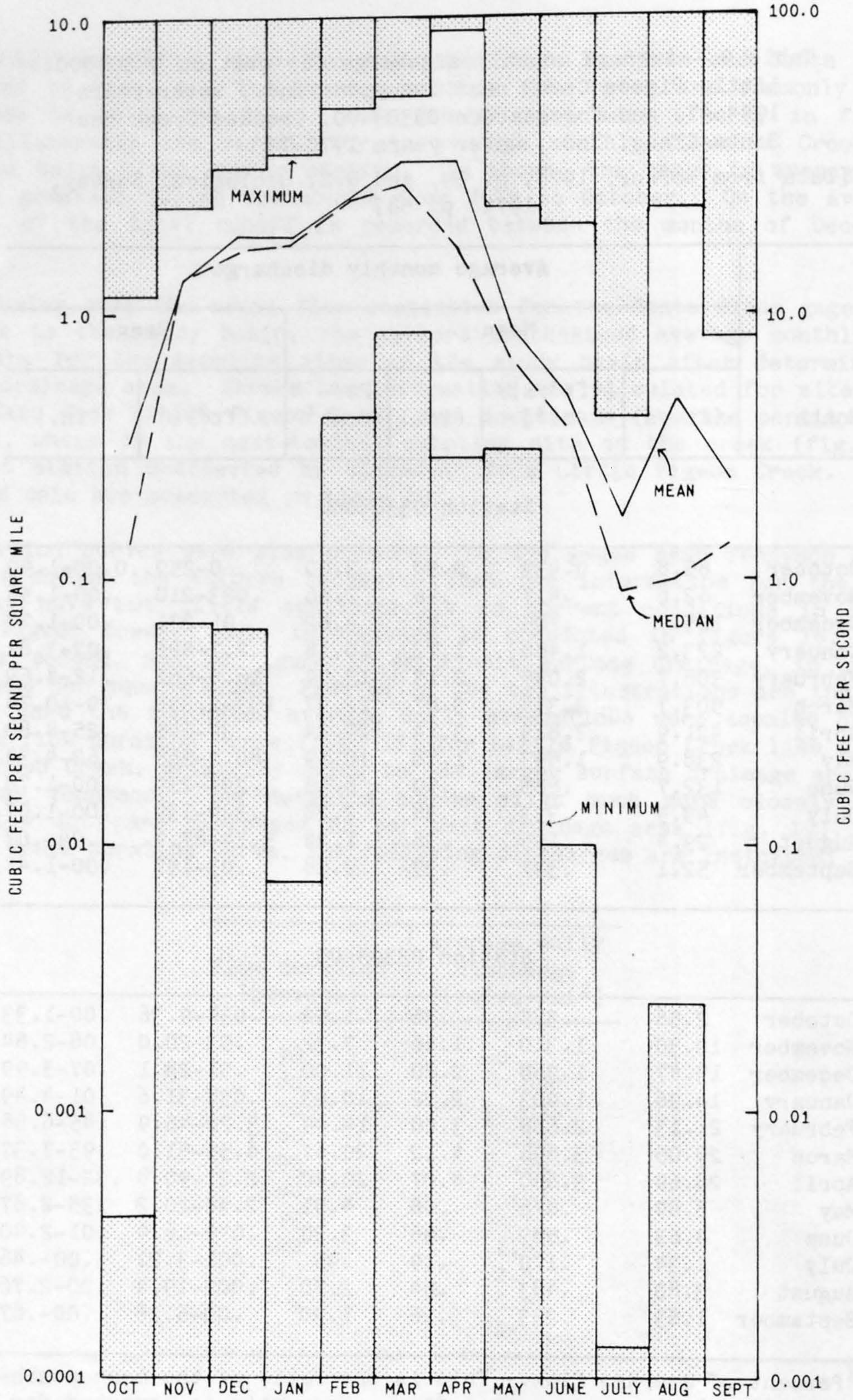


Figure 16. -- Monthly streamflow at gaging station 03303400, water years 1970-73, Crooked Creek near Santa Claus, Ind. (Data from Horner, 1976, p. 57)

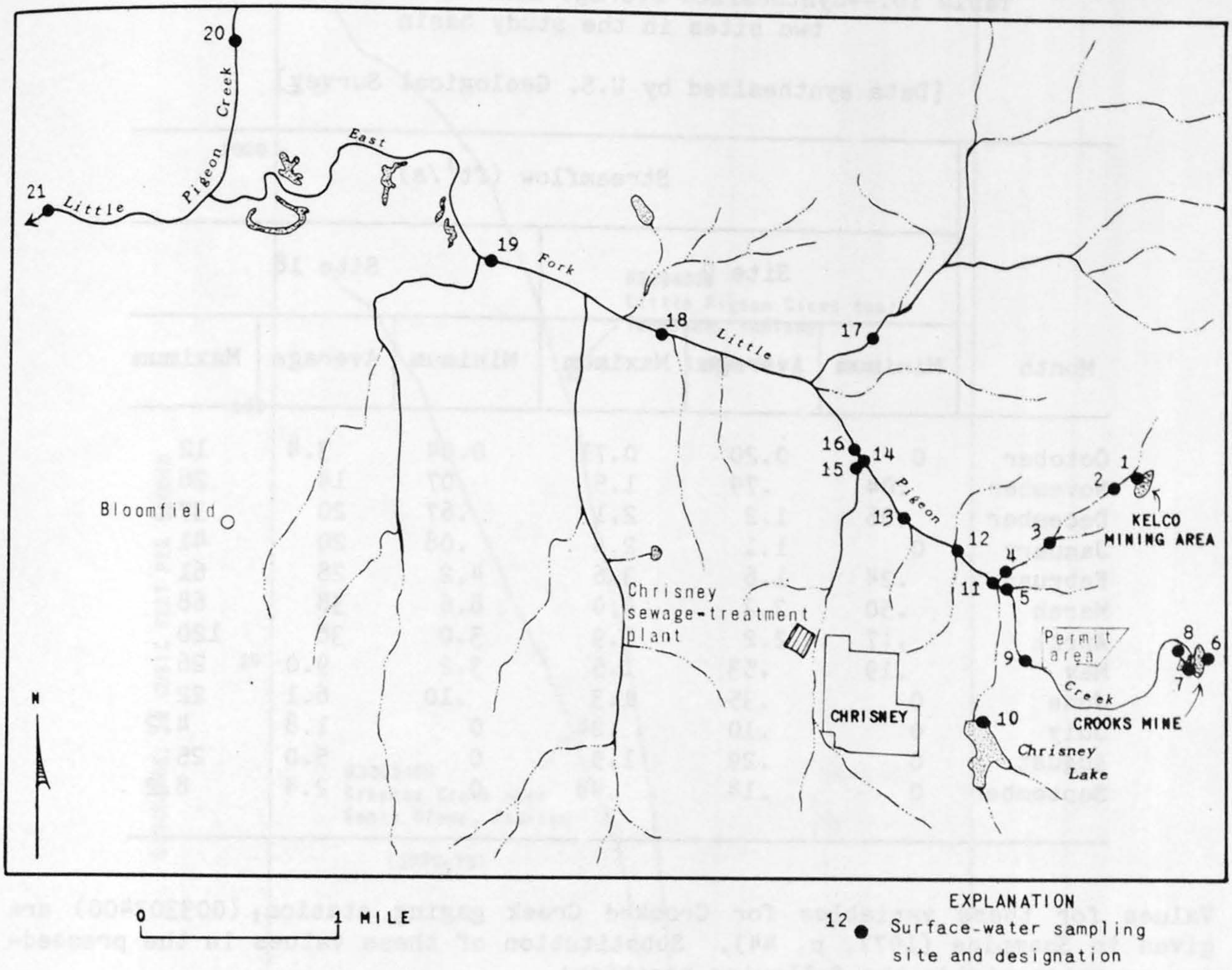


Figure 17.-- Surface-water sampling sites in the vicinity of Chrisney, Ind.

Surface-Water Quality

No surface-water-quality data are available for the study basin; thus, stream temperature, air temperature, and sediment data from nearby sampling stations were used as follows:

Air and Water Temperatures.--The source of stream-temperature data nearest the study basin is at the Crooked Creek gaging station (03303400) near Santa Claus, where the stream temperature is measured periodically. A harmonic function that describes the annual variation of water temperature at this gaging station has been reported (Shampine, 1977, p. 13):

$$T = A [\sin (0.0172x + C)] + M$$

where T is stream temperature on a given day, in degrees Celsius; M is mean annual stream temperature, in degrees Celsius; A is stream-temperature amplitude, in degrees Celsius; x is Julian date; and C is phase-angle coefficient.

Table 10.--Synthesized average monthly streamflow for two sites in the study basin

[Data synthesized by U.S. Geological Survey]

Month	Streamflow (ft^3/s)					
	Site 9			Site 18		
	Minimum	Average	Maximum	Minimum	Average	Maximum
October	0	0.20	0.71	0.04	3.4	12
November	.04	.79	1.5	.07	14	26
December	.06	1.2	2.1	.67	20	37
January	0	1.1	2.4	.08	20	41
February	.24	1.6	3.6	4.2	28	61
March	.50	2.2	4.0	8.6	38	68
April	.17	2.2	6.9	3.0	38	120
May	.19	.53	1.5	3.2	9.0	26
June	0	.35	1.3	.10	6.1	22
July	0	.10	.24	0	1.8	4.2
August	0	.29	1.5	0	5.0	25
September	0	.14	.48	0	2.4	8.2

Values for these variables for Crooked Creek gaging station (003303400) are given in Shampine (1977, p. 44). Substitution of these values in the preceeding equation yields the following equation:

$$T(x) = 11.63 [\sin (0.0172x + 4.35)] + 14.68$$

where T(x) is the temperature in degrees Celsius on day x of the water year (x = 1 for October 1, x = 31 for October 31, x = 365 for September 30, and so forth). Instantaneous water-temperature readings at station 03303400 are illustrated in figure 20, along with the harmonic function give above. Water temperatures shown in figure 20 are considered to be typical in Spencer County and were applied to the study basin. Synthesized average monthly air and stream temperatures for the study basin are shown in table 12.

Suspended Solids.--The location nearest the study basin where suspended sediment data are collected is 20 mi east of the basin at the Geological Survey gage on Middle Fork Anderson River, at Bristow, Ind. The stream at this gage has a drainage area of 41.9 mi^2. Instantaneous suspended-sediment data were periodically collected at this site, and 84 sediment analyses were made during the calendar years 1965-76 (unpublished Geological Survey data). The average annual suspended-sediment discharge at the Bristow gage was reported to be 122 (tons/yr)/mi^2 (Johnson, 1971). Further, the bedload was reported to be minimal in comparison to the suspended load (Johnson, 1971).

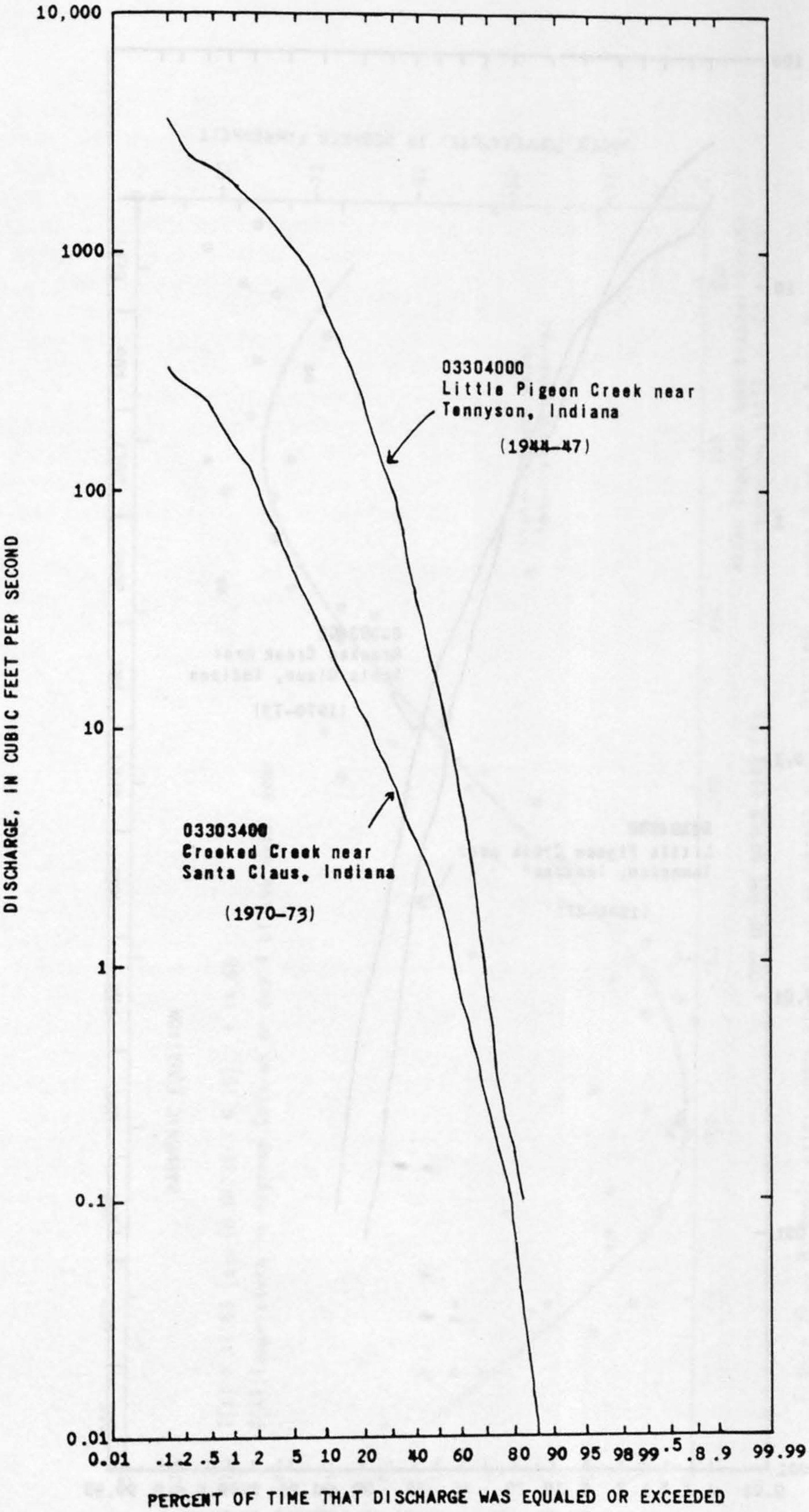


Figure 18.-- Duration curves of mean daily discharge
(data from Horner, 1976).

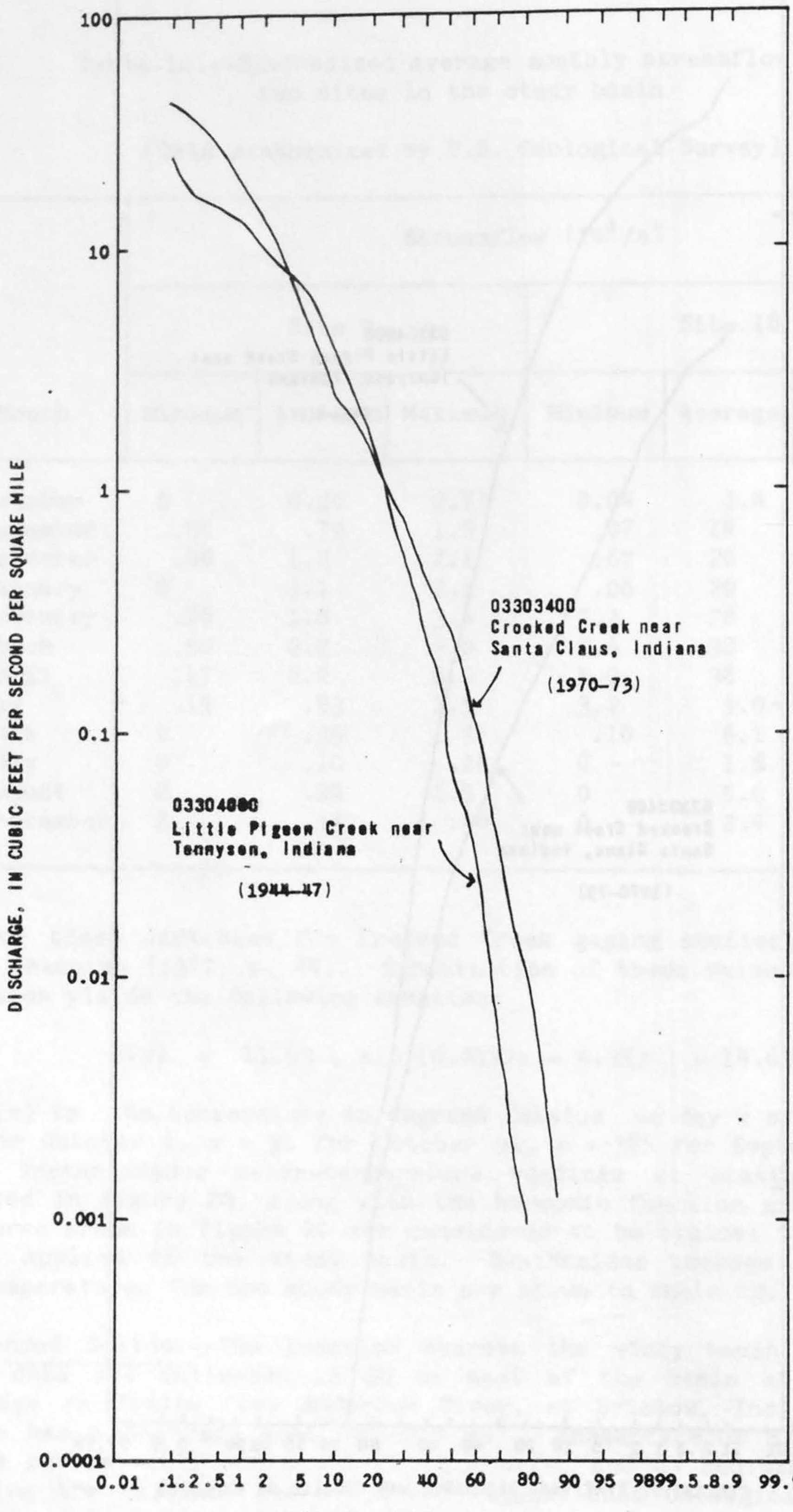


Figure 19.-- Duration curves of mean daily discharge per unit area (data from Horner, 1976).

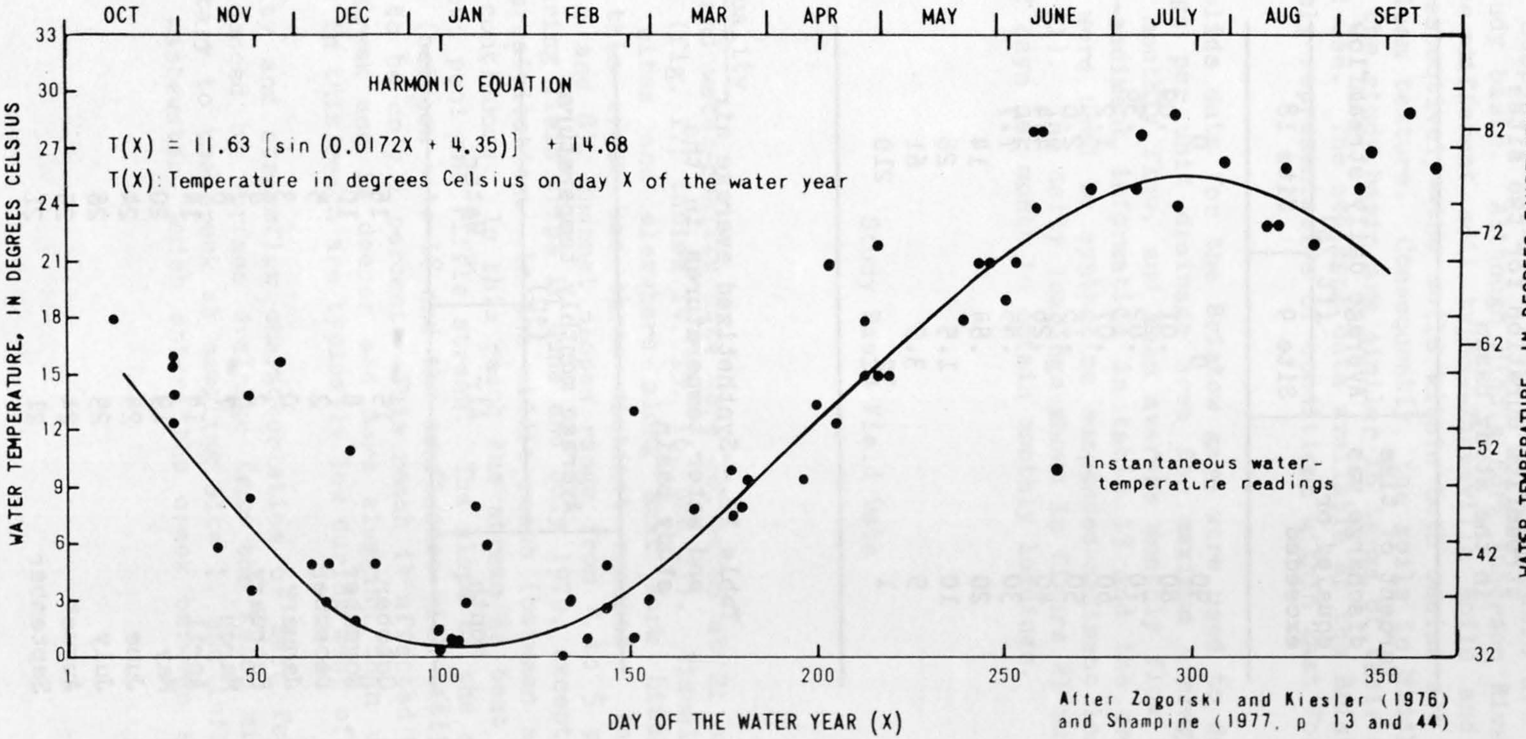


Figure 20.-- Harmonic water-temperature curve at gaging station 03303400, Crooked Creek near Santa Claus, Ind.

Table 11.--Synthesized average daily streamflow duration for two sites in the study basin

Percent of time discharge was equaled or exceeded	Average daily streamflow (ft^3/s)	
	Site 9	Site 18
90	0	0
80	.01	.09
70	.02	.36
60	.07	1.2
50	.15	2.6
40	.26	4.4
30	.45	7.7
20	.84	14
10	1.5	26
5	3.5	61
1	12	210

Table 12.--Synthetized average air and water temperatures in the study basin

Month	Average monthly temperature (°C)	
	Air	Water
October	15	16
November	8	10
December	2	5
January	0	3
February	2	4
March	7	8
April	14	14
May	19	20
June	24	24
July	25	26
August	24	25
September	21	21

Soil information for the drainage basin of the Bristow gage was reviewed to determine if suspended-sediment data from this basin are comparable with those of the study basin. Although Middle Fork Anderson River basin and the study basin have different soil types--Zanesville soils and Zanesville and Hosmer soils, respectively--the soils within both basins are highly erodible and of a silty loam texture. Consequently, the soils in Middle Fork Anderson River basin and the study basin are similar in terms of their series, texture, erodibility, and use. The sediment data available at the Bristow gage, therefore, are probably representative of conditions within East Fork Little Pigeon Creek basin.

Suspended-solids data for the Bristow gage were used to develop suspended sediment loadings per unit drainage area for maximum average monthly flow, minimum average monthly flow, and mean average monthly flow (table 13). The areal suspended-sediment information in table 13 and the drainage area for sites 9 and 18 were used to synthesize suspended-sediment loadings for these two sites (fig. 21). The daily loadings shown in figure 21 must be multiplied by the number of days per month to obtain monthly loadings.

Study Basin Field Data

Surface-Water Quality

Hydrologic and water-quality data were collected at 21 sampling sites in the study basin (fig. 17; tables 14, 15, 16, and 17). Visual observations at these sampling sites and elsewhere along East Fork Little Pigeon Creek revealed that this creek has three distinct reaches. In the headwaters (between sites 5 and 8), channel slopes range from 4 to 5 percent. No flow was observed during field trips in June and July 1979, except during or immediately after precipitation. In the middle reach (between sites 11 and 18), streamflow was continuous. In this reach the stream is best characterized as a small, shallow, pool and riffle stream. The slope of the stream channel in the lower reach (between site 18 and the confluence with Little Pigeon Creek) was calculated to be only 1 percent. This reach is affected by backwater from Little Pigeon Creek and is deeper and more sluggish than upstream reaches. Flow velocities in this reach are typically low during most of the year.

Water-quality and streamflow characteristics of East Fork Little Pigeon Creek are influenced by surface drainage from the Kelco mining area, which enters a tributary to the creek at sampling site 1, and inflow of Chrisney's partly treated wastewater, which enters the creek between sampling sites 14 and 16.

Table 13.--Summary of suspended-sediment load data for station 03303300, Middle Fork Anderson River near Bristow, Ind., water years 1961-78

[Unpublished Geological Survey data]

Month	Average suspended-sediment load (tons/mi^2)		
	For minimum flow	For mean flow	For maximum flow
October	0	0.50	1.92
November	.21	2.28	6.60
December	.33	6.02	12.4
January	1.52	6.66	15.2
February	2.74	6.44	15.3
March	3.72	8.37	15.5
April	3.75	10.6	22.5
May	4.18	5.61	13.3
June	.22	1.98	5.70
July	0	1.15	8.06
August	0	.71	2.82
September	0	.81	3.75
Total for year	16.7	51.1	123.0

Discharges measured in and near the study basin during field trips in June and July 1979 are listed in table 15, and field analyses of surface water done during the field trips are listed in table 16. Profiles of streamflow and profiles and measurements of chemical constituents and properties made along East Fork Little Pigeon Creek during the two field trips are given in figure 22 and in figures 23 and 24, respectively. There was no flow in the headwaters of East Fork Little Pigeon Creek (at and above site 5) or any of its tributaries during either field visit, except for the unnamed tributary draining the Kelco mining area and the unnamed tributary into which Chrisney's watewater is discharged. Many of the tributaries were dry or nearly dry. All the observed flow upstream from site 12 (figs. 17 and 22) originated in the Kelco mining area because several large standing bodies of water at the mining site discharge into a tributary draining the area.

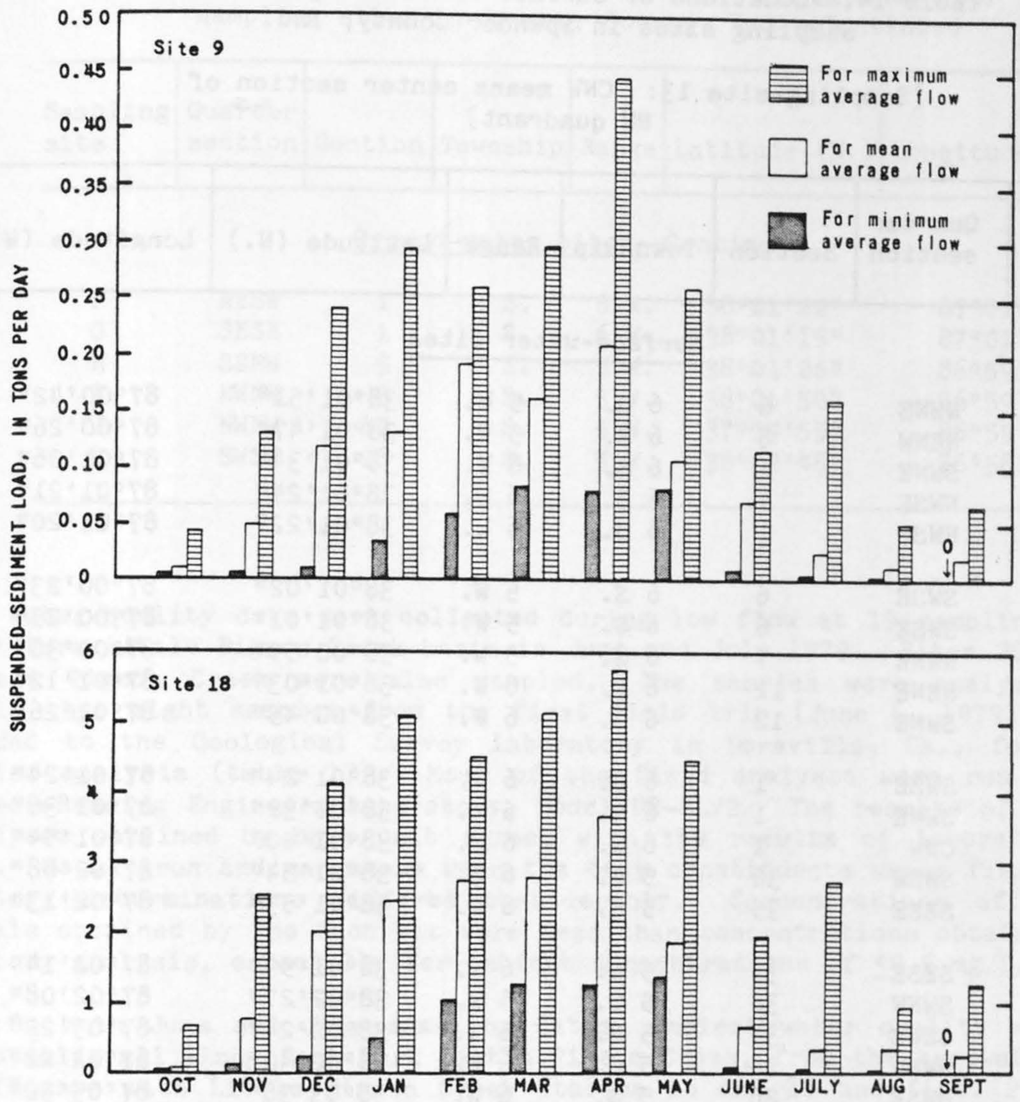


Figure 21.-- Synthesized suspended-sediment loads at sampling sites 9 and 18 on East Fork Little Pigeon Creek.

Streamflow decreased downstream from the Kelco mining area, especially along the unnamed tributary between sampling sites 2 and 4 (fig. 22). Water loss into the tributary's alluvial deposits is probably the primary cause for the decreasing streamflow pattern, but surface evaporation may also have caused the observed trend, especially in the reach between sites 12 and 14, where minimal tree and brush cover and high air and water temperatures were evident.

Streamflow from Chrisney's sewage-treatment plant enters East Fork Little Pigeon Creek between sampling sites 14 and 16 and adds about 0.1 ft^3/s to the creek's flowrate. Streamflow of East Fork Little Pigeon Creek decreases downstream from the sewage-treatment plant inflow, probably owing to surface evaporation and water loss into alluvial deposits.

Table 14.--Locations of surface-water and ground-water sampling sites in Spencer County, Ind.

[Sampling-site 13: CNW means center section of NW quadrant]

Sampling site	Quarter section	Section	Township	Range	Latitude (N.)	Longitude (W.)
Surface-water sites						
1	NWNE	6	6 S.	5 W.	38°01'51"	87°00'42"
2	NENW	6	6 S.	5 W.	38°01'47"	87°00'26"
3	SWNE	1	6 S.	6 W.	38°01'34"	87°01'06"
4	NWSE	1	6 S.	6 W.	38°01'24"	87°01'21"
5	NWSE	1	6 S.	6 W.	38°01'22"	87°01'20"
6	SWSE	6	6 S.	5 W.	38°01'02"	87°00'23"
7	SWSE	6	6 S.	5 W.	38°01'01"	87°00'25"
8	NWNE	7	6 S.	5 W.	38°00'59"	87°00'30"
9	NENE	12	6 S.	6 W.	38°01'03"	87°01'12"
10	SWNE	12	6 S.	6 W.	38°00'45"	87°01'26"
11	SWSE	1	6 S.	6 W.	38°01'24"	87°01'24"
12	SWNE	1	6 S.	6 W.	38°01'32"	87°01'36"
13	CNW	1	6 S.	6 W.	38°01'40"	87°01'54"
14	SWSW	36	5 S.	6 W.	38°01'54"	87°02'08"
15	SESE	35	5 S.	6 W.	38°01'53"	87°02'13"
16	SESE	35	5 S.	6 W.	38°01'59"	87°02'14"
17	SWNW	36	5 S.	6 W.	38°02'27"	87°02'08"
18	SENE	34	5 S.	6 W.	38°02'24"	87°03'22"
19	NWNW	34	5 S.	6 W.	38°02'40"	87°04'22"
20	SWSE	20	5 S.	6 W.	38°03'38"	87°05'50"
21	NWNE	31	5 S.	6 W.	38°02'43"	87°07'08"
22	SESE	28	5 S.	5 W.	38°02'48"	86°57'46"
23	NWNE	32	5 S.	5 W.	38°02'44"	86°59'06"
24	NWNE	32	5 S.	5 W.	38°02'44"	86°59'06"
25	NWNE	32	5 S.	5 W.	38°02'45"	86°59'04"
26	NENE	32	5 S.	5 W.	38°02'48"	86°58'43"
27	SWSW	28	5 S.	5 W.	38°02'46"	86°58'42"
Ground-water sites						
A	NENE	9	6 S.	6 W.	38°01'00"	87°04'26"
B	SWNE	3	6 S.	6 W.	38°01'34"	87°06'02"
C	SWSW	26	5 S.	6 W.	38°02'55"	87°03'14"
D	SESW	35	5 S.	6 W.	38°01'54"	87°02'48"
E	SWSE	36	5 S.	6 W.	38°01'53"	87°01'34"

Table 14.--Locations of surface-water and ground-water sampling sites in Spencer County, Ind.--Continued

Sampling site	Quarter section	Section	Township	Range	Latitude (N.)	Longitude (W.)
			Ground-water sites--Continued			
F	NESW	1	6 S.	6 W.	38°01'22"	87°01'41"
G	SESE	1	6 S.	6 W.	38°01'15"	87°01'04"
H	SENW	5	6 S.	5 W.	38°01'26"	86°59'26"
I	NWNW	5	6 S.	5 W.	38°01'50"	86°59'26"
J	NWNW	17	6 S.	5 W.	37°59'55"	86°59'49"
K	SWSW	28	5 S.	5 W.	38°02'46"	86°58'42"

Water-quality data were collected during low flow at 19 sampling sites in East Fork Little Pigeon Creek basin in June and July 1979. Sites 20 and 21 on Little Pigeon Creek were also sampled. The samples were analyzed in the field, but eight samples from the first field trip (June 6, 1979) were forwarded to the Geological Survey laboratory in Doraville, Ga., for more-detailed analysis (table 17). Most of the field analyses were run on a Hach Direct-Reading Engineers Laboratory, Model DR-EL/2. The results of most field analyses obtained by this unit agreed with the results of laboratory analyses. Total iron and manganese were the only constituents whose field and laboratory determinations differed considerably. Concentrations of these two metals obtained by the Hach kit were less than concentrations obtained by laboratory analysis, especially for ambient concentrations of $\leq$0.5 mg/L.

On both June and July sampling dates, ambient water quality varied substantially all along East Fork Little Pigeon Creek, from the headwaters to its confluence with Little Pigeon Creek (tables 16 and 17 and figs. 23 and 24). Water quality in East Fork Little Pigeon Creek was influenced by three major factors: (a) inflow from the Kelco mining area, (b) inflow from the sewage-treatment plant at Chrisney, and (c) backwater from Little Pigeon Creek.

Of the samples forwarded to the Geological Survey laboratory for analysis, sampling site 5 is the only station (fig. 25) that can be considered to be unaffected by mining. The cation-anion concentration of water at this site was approximately one-fifth that of the water leaving the Kelco mine area (sampling site 1). The major chemical constituents of the standing water sampled at site 5 were calcium, magnesium, sodium, and sulfate.

The remaining sampling sites in figure 25 illustrate the changes in proportion of the major cations and anions as water flows from the Kelco mining area (site 1) to the confluence with the headwaters of East Fork Little Pigeon Creek and, subsequently, as the creek flows to its confluence with Little Pigeon Creek. Several conclusions can be drawn from these data. First the

Table 15.--Discharge measurements within the study basin and adjoining basins

[Discharge measured by U.S. Geological Survey]

Sampling site	Date	Time	Discharge (ft^3/s)	Sampling site	Date	Time	Discharge (ft^3/s)
East Fork Little Pigeon Creek and tributaries							
2	7-18-79	[1]1715	0.09	14	6-7-79	1330	0.07
3	7-18-79	1700	.05		7-18-79	1400	.03
4	7-18-79	1530	.04	15	7-18-79	1330	.09
5	6-7-79	1245	NF	16	6-7-79	1400	.16
	7-18-79	1500	NF		7-18-79	1300	.14
9	6-7-79	1300	NF	17	6-7-79	1430	NF
	7-18-79	1415	NF		7-18-79	1200	NF
12	6-7-79	1310	.09	18	6-7-79	1445	.14
	7-18-79	1430	.04		7-18-79	1130	.10
Little Pigeon Creek							
21	7-18-79	1000	900E				
Sandy Creek and tributaries							
22	6-7-79	1200	.31	23	7-18-79	1830	.07E
	7-18-79	1900	.29E	24	7-18-79	1845	.05E

[1]The number 1715 is equivalent to 5:15 p.m.

relative proportions of major chemical constituents (calcium, magnesium, sodium, and sulfate) along the length of the creek are almost constant. Second, there is a gradual decrease in the number of total milliequivalents between stations 1 and 12, whereas there is a marked decrease in the number between sites 12 and 14. The cause of this trend is not known, but the trend supports field data in which concentrations of most constituents decreased along the unnamed tributary carrying the drainage from the Kelco mine and along the middle reach of East Fork Little Pigeon Creek. Third, analyses of samples collected upstream (site 14) and downstream (site 16) from the sewage-treatment-plant inflow show that flow from the sewage-treatment plant at Chrisney increased the concentrations of cations and anions in the creek on June 6, 1979. Lastly, the total amount of cations and anions at sampling site 16 was more than double that at site 19. This change is probably at least partly due to effects of backwater from Little Pigeon Creek.

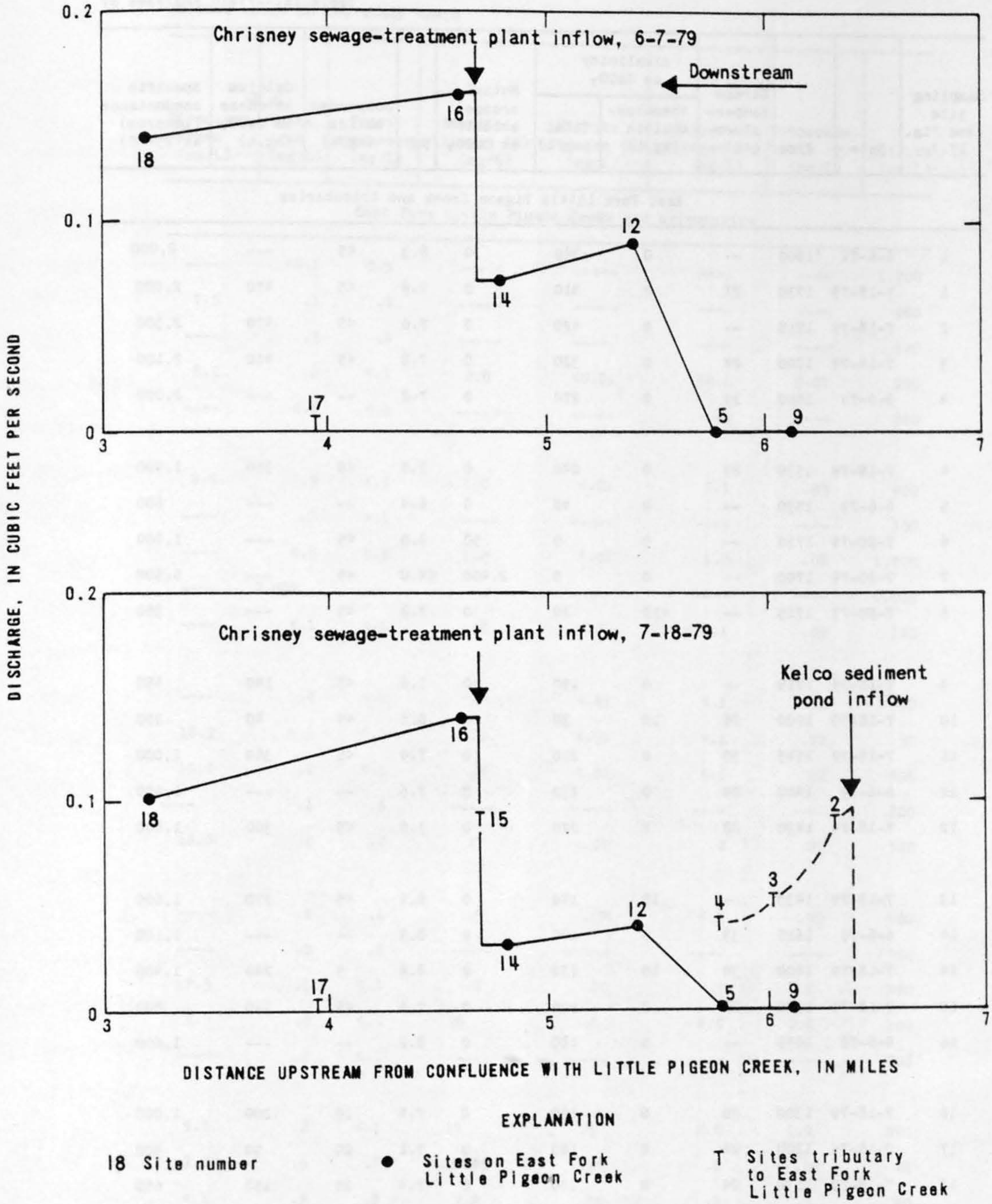


Figure 22.-- Streamflow profiles and measurements along East Fork Little Pigeon Creek and tributaries.

Table 16.--Field analyses of

Sampling site (See fig. 17.)	Date	Time	Stream temperature (°C)	Alkalinity as $CaCO_3$: Phenolphthalein (mg/L)	Alkalinity as $CaCO_3$: Total (mg/L)	Methyl-orange acidity as $CaCO_3$	pH	Suspended solids (mg/L)	Calcium hardness as $CaCO_3$ (mg/L)	Specific conductance (µmho/cm) at 25° C)
East Fork Little Pigeon Creek and tributaries										
1	6-6-79	[1]1800	--	0	380	0	6.3	<5	---	2,000
1	7-18-79	1730	27	0	410	0	7.8	<5	470	2,000
2	7-18-79	1715	--	0	420	0	7.6	<5	470	2,300
3	7-18-79	1700	24	0	320	0	7.8	<5	410	2,100
4	6-6-79	1500	29	0	270	0	7.8	--	---	2,000
4	7-18-79	1530	29	0	240	0	7.8	<5	350	1,900
5	6-6-79	1530	--	0	40	0	6.4	--	---	600
6	7-20-79	1730	--	0	0	50	4.0	<5	---	1,800
7	7-20-79	1700	--	0	0	2,400	<4.0	<5	---	5,500
8	7-20-79	1715	--	<10	20	0	7.8	<5	---	350
9	7-18-79	1415	--	0	150	0	7.6	<5	140	450
10	7-18-79	1700	28	10	30	0	8.8	<5	40	200
11	7-18-79	1545	30	0	220	0	7.9	<5	360	2,000
12	6-6-79	1400	24	0	230	0	7.6	--	---	1,900
12	7-18-79	1430	28	0	220	0	7.6	<5	300	1,800
13	7-18-79	1430	--	10	170	0	8.6	<5	270	1,600
14	6-6-79	1615	33	0	140	0	8.3	--	---	1,100
14	7-18-79	1400	30	10	130	0	8.8	5	240	1,400
15	7-18-79	1330	28	0	150	0	7.6	<5	140	800
16	6-6-79	1645	--	0	180	0	8.2	--	---	1,600
16	7-18-79	1300	30	0	160	0	7.5	10	200	1,000
17	7-18-79	1200	24	0	100	0	7.1	20	90	400
18	7-18-79	1130	24	0	140	0	7.4	20	150	650
19	6-6-79	1730	21	0	130	0	7.2	--	---	700
19	7-18-79	1030	22	0	80	0	7.0	30	70	300
Little Pigeon Creek										
20	7-18-79	0930	22	0	40	0	6.5	5	80	300
21	7-18-79	1000	23	0	40	0	6.7	20	70	300

[1]The number 1800 is equivalent to 6:00 p.m.

surface water in the study basin

Dissolved oxygen (mg/L)	Total iron (mg/L)	Total manganese (mg/L)	Ammonia nitrogen (N) (mg/L)	Nitrite nitrogen (N) (mg/L)	Nitrate nitrogen (N) (mg/L)	Orthophosphate (P) (mg/L)	Sulfate (mg/L)
East Fork Little Pigeon Creek and tributaries							
----	<0.1	0.5	-----	-----	----	----	1,200
7.5	.1	.4	-----	-----	----	----	980
----	.3	.4	-----	-----	----	----	920
8.3	.2	<.1	2.0	<0.01	<0.1	0.07	900
----	<.1	<.1	-----	-----	----	----	800
9.5	.3	<.1	1.0	<.01	<.1	.03	900
----	.1	<.1	-----	-----	----	----	180
----	4.0	4.2	1.2	<.01	1.0	.08	1,000
----	2,000	---	-----	-----	----	----	6,000
----	<.1	<.1	.2	<.01	<.1	.02	120
	.4	<.1	.4	<.01	<.1	.01	60
10.3	<.1	<.1	.2	<.01	<.1	.02	30
10.4	.1	<.1	.9	<.01	<.1	.02	800
----	.1	.6	-----	-----	----	----	800
16.8	.1	.2	.7	<.01	.2	.03	700
----	.1	.1	.5	.02	<.1	.03	680
----	.2	.8	-----	-----	----	----	320
17.3	.1	<.1	.5	.05	.2	.1	480
4.3	.2	<.1	30	.6	4.5	2.6	100
----	.1	<.1	-----	-----	----	----	700
9.5	.2	<.1	16	.5	2.8	1.9	240
3.7	.6	.5	<.05	.04	.8	.07	40
4.1	.6	.6	5.2	.06	.7	.3	90
----	.2	1.9	------	-----	----	----	160
1.6	.9	<.1	1.6	.05	.8	.3	40
Little Pigeon Creek							
4.5	.7	.2	.7	.04	2.0	.2	70
4.5	.8	.3	.7	.04	3.0	.1	60

Table 17.--Laboratory analyses of surface-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.

[Analyses by U.S. Geological Survey]

Sampling site 1

Parameter	Units of measure	Measure-ment	Parameter	Units of measure	Measure-ment
Acidity, as H^+	mg/L	0.0	pH, lab		8.0
Acidity, tot. as $CaCO_3$	mg/L	0	Phosphorus, diss. as P	mg/L	0.01
Alk, tot. as $CaCO_3$	mg/L	380	Potassium, diss.	mg/L	9.4
Aluminum, diss.	µg/L	10	Diss. solids,		
Aluminum, susp.	µg/L	100	residue at 105° C	mg/L	2,000
Aluminum, tot.	µg/L	110	Tot. solids,		
Calcium, diss.	mg/L	190	residue at 105° C	mg/L	2,020
Chloride, diss.	mg/L	4.8	Susp. solids	mg/L	54
Fluoride, diss.	mg/L	0.3	SAR		2.7
Hardness, noncarb.	mg/L	630	Silica, diss.	mg/L	4.5
Hardness, tot. as $CaCO_3$	mg/L	1,000	Sodium, diss.	mg/L	200
Iron, diss.	µg/L	20	Sodium,	percent	30
Iron, susp.	µg/L	940	Spec. conduc., field	µmho/cm	
Iron, tot.	µg/L	960		at 25° C	2,000
Magnesium, diss.	mg/L	130	Spec. conduc., lab.	µmho/cm	
Manganese, diss.	µg/L	530		at 25° C	2,230
Manganese, susp.	µg/L	90	Streamflow, inst.	ft^3/s	0.18
Manganese, tot.	µg/L	620	Sulfate, diss.	mg/L	1,000
pH, field		6.3	Water temp.	°C	23.5

Cations	(mg/L)	(meq/L)	Anions[1]	(mg/L)	(meq/L)
Calcium, diss.	190	9.481	Chloride, diss.	4.8	0.136
Magnesium, diss.	130	10.694	Fluoride, diss.	0.3	0.016
Potassium, diss.	9.4	0.241	Sulfate, diss.	1,000	20.820
Sodium, diss.	200	8.700	Alk, tot. as $CaCO_3$	380	7.593
	Total	29.116		Total	28.565

Table 17.--Laboratory analyses of surface-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.--Continued

Sampling site 4

Parameter	Units of measure	Measure-ment	Parameter	Units of measure	Measure-ment
Acidity, as H^+	mg/L	0.0	pH, lab		8.3
Acidity, tot. as $CaCO_3$	mg/L	0	Phosphorus, diss. as P	mg/L	0.01
Alk, tot. as $CaCO_3$	mg/L	280	Potassium, diss.	mg/L	8.0
Aluminum, diss.	µg/L	50	Diss. solids,		
Aluminum, susp.	µg/L	0	residue at 105° C	mg/L	1,730
Aluminum, tot.	µg/L	0	Tot. solids,		
Calcium, diss.	mg/L	160	residue at 105° C	mg/L	1,770
Chloride, diss.	mg/L	5.4	Susp. solids	mg/L	0
Fluoride, diss.	mg/L	0.3	SAR		2.7
Hardness, noncarb.	mg/L	570	Silica, diss.	mg/L	3.2
Hardness, tot. as $CaCO_3$	mg/L	850	Sodium, diss.	mg/L	180
Iron, diss.	µg/L	30	Sodium,	percent	31
Iron, susp.	µg/L	290	Spec. conduc., field	µmho/cm	
Iron, tot.	µg/L	320		at 25° C	2,000
Magnesium, diss.	mg/L	110	Spec. conduc., lab	µmho/cm	
Manganese, diss.	µg/L	170		at 25° C	2,000
Manganese, susp.	µg/L	10	Streamflow, inst.	ft^3/s	0.07
Manganese, tot.	µg/L	180	Sulfate, diss.	mg/L	950
pH, field		7.8	Water temp.	°C	23.5

Cations			Anions[1]		
	(mg/L)	(meq/L)		(mg/L)	(meq/L)
Calcium, diss.	160	7.984	Chloride, diss.	5.4	0.153
Magnesium, diss.	110	9.049	Fluoride, diss.	0.3	0.016
Potassium, diss.	8.0	0.205	Sulfate, diss.	950	19.779
Sodium, diss.	180	7.830	Alk, tot. as $CaCO_3$	280	5.595
	Total	25.068		Total	25.543

Table 17.--Laboratory analyses of surface-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.--Continued

Sampling site 5

Parameter	Units of measure	Measure- ment	Parameter	Units of measure	Measure- ment
Acidity, as H^+	mg/L	0.0	pH, lab		8.3
Acidity, tot. as $CaCO_3$	mg/L	0	Phosphorus, diss. as P	mg/L	0.01
Alk, tot. as $CaCO_3$	mg/L	57	Potassium, diss.	mg/L	2.2
Aluminum, diss.	µg/L	60	Diss. solids,		
Aluminum, susp.	µg/L	0	residue at 105° C	mg/L	404
Aluminum, tot.	µg/L	60	Tot. solids,		
Calcium, diss.	mg/L	57	residue at 105° C	mg/L	430
Chloride, diss.	mg/L	11	Susp. solids	mg/L	1
Fluoride, diss.	mg/L	0.1	SAR		0.8
Hardness, noncarb.	mg/L	190	Silica, diss.	mg/L	5.4
Hardness, tot. as $CaCO_3$	mg/L	250	Sodium, diss.	mg/L	28
Iron, diss.	µg/L	100	Sodium	percent	20
Iron, susp.	µg/L	40	Spec. conduc., field	µmho/cm	
Iron, tot.	µg/L	140		at 25° C	600
Magnesium, diss.	mg/L	25	Spec. conduc., lab.	µmho/cm	
Manganese, diss.	µg/L	270		at 25° C	573
Manganese, susp.	µg/L	0	Streamflow, inst.	ft^3/s	0.01
Manganese, tot.	µg/L	230	Sulfate, diss.	mg/L	230
pH, field		6.4	Water temp.	°C	21.0

Cations	(mg/L)	(meq/L)	Anions[1]	(mg/L)	(meq/L)
Calcium, diss.	57	2.845	Chloride, diss.	11	0.311
Magnesium, diss.	25	2.057	Fluoride, diss.	0.1	0.006
Potassium, diss.	2.2	0.057	Sulfate, diss.	230	4.789
Sodium, diss.	28	1.218	Alk, tot. as $CaCO_3$	57	1.139
	Total	6.177		Total	6.245

Table 17.--Laboratory analyses of surface-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.--Continued

Sampling site 12

Parameter	Units of measure	Measure-ment	Parameter	Units of measure	Measure-ment
Acidity, as H^+	mg/L	0.0	pH, field		7.6
Acidity, tot. as $CaCO_3$	mg/L	0	pH, lab.		8.1
Alk, tot. as $CaCO_3$	mg/L	240	Potassium, diss. as P	mg/L	0.01
Aluminum, BTM	µg/g	4,200	Potassium, diss.	mg/L	7.1
Aluminum , diss.	µg/L	30	Diss. solids, residue at 105° C	mg/L	1,580
Aluminum, susp.	µg/L	0			
Aluminum, tot.	µg/L	20	Tot. solids, residue at 105° C	mg/L	1,610
Calcium, diss.	mg/L	150			
Chloride, diss.	mg/L	6.1	Susp. solids	mg/L	0
Fluoride, diss.	mg/L	0.3	SAR		2.5
Hardness, noncarb.	mg/L	550	Silica, diss.	mg/L	1.6
Hardness, tot. as $CaCO_3$	mg/L	790	Sodium, diss.	mg/L	160
Iron, BTM	µg/g	25,000	Sodium	percent	30
Iron, diss.	µg/g	20	Spec. conduc., field	µmho/cm at 25° C	1,900
Iron, susp.	µg/L	430			
Iron, tot.	µg/L	450	Spec. conduc., lab.	µmho/cm at 25° C	1,850
Magnesium, diss.	mg/L	100			
Manganese, BTM	µg/g	2,200	Streamflow, inst.	ft^3/s	0.09
Manganese, diss.	µg/L	270	Sulfate, diss.	mg/L	850
Manganese, susp.	µg/L	0	Water temp.	°C	24.5
Manganese, tot.	µg/L	270			

Cations	(mg/L)	(meq/L)	Anions[1]	(mg/L)	(meq/L)
Calcium, diss.	150	7.485	Chloride, diss.	6.1	0.173
Magnesium, diss.	100	8.226	Fluoride, diss.	0.3	0.016
Potassium, diss.	7.1	0.182	Sulfate, diss.	850	17.697
Sodium, diss.	160	6.960	Alk, tot. as $CaCO_3$	240	4.796
	Total	22.853		Total	22.682

Table 17.--Laboratory analyses of surface-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.--Continued

Sampling site 14

Parameter	Units of measure	Measurement	Parameter	Units of measure	Measurement
Acidity, as H^+	mg/L	0.0	pH, field		8.3
Acidity, tot. as $CaCO_3$	mg/L	0	pH, lab.		7.8
Alk, tot. as $CaCO_3$	mg/L	140	Phosphorus, diss. as P	mg/L	0.03
Aluminum, BTM	µg/L	4,800	Potassium, diss.	mg/L	13
Aluminum, diss.	µg/L	20	Diss. solids, residue at 105° C	mg/L	777
Aluminum, susp.	µg/L	0			
Aluminum, tot.	µg/L	0	Tot. solids, residue at 105° C	mg/L	789
Calcium, diss.	mg/L	81			
Chloride, diss.	mg/L	39	Susp. solids	mg/L	6
Fluoride, diss.	mg/L	.3	SAR		2.1
Hardness, noncarb.	mg/L	230	Silica, diss.	mg/L	4.8
Hardness, tot. as $CaCO_3$	mg/L	370	Sodium, diss.	mg/L	92
Iron, BTM	µg/g	47,000	Sodium,	percent	34
Iron, diss.	µg/L	150	Spec. conduc., field	µmho/cm at 25° C	1,100
Iron, susp.	µg/L	400			
Iron, tot.	µg/L	550	Spec. conduc., lab.	µmho/cm at 25° C	1,120
Magnesium, diss.	mg/L	41			
Manganese, BTM	µg/g	2,300	Streamflow, inst.	ft^3/s	0.07
Manganese, diss.	µg/L	600	Sulfate, diss.	mg/L	380
Manganese, susp.	µg/L	40	Water temp.	°C	33.0
Manganese, tot.	µg/L	640			

Cations	(mg/L)	(meq/L)	Anions[1]	(mg/L)	(meq/L)
Calcium, diss.	81	4.042	Chloride, diss.	39	1.101
Magnesium, diss.	41	3.373	Fluoride, diss.	0.3	0.016
Potassium, diss.	13	0.333	Sulfate, diss.	380	7.912
Sodium, diss.	92	4.002	Alk, tot. as $CaCO_3$	140	2.798
	Total	11.750		Total	11.827

Table 17.--Laboratory analyses of surface-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.--Continued

Sampling site 16

Parameter	Units of measure	Measure-ment	Parameter	Units of measure	Measure-ment
Acidity, as H^+	mg/L	0.0	pH, field		8.2
Acidity, tot. as $CaCO_3$	mg/L	0	pH, lab.		8.2
Alk, tot. as $CaCO_3$	mg/L	160	Phosphorus, diss. as P	mg/L	0.02
Aluminum, BTM	µg/g	1,300	Potassium, diss.	mg/L	7.4
Aluminum, diss.	µg/L	30	Diss. solids,		
Aluminum, susp.	µg/L	0	residue at 105° C	mg/L	1,280
Aluminum, tot.	µg/L	0	Tot. solids,		
Calcium, diss.	mg/L	110	residue at 105° C	mg/L	1,400
Chloride, diss.	mg/L	6.6	Susp. solids	mg/L	13
Fluoride, diss.	mg/L	0.2	SAR		2.4
Hardness, noncarb.	mg/L	470	Silica, diss.	mg/L	0.8
Hardness, tot. as $CaCO_3$	mg/L	630	Sodium, diss.	mg/L	140
Iron, BTM	µg/g	9,100	Sodium,	percent	32
Iron, diss.	µg/L	40	Spec. conduc., field	µmho/cm	
Iron, susp.	µg/L	200		at 25° C	1,600
Iron, tot.	µg/L	240	Spec. conduc., lab.	µmho/cm	
Magnesium, diss.	mg/L	86		at 25° C	1,630
Manganese, BTM	µg/g	670	Streamflow, inst.	ft^3/s	0.16
Manganese, diss.	µg/L	110	Sulfate, diss.	mg/L	710
Manganese, susp.	µg/L	10	Water temp.	°C	30.0
Manganese, tot.	µg/L	120			

Cations	(mg/L)	(meq/L)	Anions[1]	(mg/L)	(meq/L)
Calcium, diss.	110	5.489	Chloride, diss.	6.6	0.187
Magnesium, diss.	86	7.075	Fluoride, diss.	0.2	0.011
Potassium, diss.	7.4	0.190	Sulfate, diss.	710	14.783
Sodium, diss.	140	6.090	Alk, tot. as $CaCO_3$	160	3.197
	Total	18.844		Total	18.178

Table 17.--Laboratory analyses of surface-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.--Continued

Sampling site 19

Parameter	Units of measure	Measurement	Parameter	Units of measure	Measurement
Acidity, as H^+	mg/L	0.0	pH, field		7.2
Acidity, tot. as $CaCO_3$	mg/L	0	pH, lab.		7.4
Alk, tot. as $CaCO_3$	mg/L	130	Phosphorus, diss. as P	mg/L	0.03
Aluminum, BTM	µg/g	1,200	Potassium, diss.	mg/L	5.8
Aluminum, diss.	µg/L	10	Diss. solids,		4.3
Aluminum, susp.	µg/L	0	residue at 105° C	mg/L	456
Aluminum, tot.	µg/L	0	Tot. solids,		
Calcium, diss.	mg/L	61	residue at 105° C	mg/L	458
Chloride, diss.	mg/L	21	Susp. solids	mg/L	9
Fluoride, diss.	mg/L	0.2	SAR		1.2
Hardness, noncarb.	mg/L	130	Silica, diss.	mg/L	5.1
Hardness, tot. as $CaCO_3$	mg/L	260	Sodium, diss.	mg/L	44
Iron, BTM	µg/g	8,300	Sodium,	percent	26
Iron, diss.	µg/L	120	Spec. conduc., field	µmho/cm	
Iron, susp.	µg/L	540		at 25° C	700
Iron, tot.	µg/L	660	Spec. conduc., lab.	µmho/cm	
Magnesium, diss.	mg/L	26		at 25° C	685
Manganese, BTM	µg/g	490	Streamflow, inst.	ft^3/s	0.13
Manganese, diss.	µg/L	2,100	Sulfate, diss.	mg/L	190
Manganese, susp.	µg/L	0	Water temp.	°C	20.6
Manganese, tot.	µg/L	2,000			

Cations	(mg/L)	(meq/L)	Anions[1]	(mg/L)	(meq/L)
Calcium, diss.	61	3.044	Chloride, diss.	21	0.593
Magnesium, diss.	26	2.139	Fluoride, diss.	0.2	0.011
Potassium, diss.	5.8	0.149	Sulfate, diss.	190	3.956
Sodium, diss.	44	1.914	Alk, tot. as $CaCO_3$	130	2.598
	Total	7.246		Total	7.158

Table 17.--Laboratory analyses of surface-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.--Continued

Sampling site 27

Parameter	Units of measure	Measurement	Parameter	Units of measure	Measurement
Acidity, as H^+	mg/L	0.0	pH, field		6.4
Acidity, tot. as $CaCO_3$	mg/L	0	pH, lab.		6.1
Alk, tot. as $CaCO_3$	mg/L	5	Phosphorus, diss. as P	mg/L	0.00
Aluminum, BTM	µg/g	5,300	Potassium, diss.	mg/L	5.9
Aluminum, diss.	µg/L	30	Diss. solids,		
Aluminum, susp.	µg/L	0	residue at 105° C	mg/L	2,640
Aluminum, tot.	µg/L	0	Tot. solids,		
Calcium, diss.	mg/L	270	residue at 105° C	mg/L	2,660
Chloride, diss.	mg/L	8.1	Susp. solids	mg/L	23
Fluoride, diss.	mg/L	0.4	SAR		0.5
Hardness, noncarb.	mg/L	1,700	Silica, diss.	mg/L	15
Hardness, tot. as $CaCO_3$	mg/L	1,700	Sodium, diss.	mg/L	47
Iron, BTM	µg/g	36,000	Sodium,	percent	6
Iron, diss.	µg/L	6,100	Spec. conduc., field	µmho/cm	
Iron, susp.	µg/L	1,300		at 25° C	2,300
Iron, total	µg/L	7,400	Spec. conduc., lab.	µmho/cm	
Magnesium, diss.	mg/L	240		at 25° C	2,550
Manganese, BTM	µg/g	1,100	Streamflow, inst.	ft^3/s	0.31
Manganese, diss.	µg/L	22,000	Sulfate, diss.	mg/L	1,700
Manganese, susp.	µg/L	0	Water temp.	°C	27.2
Manganese, tot.	µg/L	110			
	Cations			Anions[1]	
	(mg/L)	(meq/L)		(mg/L)	(meq/L)
Calcium, diss.	270	13.473	Chloride, diss.	8.1	0.229
Magnesium, diss.	240	19.743	Fluoride, diss.	0.4	0.022
Potassium, diss.	5.9	0.151	Sulfate, diss.	1,700	35.394
Sodium, diss.	47	2.045	Alk, tot. as $CaCO_3$	5	0.100
	Total	35.412		Total	35.745

[1]Note: The milliequivalent-per-liter (meq/L) values reported for total alkalinity are for the bicarbonate ion.

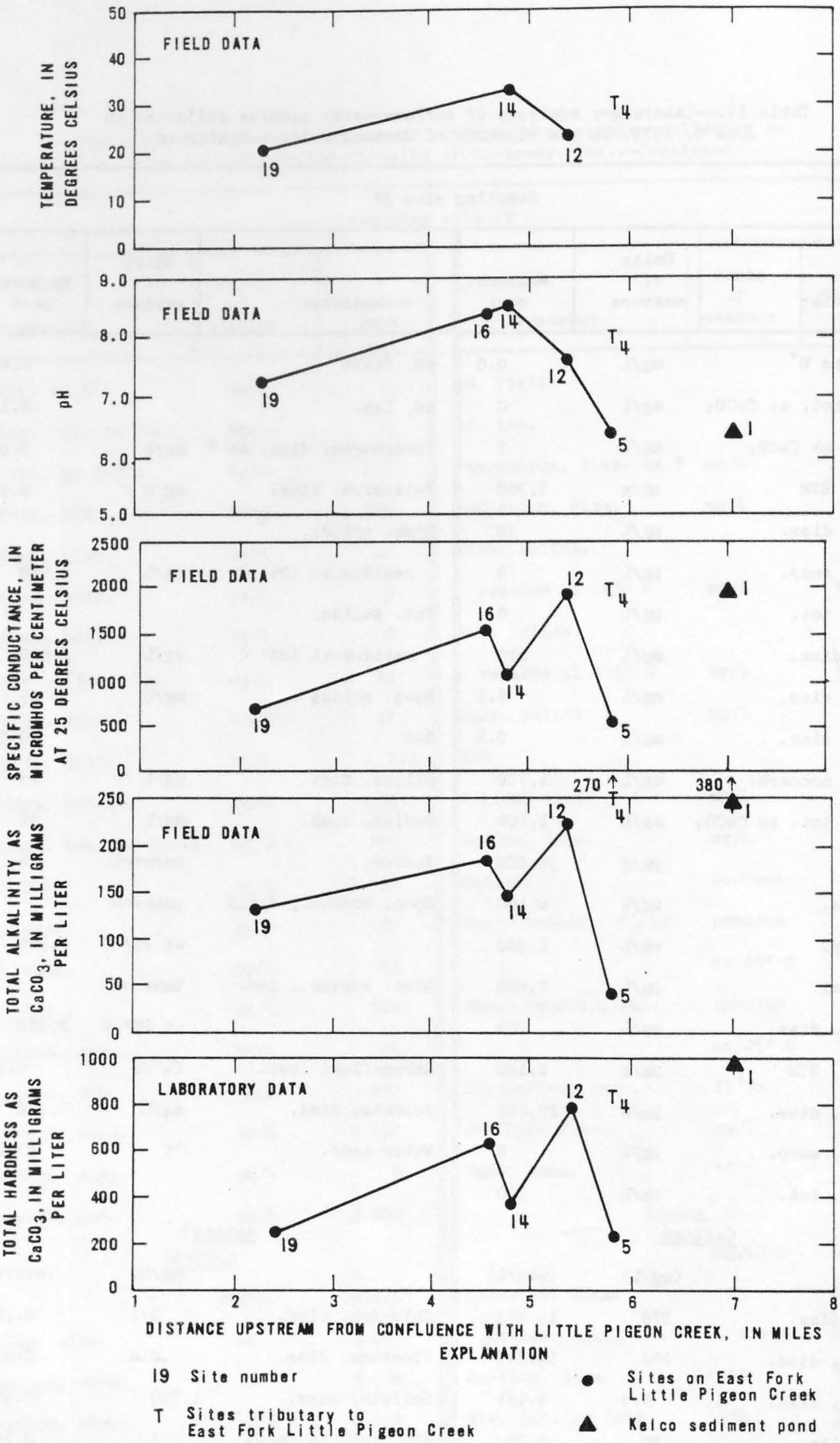


Figure 23.-- Profiles and measurements of chemical constituents and properties at selected sampling sites on East Fork Little Pigeon Creek and tributaries, June 6, 1979 (continued).

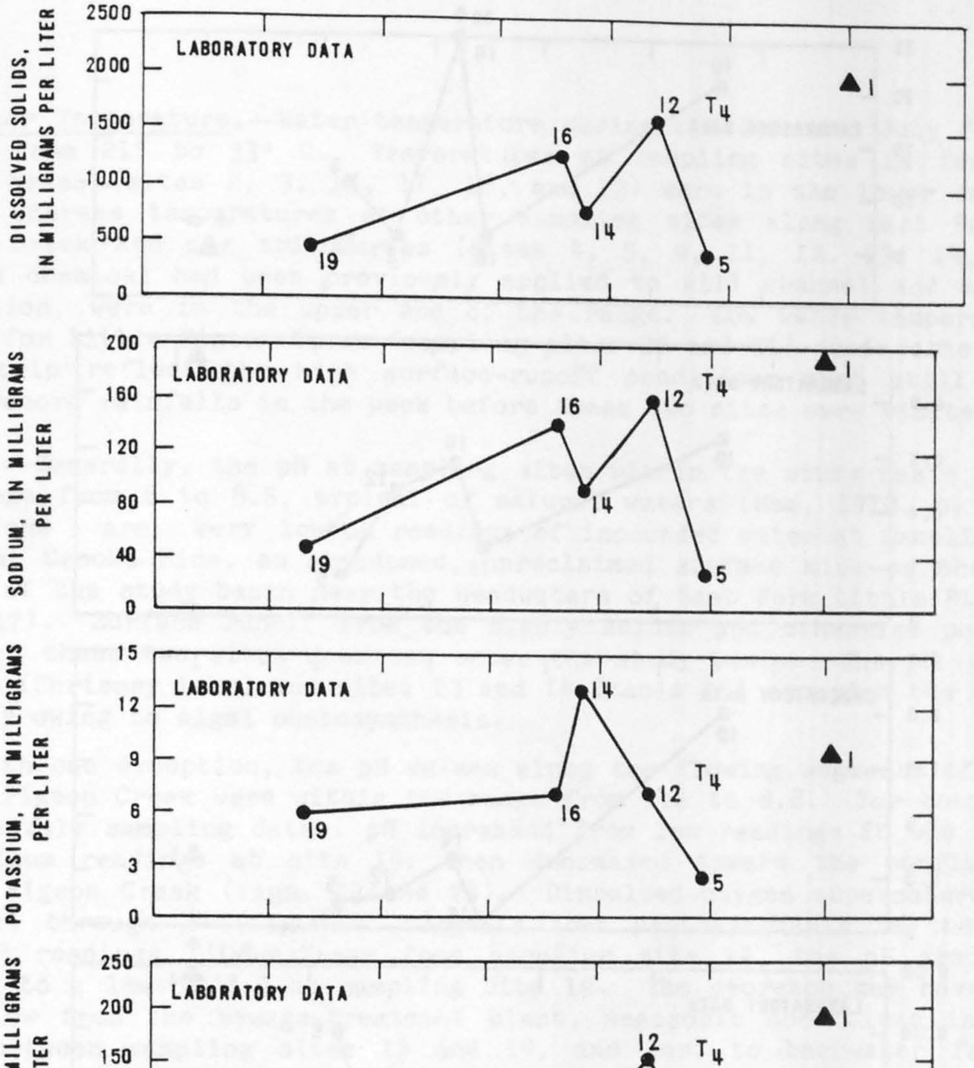


Figure 23.-- Profiles and measurements of chemical constituents and properties at selected sampling sites on East Fork Little Pigeon Creek and tributaries, June 6, 1979 (continued).

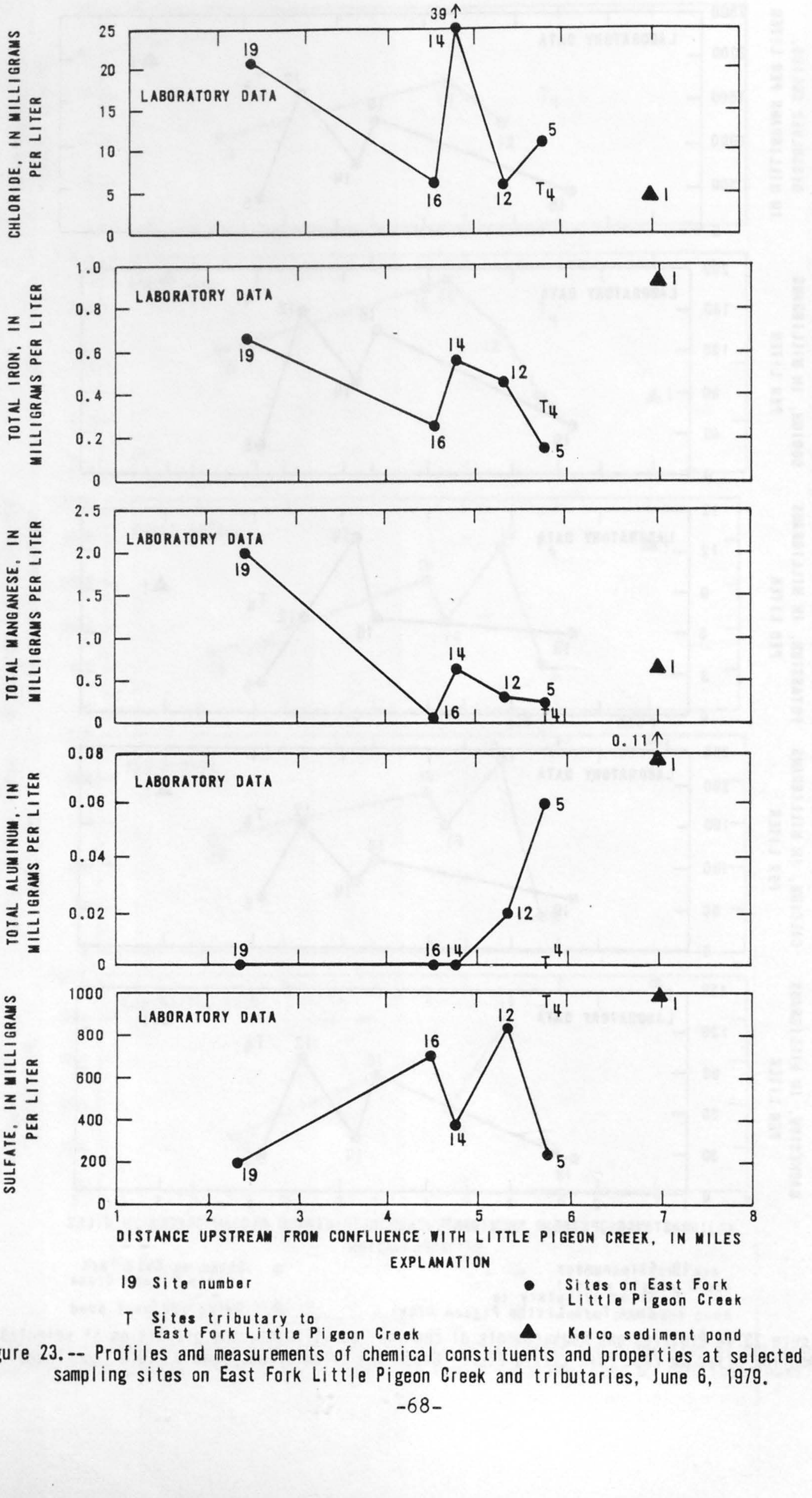


Figure 23.-- Profiles and measurements of chemical constituents and properties at selected sampling sites on East Fork Little Pigeon Creek and tributaries, June 6, 1979.

Water Temperature.--Water temperature during the June and July field trips ranged from 21° to 33° C. Temperatures at sampling sites in forested and shaded areas (sites 2, 3, 15, 17, 18, and 19) were in the lower end of this range, whereas temperatures at other sampling sites along East Fork Little Pigeon Creek and its tributaries (sites 4, 5, 9, 11, 12, 13, 14, and 16), where a chemical had been previously applied to kill channel and stream-bank vegetation, were in the upper end of the range. Low water temperatures observed for Little Pigeon Creek (sampling sites 20 and 21) during the July 1979 field trip reflect the high surface-runoff conditions that still prevailed after record rainfalls in the week before these two sites were visited.

pH.--Generally, the pH at sampling sites within the study basin was within the range from 6 to 8.5, typical of natural waters (Hem, 1970, p. 92). Two exceptions are very low pH readings of impounded water at sampling sites 6 and 7 at Crooks Mine, an abandoned, unreclaimed surface mine on the drainage divide of the study basin near the headwaters of East Fork Little Pigeon Creek (fig. 17). Surface runoff from the highly acidic and otherwise poor-quality water at these two sites does not enter the study basin. The pH readings at site 10 (Chrisney Lake) and sites 13 and 14 (table 16) exceeded the 8.5 value, probably owing to algal photosynthesis.

With one exception, the pH values along the flowing segments of East Fork Little Pigeon Creek were within the range from 7.0 to 8.8. For both the June and the July sampling dates, pH increased from low readings in the headwaters to maximum readings at site 14, then decreased toward the confluence with Little Pigeon Creek (figs. 23 and 24). Dissolved-oxygen supersaturation from sites 11 through 14 (fig. 24) suggests that photosynthesis is the cause of high pH readings. Downstream from sampling site 14, the pH gradually decreases to a low of 7.0 at sampling site 19. The decrease may have been due to inflow from the sewage-treatment plant, anaerobic conditions in the sediment between sampling sites 16 and 19, and (or) to backwater from Little Pigeon Creek.

Suspended Solids.--The concentration of suspended solids determined in field tests was ≤5 mg/L at all sites upstream from the sewage-treatment-plant inflow (sampling site 15). In contrast, the concentration of suspended solids ranged from 10 to 30 mg/L at sampling sites on East Fork Little Pigeon Creek downstream from the wastewater inflow. Visual observation and field tests at sampling site 15 indicate that the higher concentrations of suspended solids in the creek were not due directly to the sewage-treatment-plant inflow but, rather, were due to detritus, macroinvertebrates, plankton, and other biomass. The elevated suspended-solids concentration at station 16 (table 16), and especially between sampling sites 18 and 19, reflects the high concentration of particulate organic matter in the lower part of East Fork Little Pigeon Creek. This observation, which was confirmed by both field and laboratory determinations, indicates high levels of biological activity between sites 16 and 19.

The high concentration of suspended solids recorded at sampling site 17, in an unnamed tributary to East Fork Little Pigeon Creek (fig. 17), resulted from runoff from a nearby recently cultivated field and, therefore, is probably mostly inorganic matter. No streamflow was observed at this sampling site. Suspended-solids concentrations recorded for Little Pigeon Creek (sites 20 and 21) reflect the flooding during the collection of water samples at these sites.

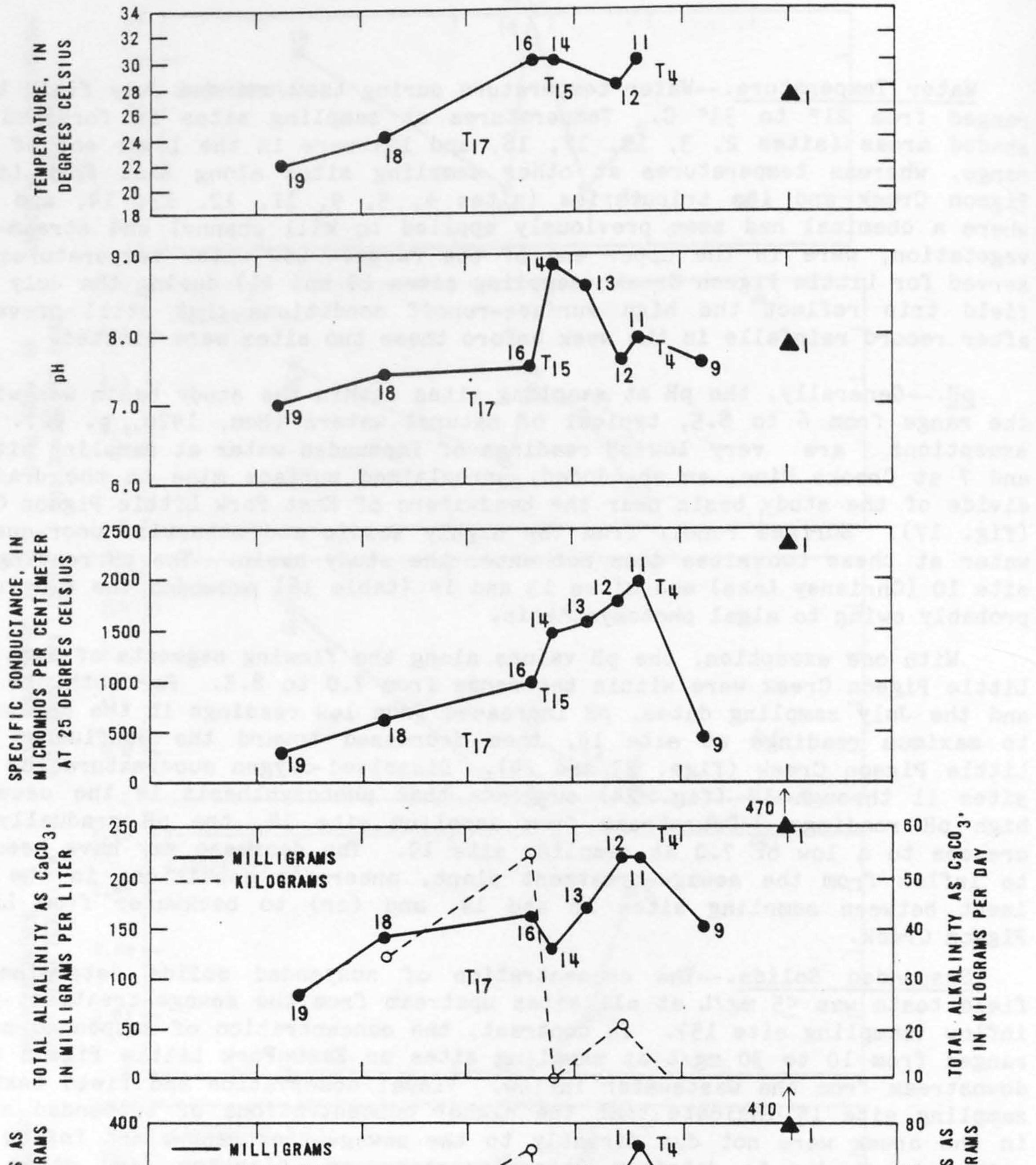


Figure 24.-- Mass profiles and field measurements of chemical constituents and properties at selected sampling sites on East Fork Little Pigeon Creek and tributaries, July 18, 1979 (continued).

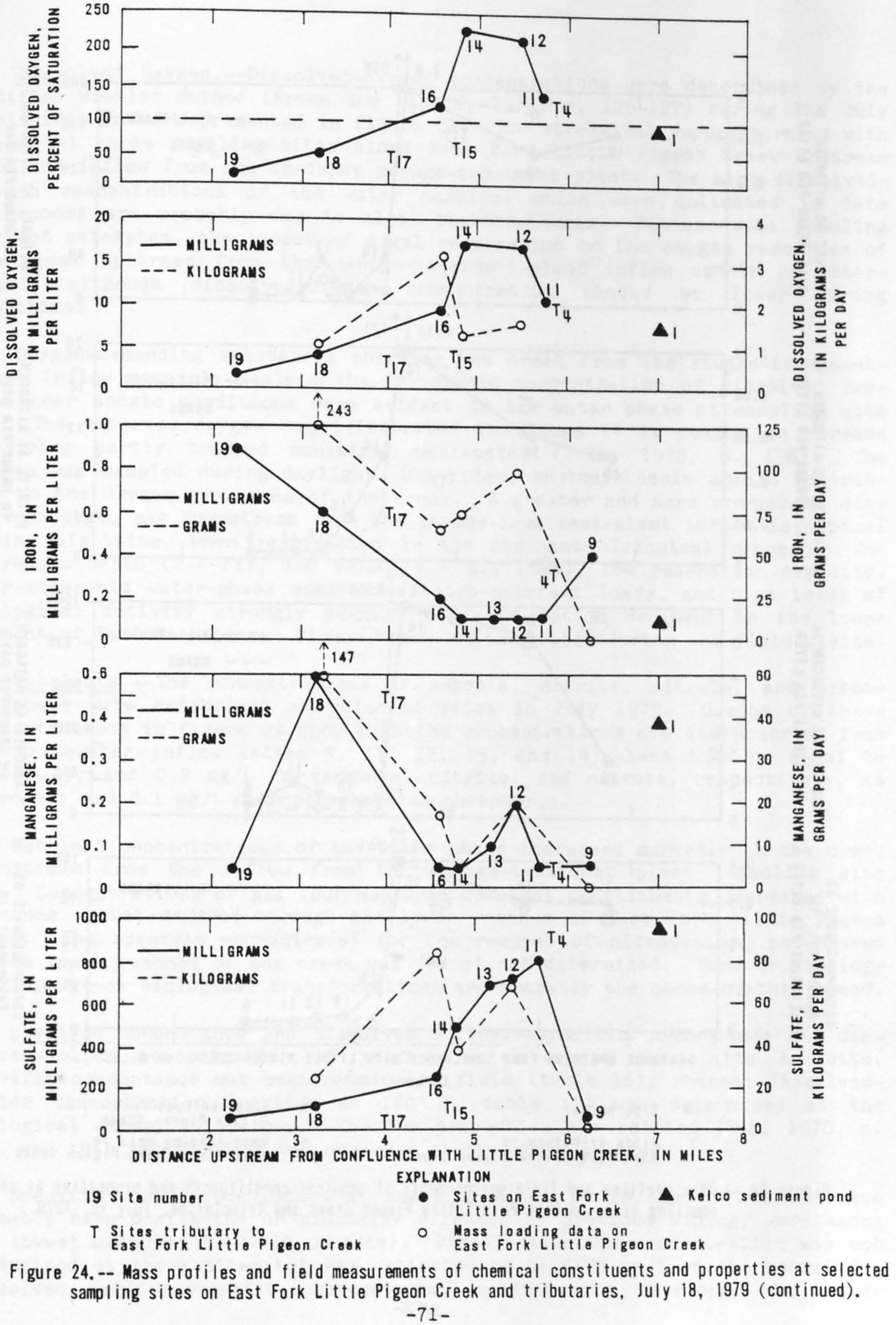


Figure 24.-- Mass profiles and field measurements of chemical constituents and properties at selected sampling sites on East Fork Little Pigeon Creek and tributaries, July 18, 1979 (continued).

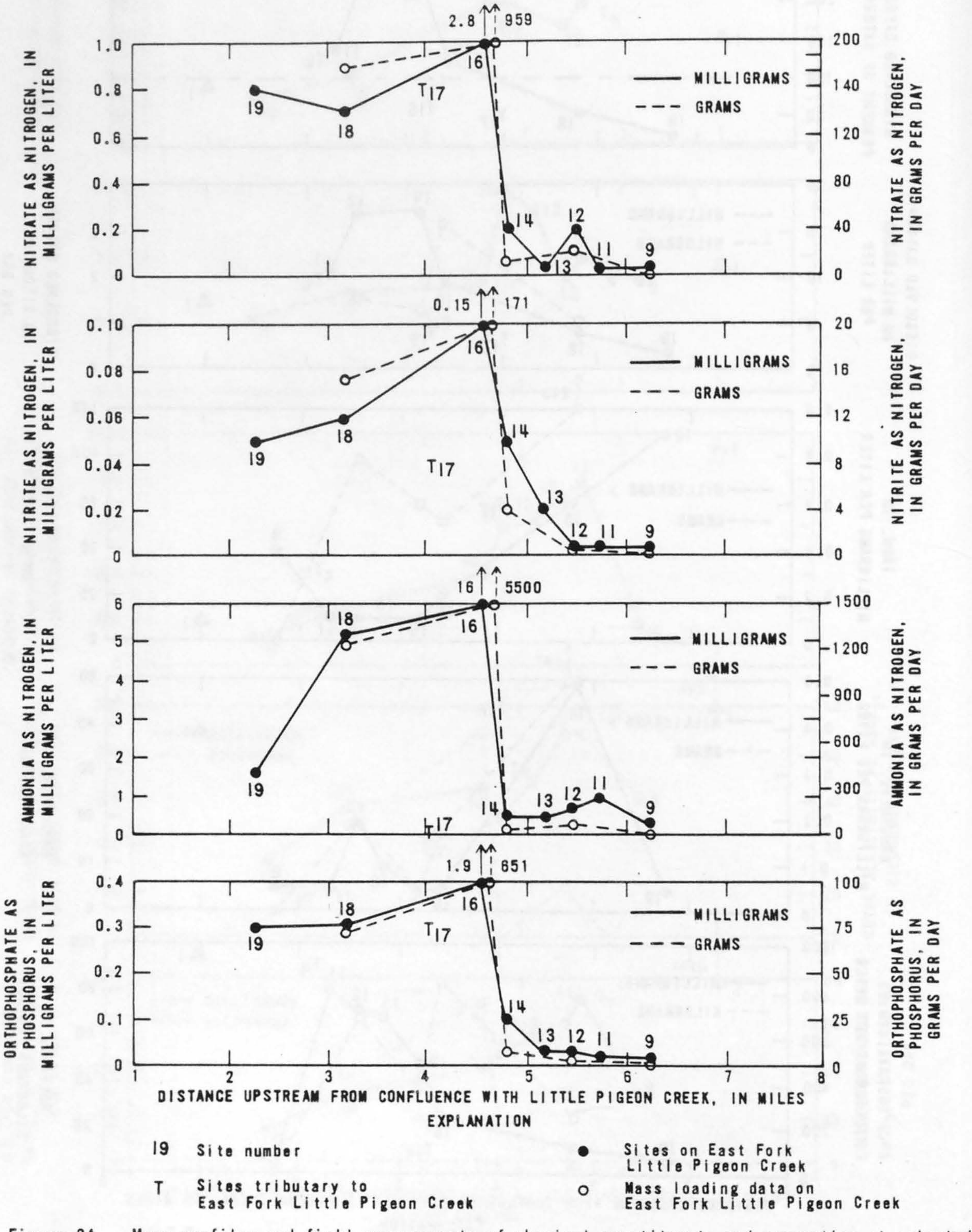


Figure 24.-- Mass profiles and field measurements of chemical constituents and properties at selected sampling sites on East Fork Little Pigeon Creek and tributaries, July 18, 1979.

Dissolved Oxygen.--Dissolved-oxygen concentrations were determined by the modified Winkler method (Brown and others, 1970, p. 126-127) during the July field trip and are presented in figure 24. The stream was supersaturated with oxygen at three sampling sites along East Fork Little Pigeon Creek upstream from the inflow from the Chrisney sewage-treatment plant. The high dissolved-oxygen concentrations of the water samples, which were collected in late afternoon, are probably due to algal photosynthesis. Because diel sampling was not attempted, the impact of algal respiration on the oxygen resources of the creek upstream from the sewage-treatment-plant inflow cannot be determined, although dissolved-oxygen concentration should be lower during nighttime.

Oxygen-demanding substances entering the creek from the sewage-treatment-plant inflow severely deplete the downstream concentration of dissolved oxygen; near anoxic conditions were evident in the water phase at sampling site 19. The observed oxygen sag illustrated in figure 24 is common in streams receiving partly treated municipal wastewater (Velz, 1970, p. 138). The stream was sampled during daylight, when plant photosynthesis should contribute to the oxygen resources of the creek. A greater and more pronounced dissolved-oxygen sag downstream from the sewage-treatment-plant inflow is typical during nighttime, when respiration is the dominant biological process. The increased depth (2-4 ft), low velocity (0.1 ft/s), low reaeration capacity, near-anaerobic water-phase conditions, high-nutrient loads, and high level of biological activity strongly suggest that the bottom sediment in the lower segment of East Fork Little Pigeon Creek was anaerobic during the field visits.

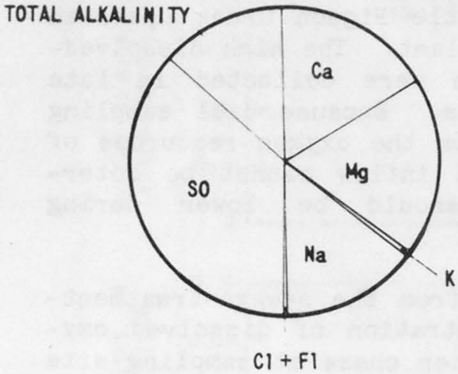
Nutrients.--The concentrations of ammonia, nitrite, nitrate, and orthophosphate were determined at selected sites in July 1979. Graphs of these concentrations in figure 24 show that the concentrations are low upstream from the wastewater inflow (sites 9, 11, 12, 13, and 14)--less than or equal to 2.0, 0.05, and 0.2 mg/L for ammonia, nitrite, and nitrate, respectively, as nitrogen; and 0.1 mg/L orthophosphate as phosphorus.

Nutrient concentrations of the water phase increased markedly in the creek downstream from the inflow from the sewage-treatment plant (sampling site 16). Concentrations of all four measured chemical constituents decreased with distance as water moved through the lower reaches of East Fork Little Pigeon Creek. The specific mechanism(s) for the removal of nitrogen and phosphorus in the lower reaches of the creek was (were) not determined. However, biological uptake or biological transformations are probably the cause of this trend.

Specific Conductance and Dissolved Solids.--Specific conductance and dissolved-solids concentration of surface water varied from site to site. Specific conductance was measured in the field (table 16), whereas dissolved-solids concentration (residue at 180° C, table 17) was determined at the Geological Survey laboratory. The two properties are related (Hem, 1970, p. 99), and this relationship was observed at the sites sampled.

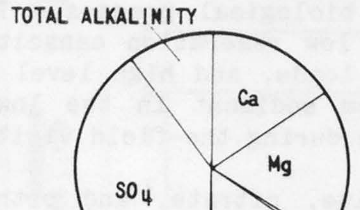
Specific conductance values at sampling sites 9, 10, and 17, which have probably been unaffected or minimally affected by previous mining, were among the lowest measured (200-450 μmho/cm). Dissolved-solids concentration was not determined at these sites but was estimated to be $\leq$175 mg/L on the basis of a dissolved solids-specific conductance relationship developed for other

SAMPLING SITE 1



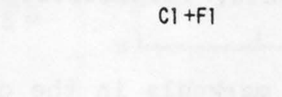
CATIONS	MILLIGRAMS PER LITER	MILLIEQUIVALENTS PER LITER
Acidity as H^+	0.0	0.000
Dissolved calcium	190	9.481
Dissolved magnesium	130	10.694
Dissolved potassium	9.4	0.241
Dissolved sodium	200	8.700
	TOTAL	29.116
ANIONS[1]		
Dissolved chloride	4.8	0.136
Dissolved fluoride	0.3	0.016
Dissolved sulfate	1000	20.820
Total alkalinity as $CaCO_3$	380	7.593
	TOTAL	28.565

SAMPLING SITE 4



CATIONS	MILLIGRAMS PER LITER	MILLIEQUIVALENTS PER LITER
Acidity as H^+	0.0	0.000
Dissolved calcium	160	7.984
Dissolved magnesium	110	9.049
Dissolved potassium	8.0	0.205
Dissolved sodium	180	7.830
	TOTAL	25.068
ANIONS[1]		
Dissolved chloride	5.4	0.153
Dissolved fluoride	0.3	0.016
Dissolved sulfate	950	19.779
Total alkalinity as $CaCO_3$	280	5.595
	TOTAL	25.543

SAMPLING SITE 5

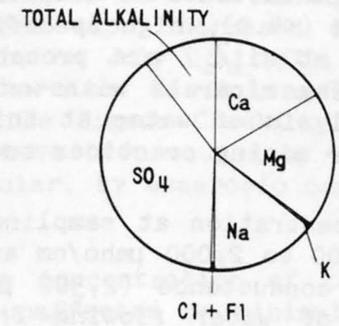


CATIONS	MILLIGRAMS PER LITER	MILLIEQUIVALENTS PER LITER
Acidity as H^+	0.0	0.000
Dissolved calcium	57	2.845
Dissolved magnesium	25	2.057
Dissolved potassium	2.2	0.057
Dissolved sodium	28	1.218
	TOTAL	6.177
ANIONS[1]		
Dissolved chloride	11	0.311
Dissolved fluoride	0.1	0.006
Dissolved sulfate	230	4.789
Total alkalinity as $CaCO_3$	57	1.139
	TOTAL	6.245

[1]Note: The milliequivalent-per-liter (meq/L) values reported for total alkalinity are for the bicarbonate ion.

Figure 25.--Concentrations of major cations and anions at selected sampling

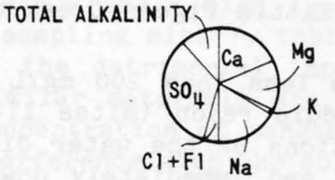
SAMPLING SITE12



CATIONS	MILLIGRAMS PER LITER	MILLIEQUIVALENTS PER LITER
Dissolved calcium	150	7.485
Dissolved magnesium	100	8.226
Dissolved potassium	7.1	0.182
Dissolved sodium	160	6.960
		TOTAL 22.853

ANIONS[1]		
Dissolved chloride	6.1	0.173
Dissolved fluoride	0.3	0.016
Dissolved sulfate	850	17.697
Total alkalinity as $CaCO_3$	240	4.796
		TOTAL 22.682

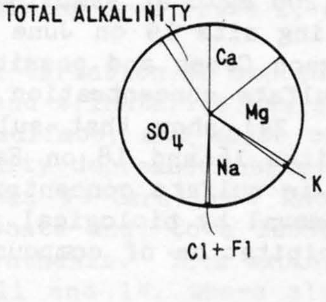
SAMPLING SITE 14



CATIONS	MILLIGRAMS PER LITER	MILLIEQUIVALENTS PER LITER
Dissolved calcium	81	4.042
Dissolved magnesium	41	3.373
Dissolved potassium	13	0.333
Dissolved sodium	92	4.002
		TOTAL 11.750

ANIONS[1]		
Dissolved chloride	39	1.101
Dissolved fluoride	0.3	0.016
Dissolved sulfate	380	7.912
Total alkalinity as $CaCO_3$	140	2.798
		TOTAL 11.827

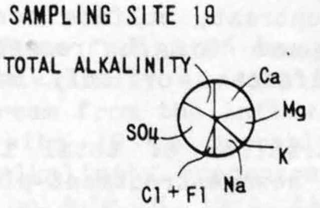
SAMPLING SITE 16



CATIONS	MILLIGRAMS PER LITER	MILLIEQUIVALENTS PER LITER
Dissolved calcium	110	5.489
Dissolved magnesium	86	7.075
Dissolved potassium	7.4	0.190
Dissolved sodium	140	6.090
		TOTAL 18.844

ANIONS[1]		
Dissolved chloride	6.6	0.187
Dissolved fluoride	0.2	0.011
Dissolved sulfate	710	14.783
Total alkalinity as $CaCO_3$	160	3.197
		TOTAL 18.178

SAMPLING SITE 19



CATIONS	MILLIGRAMS PER LITER	MILLIEQUIVALENTS PER LITER
Dissolved calcium	61	3.044
Dissolved magnesium	26	2.139
Dissolved potassium	5.8	0.149
Dissolved sodium	44	1.914
		TOTAL 7.246

ANIONS[1]		
Dissolved chloride	21	0.593
Dissolved fluoride	0.2	0.011
Dissolved sulfate	190	3.956
Total alkalinity as $CaCO_3$	130	2.598
		TOTAL 7.158

sites along and near East Fork Little Pigeon Creek, June 6, 1979.

surface-water sampling sites in the study basin. In contrast to the good quality of water at sites 9, 10, and 17, specific conductance at sampling site 7 was extremely high (5,500 µmho/cm). The low pH (<4.0), high specific conductance, and high dissolved-solids concentration at site 7 are probably due to the reaction of pyrite and other acid-producing minerals with water and oxygen over a prolonged period. The chemical analysis of water at this site illustrates the severe detrimental impact that poor mining practices and unreclaimed mines can have on water quality.

Specific conductance and dissolved-solids concentration at sampling sites along East Fork Little Pigeon Creek, ranged from 300 to 2,000 µmho/cm and from 400 to 1,600 mg/L, respectively. High specific conductance (2,300 µmho/cm) and dissolved-solids concentration (1,500 mg/L) of water flowing from the Kelco mining area gradually decreased downstream (fig. 24). Specific conductance (table 16) of the inflow from the sewage-treatment plant on 7-18-79 (800 µmho/cm) was less than that at site 14 (1,400 µmho/cm); thus, the wastewater discharge diluted the chemical constituents in the creek. Further decreases in specific conductance and dissolved-solids concentration were observed at and downstream from sampling site 18, owing in part to effects of backwater from Little Pigeon Creek. Specific conductance at sampling site 19, on July 18, 1979 (300 µmho/cm), was identical to that for Little Pigeon Creek at sampling sites 20 and 21 on the same date (table 16).

Sulfate.--Concentration of sulfate ranged from less than 200 mg/L in the headwaters (sites 5 and 9) to 800 mg/L in the middle reach (sites 11-18) of East Fork Little Pigeon Creek. Sulfate concentrations of the water discharging from the Kelco mining area (sampling site 1) and immediately downstream from the area (sites 2-4) ranged from 800 to 1,200 mg/L. Weathering of pyritic materials brought to the land surface during mining and weathering of the gray-shale overburden left exposed at the minesite are two probable causes for the high sulfate concentration of the water draining from this area.

The concentration of sulfate decreased from 1,200 mg/L at sampling site 1 (Kelco sediment pond outflow) to 160 mg/L at sampling site 19 on June 6, 1979 (table 16). Effects of backwater from Little Pigeon Creek and possible sulfate reduction may partly explain the decreased sulfate concentration at sampling site 19. However, mass-loading data (fig. 24) show that sulfate is definitely being removed from the water between sites 16 and 18 on East Fork Little Pigeon Creek. The cause of the decrease in sulfate concentration in this reach was not determined but may be due to removal by biological processes (bacterial reduction of sulfate) and (or) precipitation of compounds containing sulfur.

The high sulfate concentrations at the Crooks mining pits (1,000 and 6,000 mg/L at sampling sites 6 and 7, table 16) indicate the poor quality of the standing water at this abandoned minesite. In contrast, sulfate concentrations at sampling sites 9, 10, and 17 were 60, 30, and 40 mg/L, respectively. The water at these sites has probably been unaffected or only minimally affected by past mining in the study basin.

Iron and Manganese.--In general, the concentrations of total iron and total manganese were variable upstream from the sewage-treatment-plant inflow. Concentrations of total iron and total manganese ranged from <0.1 to 0.8 mg/L in this reach of the creek.

Figures 23 and 24 show that the concentration of iron gradually increased downstream from the sewage-treatment-plant inflow. The concentration of manganese also increased downstream from the sewage-treatment-plant inflow. However, on July 18, 1979, it reached a maximum of 0.6 mg/L at site 18 and then decreased to <0.1 mg/L at sampling site 19, comparable to concentrations in Little Pigeon Creek. The increases in iron and manganese concentrations could have been caused by low ambient dissolved-oxygen concentrations and, in particular, by anaerobic conditions in the bottom sediment between stations 16 and 19.

The concentration of total iron in water samples collected at sampling sites unaffected or minimally affected from past mining ranged from <0.1 to 0.6 mg/L. The lowest concentration was detected at sampling site 10, but higher values were detected at sampling sites 9 (0.4 mg/L) and 17 (0.6 mg/L, table 16). The higher concentrations of iron at sites 9 and 17 are presumably due to iron associated with suspended solids originating from nearby farm land. Concentration of manganese at sampling sites 9, 10, and 17 ranged from <0.1 to 0.5 mg/L (table 16).

The extremely high iron concentration of the acidic water at the Crooks mine (sampling site 7, table 16) on July 20, 1979, 2,000 mg/L, further illustrates the detrimental impact on water quality that may result when pyritic and similar materials are allowed to weather for extended periods of time. The concentration of manganese could not be determined in the field, owing to an interference with the colorimetric test.

Alkalinity and Acidity.--Concentration of total alkalinity (as calcium carbonate) at sampling sites 9, 10, and 17, which are background sites, ranged from 30 to 150 mg/L (table 16). Water at the Crooks minesite (sampling sites 6 and 7) is acidic. In contrast, the alkalinity of water discharging from the Kelco mining area (site 1, fig. 17) was 410 mg/L during the July field trip.

The variation in concentration of alkalinity along East Fork Little Pigeon Creek and tributaries was similar to variations in specific conductance, hardness, sulfate, and major cations (figs. 23 and 24). Concentration of total alkalinity decreased between sampling sites 1 and 14. The cause(s) for these decreases is (are) not known. Some alkalinity-producing ions, most notably bicarbonate and, to a lesser extent, carbonate, are used by aquatic plants in photosynthesis. This explanation is plausible for the stream reach bounded by sites 11 and 14, where algal photosynthesis was occurring, but does not explain the decrease between stations 1 and 4, where photosynthesis is not likely to be significant, owing to minimal algal biomass.

Inflow from the sewage-treatment plant increased the concentration of total alkalinity at sampling site 16. The concentration of total alkalinity downstream from the inflow ranged from 80 to 180 mg/L. Water quality at sampling site 19 is probably affected by backwater from Little Pigeon Creek; total alkalinity concentrations at site 19 were closer to those at sites 20 and 21 on July 18, 1979, than to those upstream.

Only methyl-orange acidity of water samples was determined during the field visitations, and only water samples collected at sites 6 and 7 in the Crooks mining area exhibited this acidity (table 16). The high acidity at sampling site 7 (2,400 mg/L) indicates the water's poor quality.

Calcium and Magnesium.--Calcium concentration was calculated from field determinations of calcium hardness (table 16). Calcium concentrations at sites 9, 10, and 17 ranged from 16 to 56 mg/L . Calcium concentration of the runoff from the Kelco mining area (site 1) was 4 to 12 times the concentrations at sites 9, 10, and 17 (table 16).

Variations of calcium and magnesium concentrations of East Fork Little Pigeon Creek on June 6, 1979, are shown in figures 23 and 25. Concentration of each divalent cation decreases between sampling sites 1 and 14. The concentrations of calcium and magnesium decreased as distance downstream from the sewage-treatment-plant inflow increased.

Aquatic Organisms and Communities.--East Fork Little Pigeon Creek is a small, warm-water creek, typical of most southern Indiana streams. The general trends of seasonal, ecological fluctuations in the creek are characteristic of creeks in the surrounding area.

During the annual seasonal cycle, animal and plant populations vary. Both are highly dependent on stream temperature, volume, and streamflow. Warm spring rains cause the first increase in plankton populations, which reach a stable population by early summer.

During the spring rains, many species of fish migrate upstream, and benthic insects, which have spent the winter as juveniles, begin to emerge, mature, and become breeding adults. The adults breed in late spring and early summer and repopulate the creek.

Low flow and low volume of East Fork Little Pigeon Creek during summer cause major changes in community structure. Individuals per taxon increase, but the total number of taxa decreases. Low flow forces the riffle species of fish to seek pools, and this population may undergo great stress owing to low dissolved-oxygen concentration. Colonization of the small riffle areas by aquatic insects is also hampered during low flow.

Low flow, low volume, and the influx of large quantities of allochthonous material (such as plant leaves) produce a system of nearly separate, leaf-choked ponds in early autumn. These factors cause yet another change in species numbers and composition. Late autumn rains bring an increase in flow and volume. Plankton usually undergo a population pulse during this period, and fish populations become redistributed in the length of the stream.

The phytoplankton community stabilizes during the winter months, but zooplankton normally disappear from January through March, until the advent of spring rains. The aquatic invertebrates continue to mature during the winter months, and populations remain almost constant (Parsons, 1977). Fish populations also remain stable during this period. With spring, populations of plankton grow, fish migrate upstream, and insects emerge and mature.

The general ecological patterns described in the preceding paragraphs are presumed to exist in the study area. Several factors, however, make segments of East Fork Little Pigeon Creek atypical of these general ecological patterns. One is the inflow of water from the Kelco mining area. This inflow provides additional flow to a tributary that would normally dry up in the summer months. The authors do not know whether this tributary will go dry in late summer, but it was flowing during both sampling periods when other similar and larger tributaries were not flowing. A second factor is the inflow of wastewater rich in nutrients and organic material from Chrisney's sewage-treatment plant, which adversely affects the downstream ecology. A third factor is effects of backwater from Little Pigeon Creek, which cause the populations to change from organisms typical of flowing water to those tolerant of standing or pooled water.

Biological sampling of the study basin was completed during the June and July 1979 field trips, but seasonal fluctuations of the aquatic communities in the study basin could not be observed because of the short duration of the project; therefore, sampling procedures were designed to give an overall qualitative perspective of the biological communities in the stream during summer. A tabulation of field observations characterizing aquatic organisms identified in the study basin is presented in table 18.

There was no flow at sites 5 and 17 during sampling. Organisms at these sites were tolerant of very low dissolved-oxygen concentrations. Examples given in table 18 are mosquito larvae (Anopheles sp.), sowbug (Lirceus sp.), and bloodworm (Chironomous sp.). Some organisms at these sites, such as water strider (Gerris sp.) and snail (Physa sp.), can breathe air. Filamentous algae were dominant with associated epiphytic diatoms.

Standing pools at sampling site 17, on a tributary to East Fork Little Pigeon Creek, were larger than those at site 5. Several tolerant species of fish, such as creek chub (Semotilus atromaculatus) and bluntnose minnow (Pimephales notatus), were observed at site 17. No fish were observed at or upstream from sampling site 5.

The unnamed tributary draining the Kelco mining area flowed during the two sampling trips. The biological community at this tributary was much more diverse than the ones at other headwater tributaries (sampling sites 5 and 17). Biological samples were collected at sites 2, 3, and 4, along the flowing tributary, and at site 1 in the Kelco sediment pond (fig. 17). The sedimentation pond was green, owing to a large population of the blue-green alga (Oscillatoria sp. and Gerris sp.). Leopard frog (Rana pipiens) was also present. Benthic organisms and fish were not sampled at the sediment pond. The tributary receiving the outflow from the sediment pond is best described as a bubbling brook, with long reaches of riffles and a few pools. Filamentous algae (Rhizoclonium sp., Oedogonium sp., and Spirogyra sp.) were attached to the streambed and tree roots. Crustacea (Cambarus sp.), crayfish (Lirceus sp.), and copepods were present, and in some areas were plentiful. Aquatic insects present included water penny (Psephenus sp.) and midges (Chironomous sp.), which are tolerant of low dissolved-oxygen concentration, and insects such as may fly (Ephemera sp.), which are intolerant. Mollusca (for example,

Table 18.--Taxonomy of aquatic organisms

	CYANOPHYTA				CHLOROPHYTA											BACILLARACAE								PL[1]	ROTIFERA				AN[2]		CRUSTACEA						
SAMPLING SITE	Anabaena sp.	Chamaesiphon sp.	Merismopena sp.	Oscillatoria sp.	Chlorococcus sp.	Cylindrocapsa sp.	Closterium sp.	Cosmarium sp.	Colacium sp.	Gonium sp.	Microspora sp.	Oedogonium sp.	Rhizoclonium sp.	Spirogyra sp.	Volvox sp.	Fragillaria sp.	Gyrosigma sp.	Lichmophora sp.	Melosira sp.	Navicula sp.	Nitchszia sp.	Synedra sp.	Tabellaria sp.	Dugesia sp.	Asplanchna sp.	Keratella sp.	Polyarthra sp.	Unidentified rotifer	Tubifex sp.	Placobdella sp.	Calanoids	Cyclops spp.	Bosmina sp.	Daphnia sp.	Lirceus sp.	Cambarus sp.	Orconectes sp.
1				●					●								●		●	●			●														
2				●													●		●	●			●		●	●		●			●	●	●		●	●	
3	●			●					●			●	●	●			●			●			●						●		●	●					
4							●		●				●	●					●	●		●	●												●	●	
5						●						●	●	●		●	●			●	●							●	●							●	
11					●			●					●	●		●	●			●	●		●												●	●	
12				●			●		●		●	●	●	●			●			●			●							●					●	●	
14		●		●				●	●	●			●	●			●		●	●			●							●						●	●
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16				●			●		●				●					●	●	●			●						●	●							
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18				●								●								●		●	●	●	●			●				●			●	●	
19																●			●	●		●		●	●	●	●			●		●	●	●	●	●	
20	●		●	●			●					●			●	●			●	●			●		●	●	●					●	●	●		●	
21									●			●			●	●				●					●	●						●	●	●			
27				●													●																				

[1] PL. Platyhelminthes.

[2] AN. Annelida.

identified in the vicinity of Chrisney, Ind.

INSECTA																							MOLLUSCA					VERTEBRATA												
Baetis sp.	Ephemera sp.	Argia sp.	Belostoma sp.	Gerris sp.	Notonecta undulata	Sigara sp.	Corydalis sp.	Sialis sp.	Agabus sp.	Gyrinus sp.	Laccophilus sp.	Psephenus sp.	Unidentified plecopteran	Helicopsyche sp.	Hydropsyche sp.	Anopheles sp.	Chaoborus sp.	Chironimous spp.	Culex sp.	Simulium sp.	Tipula sp.	Unidentified dipteran	Goniobasis sp.	Lymnaea sp.	Physa sp.	Pisidium sp.	Sphaerium sp.	Campostoma anomalum	Catostomus commersoni	Notropsis cornutus	Pimephales notatus	Semotilus atromaculatus	Notropsis umbratilus	Fundulus notatus	Lepomis machrochirus	Lepomis cyanellus	Etheostoma flabellare	Esox americanus	Ictalurus sp.	Amia calva
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snails, Lymnaea sp. and Physa sp., and clams, Pisidium sp.), as well as numerous species of fish, were also present. In summary, the tributary contained diverse and plentiful populations that showed no sign of having recently experienced no-flow conditions.

East Fork Little Pigeon Creek exhibits its true riffle-and-pool nature from sampling site 11 downstream to sampling site 14 and its most diverse community structure in this reach. Numerous organisms, adapted to live in riffles, or pools with sufficient dissolved-oxygen concentrations, were observed in this reach. However, some of these organisms were not seen elsewhere in the study basin.

Filamentous algae, such as those in the tributary draining the Kelco mine area, were very dominant in the reach from site 11 to site 14, and planktonic alga (for example, Cosmarium sp.) were numerous. Benthic invertebrates show a definite division between riffle and pool organisms in the reach. May flies (Baetis sp. and Ephemera sp.), caddis fly (Hydropsyche sp.), and an unidentified stonefly (Plecoptera) were collected in the riffle areas, whereas phantom midge (Chaoborus sp.), midges (Chironomous sp.), and whirligig beetle (Gyrinus sp.) were collected in the pools. Species of fish were numerous in both the riffles and pools. Fantail darter (Etheostoma flabellare) was collected in a riffle, and sunfish (Lepomis sp.) and pickerel (Esox americanus) were collected in pools. Table 18 shows the variety of insects and fish collected in the reach from site 11 to site 14. Muskrats (Ondatra zibethicus) and muskrat dens were observed in this reach.

Large schools of mixed Cyprinids (minnows) and other fish were observed at sampling site 14, just upstream from the sewage-treatment-plant inflow, during the field trips in June and July 1979. This condition was likely caused by upstream migration in response to discharge at the plant. The fewer taxa collected at sampling site 16, just downstream from the plant's inflow, indicate the effect of pollution from Chrisney's partly treated wastewater on the aquatic community. Many species observed at sites 12 and 14 were absent at site 16, and, although not quantified, some organisms such as Chironomous sp. and Tubifex sp. were noticeably more evident than elsewhere on the stream. Fish populations at site 16 were reduced to tolerant species such as creek chub (Semotilus atromaculatus) and bluntnosed minnow (Pimephales notatus).

The aquatic community in the backwater reach of East Fork Little Pigeon Creek, from just downstream from sampling site 18 to the confluence with Little Pigeon Creek, differs from those at upstream reaches. Organisms adapted to riffle areas are missing, and pool-tolerant organisms are dominant. Attached filamentous algae (for example, Rhizoclonium sp. and Spirogyra sp.) were not present, but planktonic algae (for example, Oscillatoria sp. and Synedra sp.) were observed at site 19. Planktonic invertebrates (for example, Keratella sp., Bosmina sp., Daphnia sp., and numerous copepods) were also present. Large stream fish (for example, bowfin (Amia calva) and wood ducks (Aix sponsa) and newly-hatched ducklings were seen by the authors during their June and July 1979 field trips.

Bottom Sediment.--Samples of bottom sediment collected at four stations in the study basin were forwarded to the Geological Survey laboratory for determination of amounts of adsorbed aluminum, iron, and manganese. The quantities of the adsorbed metals are shown in table 19. Concentrations of these metals in the water phase, in dissolved and particulate form, are also included in the table for comparison. Bar graphs of these data are given in figures 26-28. Locations of sampling sites are shown in figures 14 and 17.

The quantities of iron, manganese, and aluminum adsorbed on the bottom sediments were higher at sampling sites 12 and 14 on East Fork Little Pigeon Creek than at sampling sites 16 and 19, which are in the lower reaches of the creek. The reason for the difference in quantities absorbed is not known but may have been due to anaerobic conditions in the bottom sediment at sites 16 and 19. Under anaerobic conditions, metals such as iron and manganese can be released to the liquid phase (Hem, 1970, p. 227).

Bottom-sediment samples were not collected at sites on the unnamed tributary draining the Kelco mining area (sites 1-4) or at sites unaffected or minimally affected by mining (sites 5, 9, 10, and 17). Therefore, the authors cannot state explicitly that the quantities of metals adsorbed on bottom sediment at the sampling sites along East Fork Little Pigeon Creek (sites 12 and 14) resulted from mining. Further, the extent of the observed impact is difficult to project because background data were not available for the study basin. Fortunately, bottom-sediment samples were recently collected from sites nearby as part of another Geological Survey coal-hydrology project. Quantities of aluminum, iron, and manganese absorbed on bottom sediment at the nearby sites are shown under "Other basins in southwestern Indiana" in table 19. The extent of mining within each of these basins has not been determined to date. However, the authors' preliminary review of these basins indicates that sampling sites 241 and 247 are in watersheds that have not been mined. As shown in table 19, the quantities of metals absorbed on bottom sediment at these sites were low. In contrast, quantities of metals absorbed on bottom sediment at sampling sites 27 and 267, which are known to be affected by acid mine drainage, were high.

A comparison of the bottom-sediment determinations for sites 12 and 14 with those just described for nonaffected and affected basins, in terms of a history of coal mining, shows that the reach from sites 12 through 14 is in the affected category. This observation and local mining history strongly suggest that East Fork Little Pigeon Creek has been subjected to much greater loads of metals than those present during the field trips in June and July 1979. The source of the high quantities of metals adsorbed on the bottom sediment of East Fork Little Pigeon Creek is probably drainage from the Kelco mining area. Less likely sources are the Crooks Mullen Pit (number 3, fig. 11) and an unidentified mine along the east drainage divide of the study basin (number 2, fig. 11).

Summary of Surface-Water Information.--On the basis of chemical, physical, biological, and visual observations during field trips, the creeks in the study basin can be segregated into at least six reaches:

(1) The headwaters of East Fork Little Pigeon Creek, upstream from sampling site 11, draining primarily agricultural land and minimally affected by previous mining. The permit area is along the creek in this segment (fig. 17).

Table 19.--Concentrations of selected metals in streams in

[Streamflow measured by

Sampling site	Location[1]	Date	Instantaneous streamflow (ft^3/s)	Aluminum dissolved (mg/L)	Aluminum suspended (mg/L)	Aluminum total (mg/L)	Aluminum on bottom sediment (µg/g)
			East Fork Little Pigeon Creek near Chrisney				
12	East Fork Little Pigeon Creek near Chrisney	6-4-79	0.04	0.03	0	0.03	4,200
14	East Fork Little Pigeon Creek near Chrisney	6-4-79	.03	.02	0	.02	4,800
16	East Fork Little Pigeon Creek near Chrisney	6-4-79	.14	.03	0	.03	1,300
19	East Fork Little Pigeon Creek near Chrisney	6-4-79	.08E	.01	0	.01	1,200
			Other basins in southwestern Indiana				
275	Anderson River near Adyeville	5-31-79	17	----	-	.35	2,800
247	Straight River near Huntingburg	5-22-79	8.2	----	-	.26	430
241	Mill Creek near Jasper	5-22-79	6.4	----	-	.00	300
243	Little Flat Creek near Otwell	5-22-79	1.6	----	-	.28	2,700
267	Little Pigeon Creek near Tennyson	5-31-79	5.1	----	-	1.1	5,500
27	Sandy Creek near headwaters	6-4-79	.31	.03	0	.03	5,300

[1]See figure 17 for locations of sampling sites on East Fork Little Pigeon Creek and figures 14 and 33 for the remaining sites.

southwestern Indiana and quantities of metals adsorbed on bottom sediment

U.S. Geological Survey]

Iron dissolved (mg/L)	Iron suspended (mg/L)	Iron total (mg/L)	Iron on bottom sediment (µg/g)	Manganese dissolved (mg/L)	Manganese suspended (mg/L)	Manganese total (mg/L)	Manganese on bottom sediment (µg/g)	Total cations and anions (meq/L)
East Fork Little Pigeon Creek near Chrisney								
0.02	0.43	0.45	25,000	0.27	0.00	0.27	2,200	45.53
.15	.40	.55	47,000	.60	.04	.64	2,300	23.57
.04	.20	.24	9,100	.11	.01	.12	670	37.02
.12	.54	.66	8,300	2.1	.00	2.1	490	14.4
Other basins in southwestern Indiana								
.04	1.6	1.6	8,900	.64	.00	.63	490	5.88
.08	2.1	2.2	3,200	.51	.08	.59	300	4.55
.08	.8	.88	1,800	.10	.02	.12	160	6.2
.03	.79	.82	10,000	.19	.06	.25	430	11.63
.03	1.5	1.5	15,000	1.6	.00	1.6	550	12.00
6.1	1.3	7.4	36,000	22	.00	22	1,100	71.2

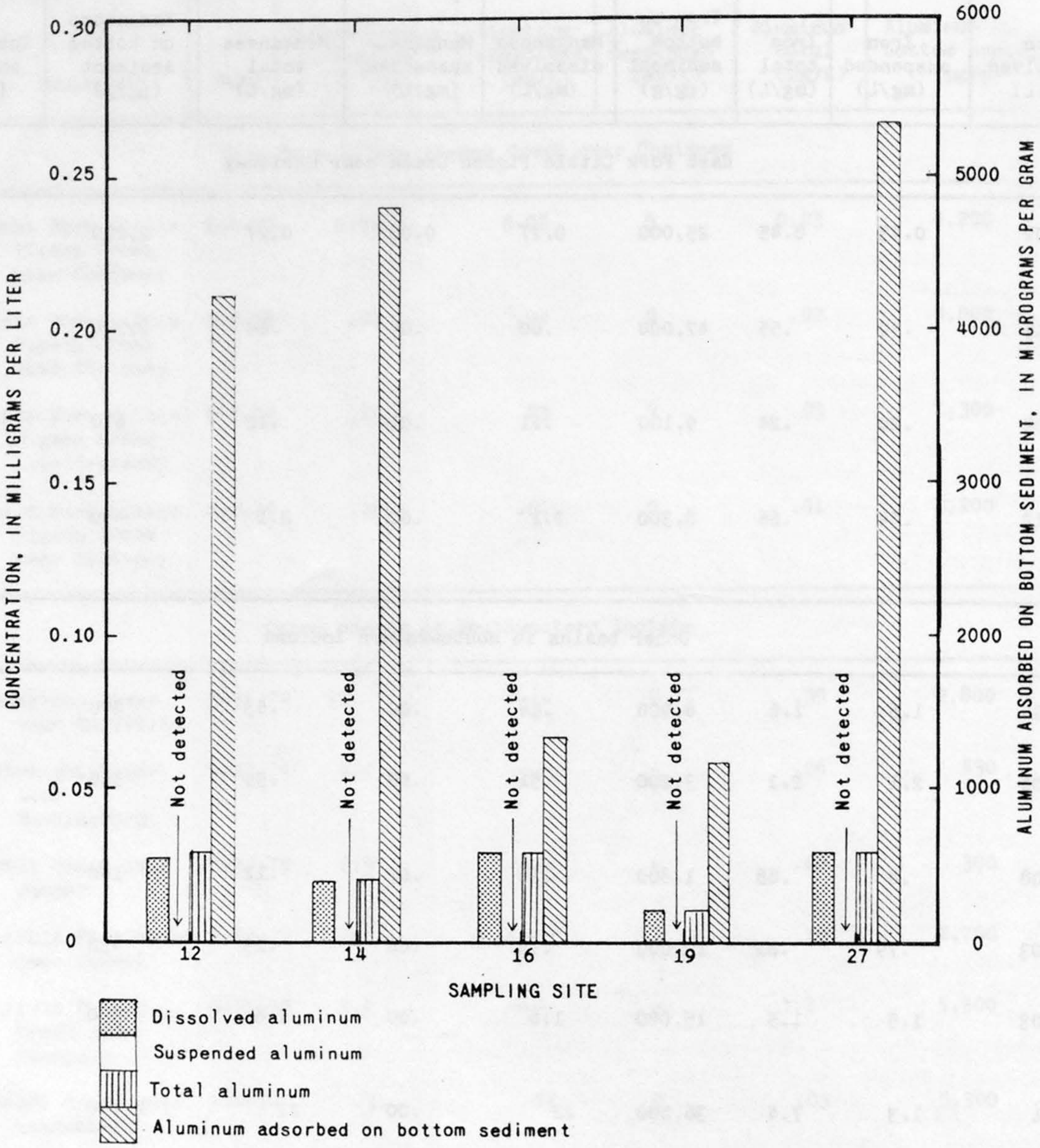


Figure 26.-- Dissolved, suspended, and adsorbed aluminum in streams in southwestern Indiana, June 6, 1979.

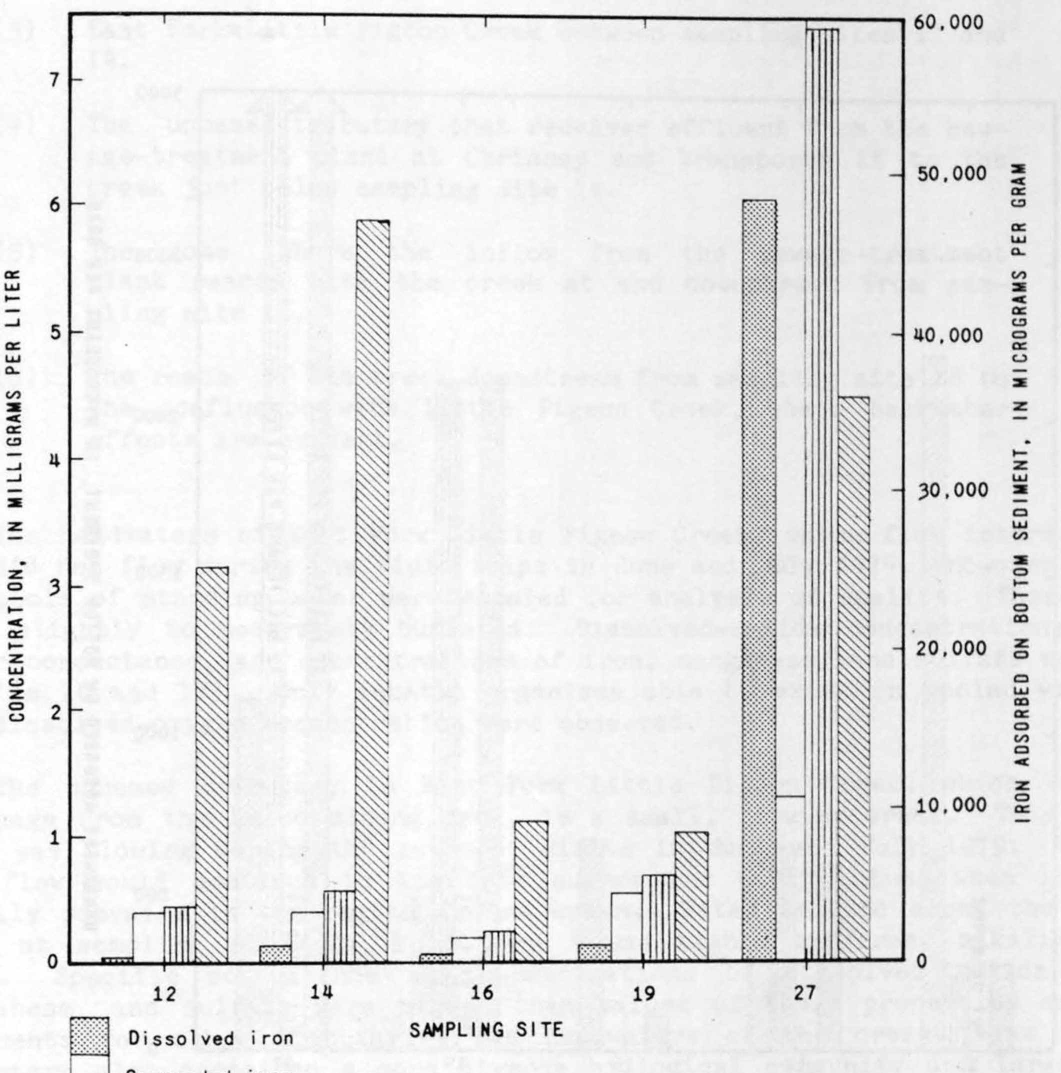


Figure 27.-- Dissolved, suspended, and adsorbed iron in streams in southwestern Indiana, June 6, 1979.

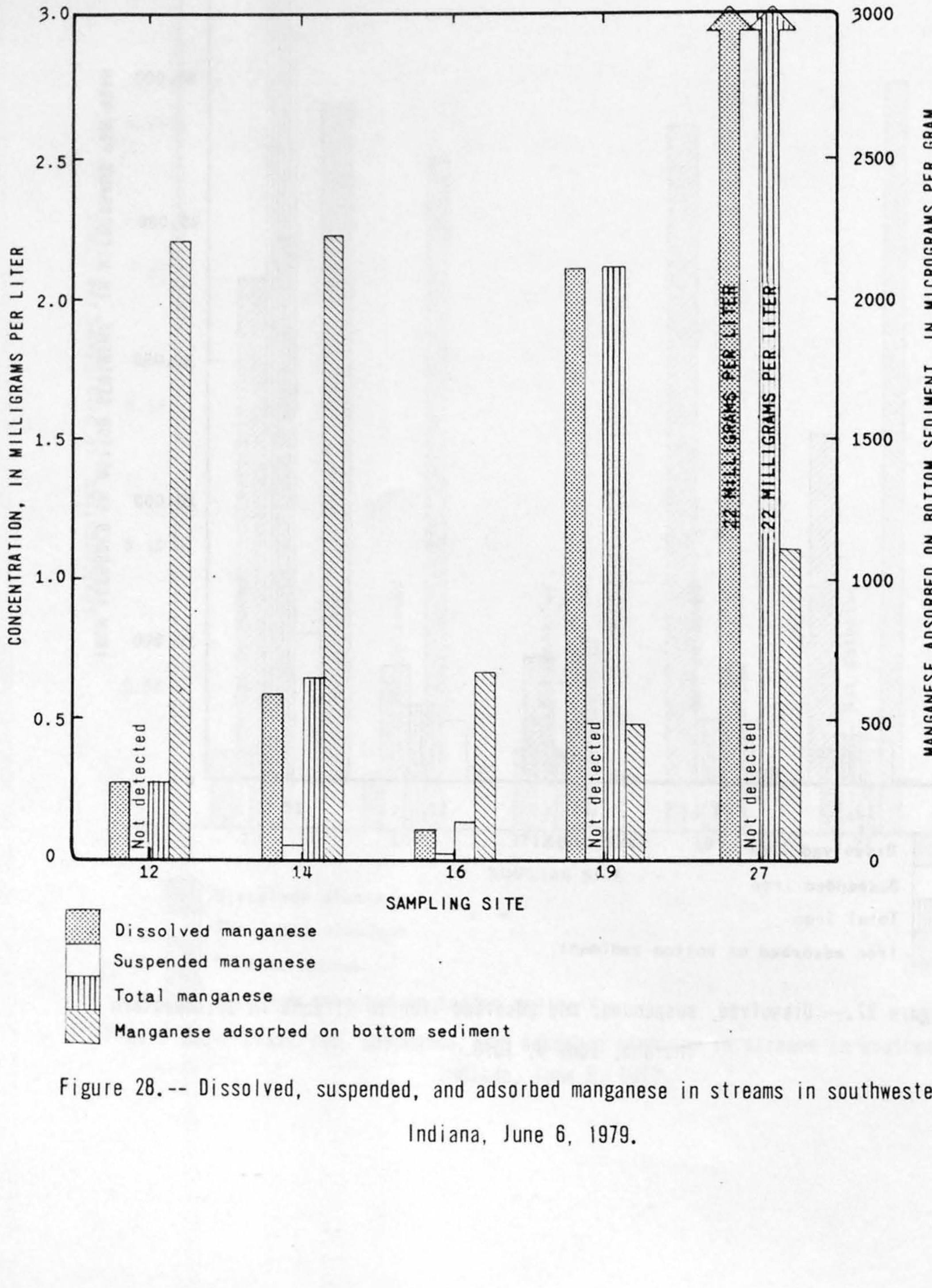


Figure 28.-- Dissolved, suspended, and adsorbed manganese in streams in southwestern Indiana, June 6, 1979.

(2) The unnamed tributary to the creek receiving drainage from the Kelco mining area. The water quality of the creek has been affected by the mine.

(3) East Fork Little Pigeon Creek between sampling sites 11 and 14.

(4) The unnamed tributary that receives effluent from the sewage-treatment plant at Chrisney and transports it to the creek just below sampling site 14.

(5) The zone where the inflow from the sewage-treatment plant reacts with the creek at and downstream from sampling site 16.

(6) The reach of the creek downstream from sampling site 18 to the confluence with Little Pigeon Creek, where backwater effects are evident.

The headwaters of East Fork Little Pigeon Creek, which flow intermittently, did not flow during the field trips in June and July 1979. However, shallow pools of standing water were sampled for analysis of quality. These pools were slightly to moderately buffered. Dissolved-solids concentrations, specific conductance, and concentrations of iron, manganese, and sulfate were low (tables 16 and 17). Only aquatic organisms able to exist in pooled water of low dissolved-oxygen concentration were observed.

The unnamed tributary to East Fork Little Pigeon Creek, which receives drainage from the Kelco mining area, is a small, flowing creek. This tributary was flowing during the authors' visits in June and July 1979. Whether the flow would continue in the late summer and early autumn when low flow usually prevails in the region is not known. Water sampled along the tributary at sampling sites 1, 2, 3, and 4 was highly buffered, alkaline, and hard. Specific conductance and concentrations of dissolved solids, iron, manganese, and sulfate were higher than values of these properties and constituents for other tributaries and headwaters of the creek. The unnamed tributary also contained a more diverse biological community and larger numbers of organisms than the headwaters of the creek, probably caused by differences in flow regime rather than in water quality.

The stream reach bounded by sampling sites 11 and 14 on East Fork Little Pigeon Creek consists of a network of long, deep pools and connecting flowing riffles. Most of this reach is treeless. Measurements of chemical characteristics of water in this reach are similar to those of the unnamed tributary draining the Kelco mining area. A general trend of decreasing concentrations of total cations and anions was determined, but the chemical water type did not change. The aquatic community within the reach was very diverse. Filamentous algae covered rocks in the riffle areas, and planktonic algae abounded in pool areas. Both riffles and pools along the creek contained many species of crustaceans, insects, mollusks, and fish. Some of the fish were of recreational value.

Both banks of the unnamed tributary receiving discharge from the sewage-treatment plant at Chrisney were covered by vegetation. Streamflow at site 15 on this tributary was approximately equal to the flow at sampling site 14 on East Fork Little Pigeon Creek, just above the confluence with the inflow. Dissolved-oxygen concentration in the tributary was low (4.3 mg/L), and nutrient concentrations were very high. Calcium hardness of the water was 140 mg/L (table 16) as calcium carbonate. This concentration is within the range of "hard" water according to Hem (1970, p. 225). The tributary was impacted by oxygen-demanding substances as indicated by the low dissolved-oxygen concentration, the few species collected, and the many individuals per species observed in the field analysis. Only organisms adapted to breathing air or tolerant of low dissolved-oxygen concentration were present.

The maximum streamflow in the study basin was observed in the mixing zone downstream from the sewage-treatment-plant inflow. This area consisted of small pools and riffles and little or no vegetative cover. Chemical characteristics of the mixing zone were similar to those described in the preceding paragraph. However, the concentrations of some of the major cations and anions in this zone varied. Also, the number of aquatic species in the mixing zone exceeded the number in the tributary receiving effluent from the sewage-treatment plant. Far fewer organisms were found at either sampling site 15 or 16 than in East Fork Little Pigeon Creek upstream from the inflow (site 14). Organisms identified in the mixing zone were tolerant of low dissolved-oxygen concentration.

The lower reach of East Fork Little Pigeon Creek, between sites 18 and 19, consists of well-shaded, deep pools affected by backwater. These pools were stagnant when observed in June and July 1979. The concentrations of nutrients in the reach were high (ammonia, 1.6 to 5.2 mg/L; nitrate, 0.7 to 0.8 mg/L; and orthophosphate, 0.3 mg/L). Other properties and dissolved constituents and their ranges of values included total alkalinity (from 80 to 140 mg/L as $CaCO_3$), specific conductance (from 300 to 700 µmho/cm); and sulfate concentration (from 40 to 160 mg/L); the prevalent water type remained unchanged. The aquatic community in the reach differed from that anywhere else in the study basin. The planktonic species replaced the species adapted to flowing water, and planktonic algae and microinvertebrates dominated the aquatic community.

Permit Area

The permit area contains no lakes, ponds, or creeks. Surface drainage from the area is provided by a single swale that flows into the headwaters of East Fork Little Pigeon Creek immediately south of the hypothetical minesite (fig. 29). This swale drains nearly all the permit area plus an additional 25 acres northeast of the area. The swale generally contains water only during and immediately after rainfall, except for continuous flow during March and April when seasonally high ground-water and saturated-soil conditions prevail. The entire length of the swale was dry during both field trips in June and July 1979.

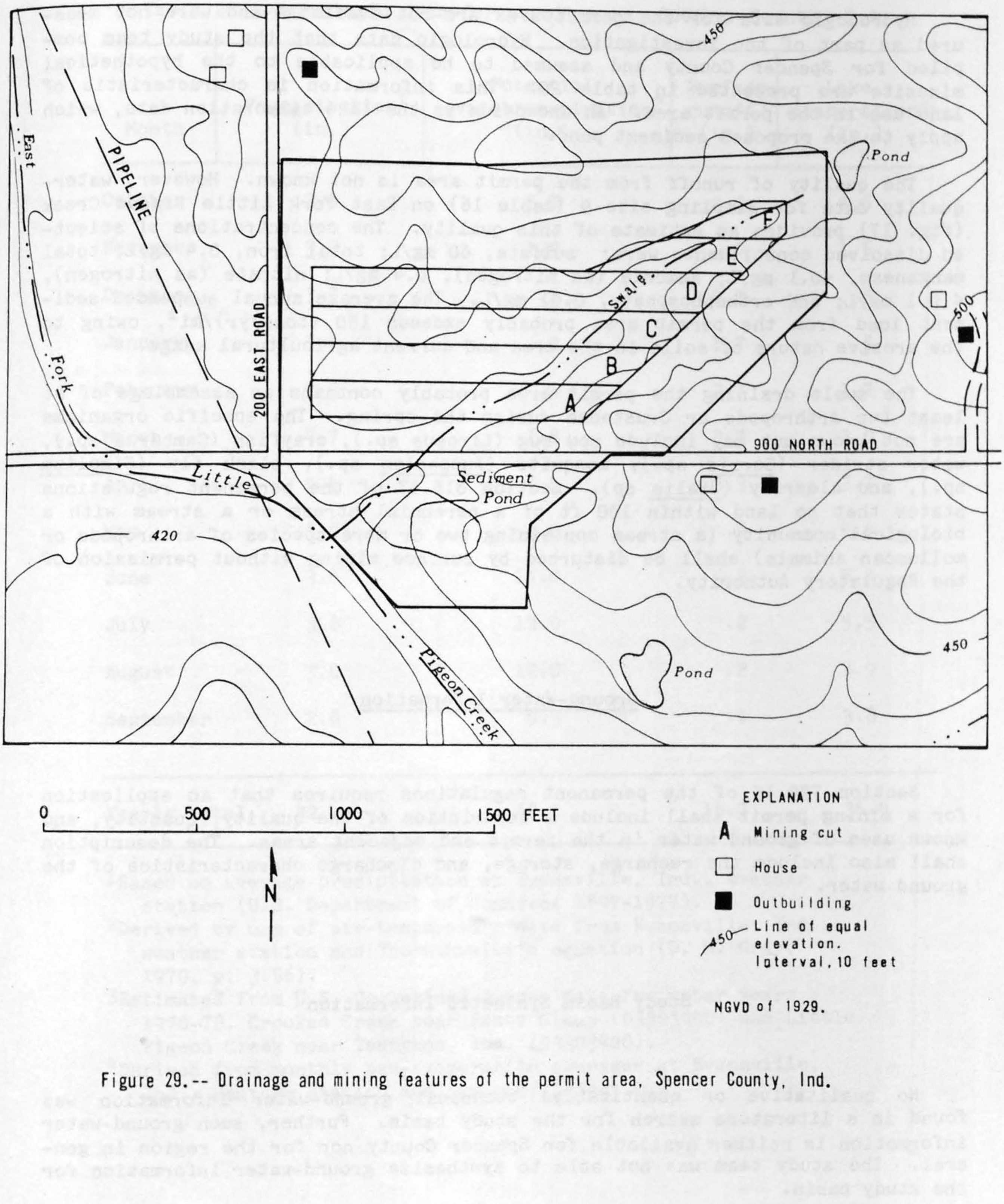


Figure 29.-- Drainage and mining features of the permit area, Spencer County, Ind.

Hydrologic data for the permit area are not available and were not measured as part of the investigation. Hydrologic data that the study team compiled for Spencer County and assumed to be applicable to the hypothetical minesite are presented in table 20. This information is characteristic of land use in the permit area. An exception is the lake evaporation data, which apply to the proposed sediment pond.

The quality of runoff from the permit area is not known. However, water-quality data for sampling site 9 (table 16) on East Fork Little Pigeon Creek (fig. 17) provides an estimate of this quality. The concentrations of selected dissolved constituents were: sulfate, 60 mg/L; total iron, 0.4 mg/L; total manganese, <0.1 mg/L; ammonia (as nitrogen), 0.4 mg/L; nitrate (as nitrogen), < 0.1 mg/L; and orthophosphate, 0.01 mg/L. The average annual suspended-sediment load from the permit area probably exceeds 150 (tons/yr)/mi^2, owing to the erosive nature of soils in the area and current agricultural usage.

The swale draining the permit area probably contains an assemblage of at least two Arthropods or Crustacea during the spring. The specific organisms are not known but may include sow bug (Lirceus sp.), crayfish (Cambarus sp.), water strider (Gerris sp.), mosquito (Anopheles sp.), black fly (Simulium sp.), and alderfly (Sialis sp). Section 816.57 of the permanent regulations states that no land within 100 ft of a perennial stream or a stream with a biological community (a stream containing two or more species of arthropods or molluscan animals) shall be disturbed by surface mining without permission of the Regulatory Authority.

Ground-Water Information

Section 779.15 of the permanent regulations requires that an application for a mining permit shall include a description of the quality, quantity, and known uses of ground water in the permit and adjacent areas. The description shall also include the recharge, storage, and discharge characteristics of the ground water.

Study Basin Synthetic Information

No qualitative or quantitative technical ground-water information was found in a literature search for the study basin. Further, such ground-water information is neither available for Spencer County nor for the region in general. The study team was not able to synthesize ground-water information for the study basin.

Table 20.--Hydrologic data for permit area, Spencer County, Ind.

Month	Precipitation[1] (in.)	Potential evapotranspiration[2] (in.)	Surface runoff[3] (in.)	Lake evaporation[4] (in.)
October	2.5	5.5	0.2	2.6
November	3.2	1.9	.8	1.6
December	3.3	.2	1.7	.8
January	3.4	.0	1.7	.8
February	3.3	.3	2.7	1.2
March	4.7	1.8	3.7	2.0
April	4.1	5.1	3.3	3.7
May	4.4	8.0	.8	4.6
June	3.6	11.0	.3	5.4
July	3.8	13.0	.2	5.5
August	3.0	12.0	.2	4.9
September	2.8	9.3	.1	3.8
Yearly total	42.1	68.1	15.7	36.9

[1]Based on average precipitation at Evansville, Ind., weather station (U.S. Department of Commerce 1897-1977).

[2]Derived by use of air-temperature data from Evansville, Ind., weather station and Thornthwaite's equation (D. M. Gray, 1970, p. 3.56).

[3]Estimated from U.S. Geological Survey data for water years 1970-78, Crooked Creek near Santa Claus (03303400) and Little Pigeon Creek near Tennyson, Ind. (03303400).

[4]Derived from monthly pan-evaporation averages at Evansville, Ind., weather station and pan coefficient 0.7.

A review of well logs and discussion with landowners indicated that no major aquifer is within 200 ft of land surface. Depth of wells that can provide water at a maximum rate of only 2 to 3 gal/min ranges from 15 to 125 ft below land surface.

For this study, the authors assumed that the direction of ground-water movement is generally down dip, or southwest, but numerous changes in lithology within the study basin suggest that aquifers are localized. Discussions with landowners and drillers and a review of well logs suggest that small amounts of ground water may be present along the upper edges of both the unnamed coal seam and the Buffaloville coal seam (fig. 7).

The locations of 11 water wells in or near the study basin that were sampled during the field trips in June and July 1979 are shown in figure 30. Results of on-site chemical analyses during the field trips and other analyses in the laboratory are given in tables 21 and 22, respectively. Some of the laboratory-derived data and the major cation-anion balances of ground-water samples collected in and near the study basin are summarized in figure 31.

For discussion, the wells that were sampled are separated into two groups:

(1) Wells pumping aquifers stratigraphically above potential impacts from local mining (wells A, B, C, and D); and
(2) Wells pumping aquifers that are in the proper stratigraphic position for possible impacts from local mining (wells E, F, G, and J).

Wells A, B, C, and D, west or northwest of Chrisney (fig. 30), draw water from depths far above both the unnamed coal seam and the Buffaloville coal seam. Field chemical analyses of water from wells A, B, C, and D are given in table 21, and laboratory chemical analyses of water sampled from wells A and C are given in table 22. Field and laboratory analyses of water from wells A and C are in good agreement, except for calcium concentration at well A, total alkalinity concentration at well C, and magnesium concentration at well C. Laboratory analyses show that the predominant cations and anions in the ground water sampled from well A are calcium, sodium, magnesium, sulfate, and bicarbonate. (Alkalinity shown in table 22 is for the bicarbonate ion. (See Hem, 1970, p. 152-154.) The combined concentration of cations and anions is approximately 32 meq/L, the highest value observed in the study basin (table 22 and fig. 31). Well A is next to a livestock barn and may be contaminated by animal waste. Contamination is suggested by the high concentrations of chloride and sulfate (100 mg/L and 320 mg/L, respectively, table 22).

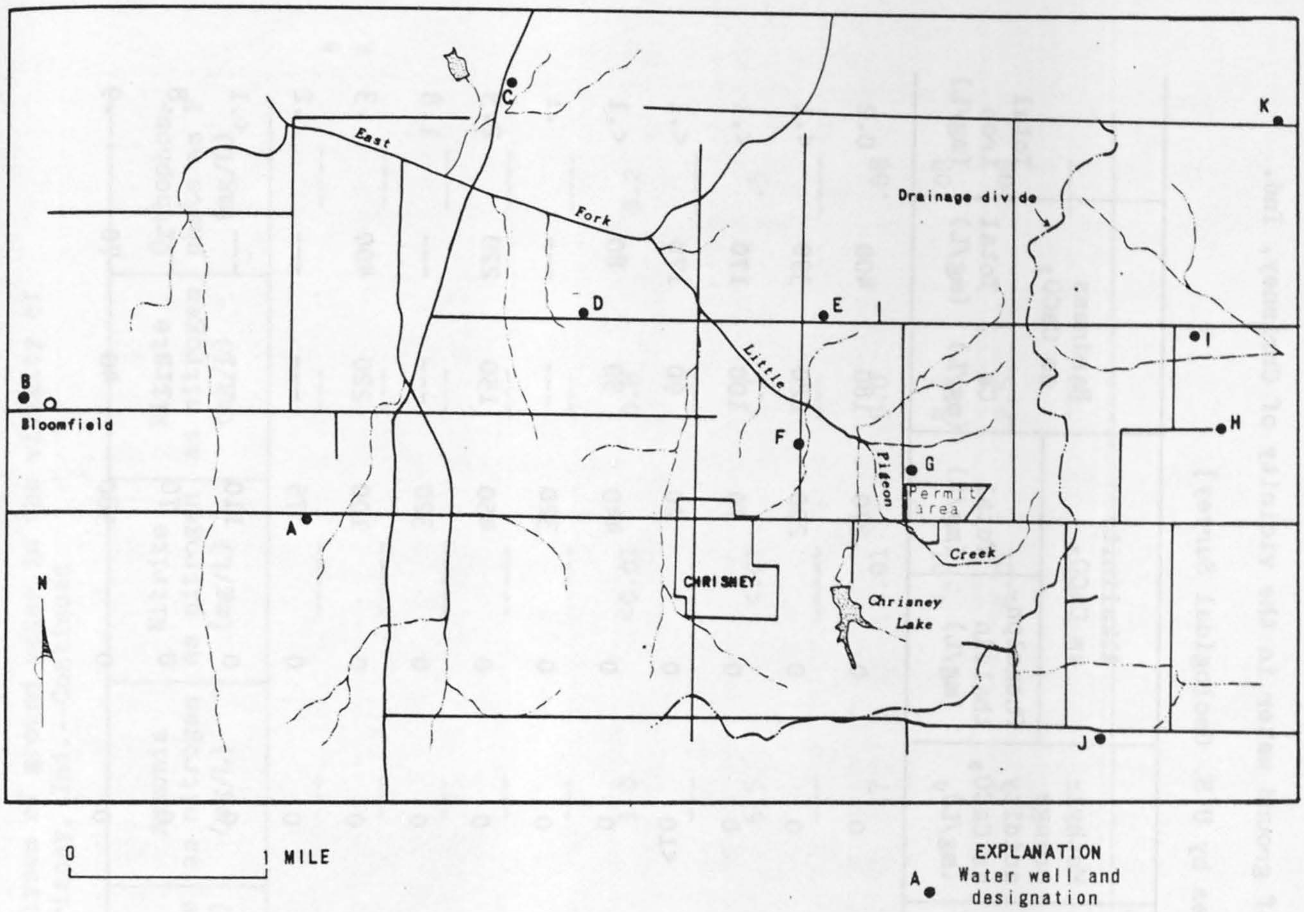


Figure 30.-- Water wells sampled in the vicinity of Chrisney, Ind.

The laboratory analysis of water from well C shows that the predominant ions of this water are calcium, magnesium, sodium, and sulfate. The combined concentration of cations and anions is approximately 8 meq/L, the lowest value determined in the study basin (table 22 and fig. 31).

Water samples from wells B and D were not analyzed in the laboratory. However, field analyses of water from wells A, B, C, and D (table 21) indicate that the quality of water in well A is similar to that in well B. For example, pH and specific conductance of water in the two wells are identical. Also, concentrations of total alkalinity and total hardness of water in the two wells are nearly equal. The similarity of water quality in wells A and B suggests that these wells draw water from the same aquifer or from aquifers that are similar mineralogically. Analyses of water from wells C and D indicate that the quality of water in these wells is similar and that wells C and D have the lowest dissolved-solids concentration of the 10 wells sampled. The

Table 21.--Field analyses of ground water in the vicinity of Chrisney, Ind.

[Analyses by U.S. Geological Survey]

Well	Date of sampling	pH	Specific conductance (µmho/cm at 25° C)	Methyl-orange acidity as $CaCO_3$ (mg/L)	Alkalinity as $CaCO_3$		Hardness as $CaCO_3$		Total iron (mg/L)
					Phenolphthalein (mg/L)	Total (mg/L)	Ca (mg/L)	Total (mg/L)	
A	6-7-79	6.8	1,200	0	0	270	180	400	0.2
B	6-7-79	6.8	1,200	0	0	290	220	390	<.1
C	6-7-79	6.2	400	0	0	70	100	170	<.1
D	6-7-79	5.8	400	<10	0	20	90	170	<.1
E	6-7-79	7.7	1,000	0	0	440	50	80	<.1
	7-20-79	7.8	1,300	0	0	320	---	---	.1
F	6-7-79	7.2	800	0	0	450	150	220	2.3
	7-20-79	7.2	750	0	0	320	---	---	1.8
G	6-7-79	6.4	900	0	0	100	220	400	.3
	7-20-79	6.5	1,200	0	0	75	---	---	.2
H	7-20-79	6.8	900	0	0	110	---	---	<.1
I	7-20-79	6.9	950	0	0	70	---	---	.8
J	6-7-79	7.5	850	0	0	580	40	70	.9

Table 21.--Field analyses of ground water in the vicinity of Chrisney, Ind.--Continued

Well	Total manganese (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Ammonia as nitrogen (mg/L)	Nitrite as nitrogen (mg/L)	Nitrate as nitrogen (mg/L)	Orthophosphate as P (mg/L)
A	<0.1	110	350	---	-----	---	----
B	<.1	---	140	---	-----	---	----
C	<.1	20	80	---	-----	---	----
D	<.1	---	80	---	-----	---	----
E	<.1	20	140	---	-----	---	----
	<.1	---	40	1.0	<0.01	0.8	0.2
F	<.1	70	<5	---	-----	---	----
	<.1	36	<5	5.5	<.01	<.1	.5
G	<.1	105	150	---	-----	---	----
	<.1	131	40	.7	<.01	5.0	.08
H	<.1	55	30	.4	<.01	4.6	.08
I	.2	25	50	.6	<.01	2.5	.09
J	<.1	10	<5	---	-----	---	----

Table 22.--Laboratory analyses of ground-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.

[Analyses by U.S. Geological Survey]

Well A: Depth below land surface, 40 ft

Parameter	Unit of measure	Measurement	Parameter	Unit of measure	Measurement
Acidity, as H^+	mg/L	0.0	pH, field.		6.8
Acidity, tot. as $CaCO_3$	mg/L	0	pH, lab.		7.8
Alk, tot. as $CaCO_3$	mg/L	260	Phosphorus, diss. as P	mg/L	0.02
Aluminum, diss.	µg/L	0	Potassium, diss.	mg/L	2.8
Aluminum , susp.	µg/L	0	Diss. solids,		
Aluminum, tot.	µg/L	0	residue at 105° C	mg/L	1,110
Calcium, diss.	mg/L	140	Tot. solids,		
Chloride, diss.	mg/L	100	residue at 105° C	mg/L	1,120
Fluoride, diss.	mg/L	.1	Susp. solids	mg/L	0
Hardness, noncarb.	mg/L	290	SAR		2.6
Hardness, tot. as $CaCO_3$	mg/L	550	Silica, diss.	mg/L	15
Iron, diss.	µg/L	10	Sodium, diss.	mg/L	140
Iron, susp.	µg/L	190	Sodium	percent	35
Iron, tot.	µg/L	200	Spec. conduc., field	µmho/cm	
Magnesium, diss.	mg/L	49		at 25° C	1,200
Manganese, diss.	µg/L	0	Spec. conduc., lab	µmho/cm	
Manganese, susp.	µg/L	0		at 25° C	1,520
Manganese, tot.	µg/L	0	Sulfate, diss.	mg/L	320
			Water temp.	°C	14.0

Cations	(mg/L)	(meq/L)	Anions [1]	(mg/L)	(meq/L)
Calcium, diss.	140	6.986	Chloride, diss.	100	2.821
Magnesium, diss.	49	4.031	Fluoride, diss.	0.1	0.006
Potassium, diss.	2.8	0.072	Sulfate, diss.	320	6.663
Sodium, diss.	140	6.090	Alk, tot. as $CaCO_3$	260	5.195
	Total	17.179		Total	14.685

Table 22.--Laboratory analyses of ground-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.--Continued

Well C: Depth below land surface, 72 ft

Parameter	Unit of measure	Measure-ment	Parameter	Unit of measure	Measure-ment
Acidity, as H^+	mg/L	0.0	pH, field		6.2
Acidity, tot. as $CaCO_3$	mg/L	0	pH, lab.		6.4
Alk, tot. as $CaCO_3$	mg/L	52	Phosphorus, diss. as P	mg/L	.02
Aluminum, diss.	µg/L	10	Potassium, diss.	mg/L	1.0
Aluminum, susp.	µg/L	0	Diss. solids,		
Aluminum, tot.	µg/L	0	residue at 105° C	mg/L	330
Calcium, diss.	mg/L	34	Tot. solids,		
Carbon dioxide	mg/L	64	residue at 105° C	mg/L	331
Chloride, diss.	mg/L	15	Susp. solids	mg/L	0
Fluoride, diss.	mg/L	0.1	SAR		1.2
Hardness, noncarb.	mg/L	95	Silica, diss.	mg/L	34
Hardness, tot. as $CaCO_3$	mg/L	150	Sodium + potassium	mg/L	34
Iron, diss.	µg/L	10	Sodium, diss.	mg/L	33
Iron, susp.	µg/L	50	Sodium	percent	33
Iron, tot.	µg/L	60	Spec. conduc., field	µmho/cm	
Magnesium, diss.	mg/L	15		at 25° C	400
Manganese, diss.	mg/L	0	Spec. conduc., lab.	µmho/cm	
Manganese, susp.	µg/L	0		at 25° C	451
Manganese, tot.	µg/L	0	Sulfate, diss.	mg/L	110
			Water temp.	°C	14.0

Cations	(mg/L)	(meq/L)	Anions[1]	(mg/L)	(meq/L)
Calcium, diss.	34	1.697	Chloride, diss.	15	0.423
Magnesium, diss.	15	1.234	Fluoride, diss.	0.1	0.005
Potassium, diss.	1.0	0.026	Sulfate, diss.	110	2.290
Sodium, diss.	33	1.436	Alk, tot. as $CaCO_3$	52	1.039
	Total	4.393		Total	3.757

Table 22.--Laboratory analyses of ground-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.--Continued

Well E: Depth below land surface, 102 ft

Parameter	Unit of measure	Measurement	Parameter	Unit of measure	Measurement
Acidity, as H^+	mg/L	0.0	pH, field		7.7
Acidity, tot. as $CaCO_3$	mg/L	0	pH, lab		8.1
Alk, tot. as $CaCO_3$	µg/L	420	Phosphorus, diss. as P	mg/L	.02
Aluminum, diss.	µg/L	20	Potassium, diss.	mg/L	2.5
Aluminum, susp.	µg/L	10	Diss. solids, residue at 105° C	mg/L	818
Aluminum, tot.	µg/L	30			
Calcium, diss.	mg/L	15	Tot. solids, residue at 105° C	mg/L	820
Carbon dioxide	mg/L	52			
Chloride, diss.	mg/L	18	Susp. solids	mg/L	2
Fluoride, diss.	mg/L	.4	SAR		15
Hardness, noncarb.	mg/L	0	Silica, diss.	mg/L	15
Hardness, tot. as $CaCO_3$	mg/L	64	Sodium + potassium	mg/L	270
Iron, diss.	µg/L	10	Sodium, diss.	mg/L	270
Iron, susp.	µg/L	80	Sodium	percent	90
Iron, tot.	µg/L	90	Spec. conduc., field	µmho/cm at 25° C	1,000
Magnesium, diss.	mg/L	6.4			
Manganese, diss.	µg/L	0	Spec. conduc., lab.	µmho/cm at 25° C	1,260
Manganese, susp.	µg/L	0			
Manganese, tot.	µg/L	0	Sulfate, diss.	mg/L	230
			Water temp.	°C	14.0

Cations	(mg/L)	(meq/L)	Anions[1]	(mg/L)	(meq/L)
Calcium, diss.	15	0.749	Chloride, diss.	18	0.508
Magnesium, diss.	6.4	0.526	Fluoride, diss.	0.4	0.021
Potassium, diss.	2.5	0.064	Sulfate, diss.	230	4.789
Sodium, diss.	270	11.745	Alk, tot. as $CaCO_3$	420	8.392
	Total	13.084		Total	13.710

Table 22.--Laboratory analyses of ground-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.--Continued

Well G: Depth below land surface, 52 ft					
Parameter	Unit of measure	Measure-ment	Parameter	Unit of measure	Measure-ment
Acidity, as H^+	mg/L	0.0	pH, field		6.4
Acidity, tot. as $CaCO_3$	mg/L	0	pH, lab		6.5
Alk, tot. as $CaCO_3$	mg/L	83	Phosphorus, diss. as P	mg/L	.01
Aluminum, diss.	µg/L	20	Potassium, diss.	mg/L	2.2
Aluminum, susp.	µg/L	0	Diss. solids, residue at 105° C	mg/L	738
Aluminum, tot.	µg/L	0			
Calcium, diss.	mg/L	74	Tot. solids, residue at 105° C	mg/L	747
Chloride, diss.	mg/L	120			
Fluoride, diss.	mg/L	0.3	Susp. solids	mg/L	0
Hardness, noncarb.	mg/L	290	SAR		1.9
Hardness, tot. as $CaCO_3$	mg/L	370	Silica, diss.	mg/L	19
Iron, diss.	µg/L	110	Sodium, diss.	mg/L	83
Iron, susp.	µg/L	190	Sodium	percent	33
Iron, tot.	µg/L	300	Spec. conduc., field at 25° C	µmho/cm	900
Magnesium, diss.	mg/L	45			
Manganese, diss.	µg/L	0	Spec. conduc., lab. at 25° C	µmho/cm	1,090
Manganese, susp.	µg/L	40			
Manganese, tot.	µg/L	40	Sulfate, diss.	mg/L	270
			Water temp.	°C	15.0

Cations	(mg/L)	(meq/L)	Anions[1]	(mg/L)	(meq/L)
Calcium, diss.	74	3.693	Chloride, diss.	120	3.386
Magnesium, diss.	45	3.702	Fluoride, diss.	0.3	0.016
Potassium, diss.	2.2	0.057	Sulfate, diss.	270	5.622
Sodium, diss.	83	3.611	Alk, tot. as $CaCO_3$	83	1.659
	Total	11.063		Total	10.683

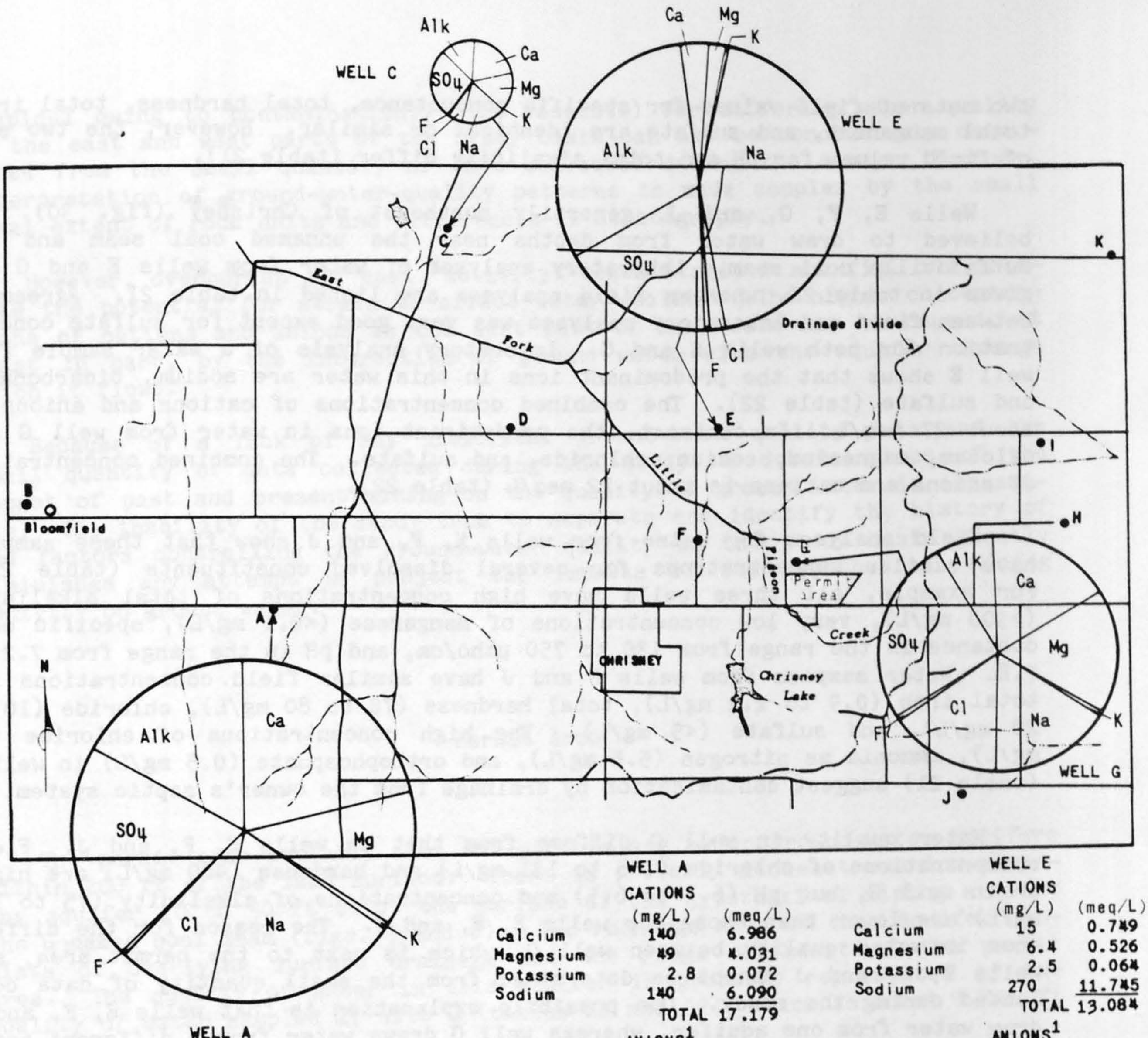
Table 22.--Laboratory analyses of ground-water samples collected on June 6, 1979, in the vicinity of Chrisney, Ind.--Continued

Well K: Depth below land surface, 52 ft

Parameter	Unit of measure	Measure-ment	Parameter	Unit of measure	Measure-ment
Acidity, as H^+	mg/L	0.0	pH, field		7.4
Acidity, tot. as $CaCO_3$	mg/L	0	pH, lab		7.8
Alk, tot. as $CaCO_3$	mg/L	300	Phosphorus, diss. as P	mg/L	.18
Aluminum, diss.	µg/L	20	Potassium, diss.	mg/L	2.6
Aluminum, susp.	µg/L	10	Diss. solids,		
Aluminum, tot.	µg/L	30	residue at 105° C	mg/L	363
Calcium, diss.	mg/L	20	Tot. solids,		
Chloride, diss.	mg/L	21	residue at 105° C	mg/L	367
Fluoride, diss.	mg/L	1.2	Susp. solids	mg/L	4
Hardness, noncarb.	mg/L	0	SAR		5.4
Hardness, tot. as $CaCO_3$	mg/L	80	Silica, diss.	mg/L	12
Iron, diss.	µg/L	80	Sodium diss.	mg/L	110
Iron, susp.	µg/L	1,200	Sodium	percent	74
Iron, tot.	µg/L	1,300	Spec. conduc., field	µmho/cm	
Magnesium, diss.	mg/L	7.3		at 25° C	600
Manganese, diss.	µg/L	20	Spec. conduc., lab.	µmho/cm	
Manganese, susp.	µg/L	2,100		at 25° C	605
Manganese, tot.	µg/L	2,100	Sulfate, diss.	mg/L	5.8
			Water temp.	°C	14.0

Cations	(mg/L)	(meq/L)	Anions[1]	(mg/L)	(meq/L)
Calcium, diss.	20	0.998	Chloride, diss.	21	0.593
Magnesium, diss.	7.3	0.601	Fluoride, diss.	1.2	0.064
Potassium, diss.	2.6	0.067	Sulfate, diss.	5.8	0.121
Sodium, diss.	110	4.785	Alk, tot. as $CaCO_3$	300	5.994
	Total	6.451		Total	6.772

[1]Note: The milliequivalent-per-liter (meq/L) values reported for total alkalinity are for the bicarbonate ion.



WELL A

CATIONS	(mg/L)	(meq/L)
Calcium	140	6.986
Magnesium	49	4.031
Potassium	2.8	0.072
Sodium	140	6.090
	TOTAL	17.179
ANIONS[1]		
Chloride	100	2.821
Fluoride	0.1	0.006
Sulfate	320	6.663
Alk, total as $CaCO_3$	260	5.195
	TOTAL	14.685

WELL E

CATIONS	(mg/L)	(meq/L)
Calcium	15	0.749
Magnesium	6.4	0.526
Potassium	2.5	0.064
Sodium	270	11.745
	TOTAL	13.084
ANIONS[1]		
Chloride	18	0.508
Fluoride	0.4	0.021
Sulfate	230	4.789
Alk, total as $CaCO_3$	420	8.392
	TOTAL	13.710

EXPLANATION

A ● Water well and designation

Alk, Alkalinity

WELL C

CATIONS	mg/L)	(meq/L)
Calcium	34	1.697
Magnesium	15	1.234
Potassium	1.0	0.026
Sodium	33	1.436
	TOTAL	4.393
ANIONS[1]		
Chloride	15	0.423
Fluoride	0.1	0.005
Sulfate	110	2.290
Alk, total as $CaCO_3$	52	1.039
	TOTAL	3.757

WELL G

CATIONS	(mg/L)	(meq/L)
Calcium	74	3.693
Magnesium	45	3.702
Potassium	2.2	0.057
Sodium	83	3.611
	TOTAL	11.063
ANIONS[1]		
Chloride	120	3.386
Fluoride	0.3	0.016
Sulfate	270	5.622
Alk, total as $CaCO_3$	83	1.659
	TOTAL	10.683

[1]Note: The milliequivalent-per-liter (meq/L) values reported for total alkalinity are for the bicarbonate ion.

Figure 31.-- Laboratory analyses illustrating major cation-anion balance of water in four wells in the study basin, June 6, 1979.

two sets of field values for specific conductance, total hardness, total iron, total manganese, and sulfate are identical or similar. However, the two sets of field values for pH and total alkalinity differ (table 21).

Wells E, F, G, and J, generally northeast of Chrisney (fig. 30), are believed to draw water from depths near the unnamed coal seam and the Buffaloville coal seam. Laboratory analyses of water from wells E and G are given in table 22, whereas field analyses are listed in table 21. Agreement between field and laboratory analyses was very good except for sulfate concentration for both wells E and G. Laboratory analysis of a water sample from well E shows that the predominant ions in this water are sodium, bicarbonate, and sulfate (table 22). The combined concentrations of cations and anions is about 27 meq/L. In contrast, the predominant ions in water from well G are calcium, magnesium, sodium, chloride, and sulfate. The combined concentration of anions and cations is about 22 meq/L (table 22).

Field analyses for water from wells E, F, and J show that these samples have similar concentrations for several dissolved constituents (table 21). For example, all three wells have high concentrations of total alkalinity (>300 mg/L), very low concentrations of manganese (<0.1 mg/L), specific conductance in the range from 130 to 750 µmho/cm, and pH in the range from 7.2 to 7.8. Water samples from wells F and J have similar field concentrations for total iron (0.9 to 2.3 mg/L), total hardness (70 to 80 mg/L), chloride (10 to 20 mg/L), and sulfate (<5 mg/L). The high concentrations of chloride (70 mg/L), ammonia as nitrogen (5.5 mg/L), and orthophosphate (0.5 mg/L) in well F (table 21) suggest contamination by drainage from the owner's septic system.

Water quality in well G differs from that in wells E, F, and J. Field concentrations of chloride (105 to 131 mg/L) and hardness (400 mg/L) are higher in well G, but pH (6.4 to 6.5) and concentrations of alkalinity (75 to 100 mg/L) are lower than those for wells E, F, and J. The reason for the difference in water quality between well G, which is next to the permit area, and wells E, F, and J cannot be determined from the small quantity of data collected during the study. One possibile explanation is that wells E, F, and J draw water from one aquifer, whereas well G draws water from a different aquifer. Geologic sections in the east part of the study basin and information on depth of wells provided by homeowners indicate that well G draws water from the vicinity of the unnamed coal seam (figs. 7 and 8). In contrast, wells E and F both draw water from an aquifer near the Buffaloville coal seam, whereas well J seems to draw water above both coal seams. Most homeowners could provide only a rough estimate of the depth of their well. Therefore, the authors suspect that the depth of well J relative to wells E, F, and G is incorrect and that well J is more likely to be drawing water from the same aquifer as wells E and F.

Few conclusions can be supported by the ground-water-quality data collected during the study. Wells in the east part of the study basin (E, F, G, and J), except for well G, have higher pH values and total alkalinity concentrations than wells in the west part of the basin. Also, the combined concentration of major cations and anions seems to be higher for wells sampled in the east part of the study basin (E and G), than for well C in the west part. (The authors assume that the combined concentration of ions for well A is atypical owing to contamination.) The reason(s) for differing water quality in the east and west parts of the study basin can not be conclusively determined from the small quantity of data collected during the study. Further, interpretation of ground-water-quality patterns is made complex by the small areal extent of rock units and differences in stratigraphy.

However, overburden and coal "activity" tests (table 4 and fig. 10) indicate the potential for strata to affect water quality. The higher concentrations of cations and anions in the east part of the basin may be caused, at least in part, by the interaction of ground water with the aquifer through which it flows.

Because of a lack of any historical ground-water-quality data and the small quantity of data collected during the study, a determination of the impact of past and present mining on the quality of ground water is impossible. The inability of the study team to separate and identify the history of and factors controlling the ground-water quality in the study basin greatly diminishes any attempt to project the impacts of the hypothetical mining activity on ground water.

Permit Area

The permit area probably does not contain any major ground-water aquifers within 200 ft of the land surface. There is probably at least one low-yielding aquifer 10 to 30 ft below the surface of the hypothetical mining area at the unnamed coal seam (figs. 7 and 8). The recharge area of this aquifer consists of overlying surface drainage and the ridge northeast of the permit area. The quality of water in this aquifer is probably represented by the quality of water sampled at site G (tables 21 and 22), which is about 1,000 ft north of the permit area.

Other aquifers may underlie the permit area. Most noteworthy is a potential water-bearing stratum at the Buffaloville coal seam. This stratum is an aquifer in the vicinity of the permit area and some wells produce from this aquifer. However, the aquifer is not continuous throughout the region, as was illustrated at the exploration hole drilled as part of the study where water was found only at the unnamed coal seam (table 3). For the study, the authors assumed that water is not present at the Buffaloville coal seam in the permit area.

Sections 776.12, 778.17, and 780.11 of the permanent regulations require that a mine plan be included in the permit application. Pertinent sections from parts 771, 776, 778, 779, 780, 815, and 816 of the permanent regulations were used to develop the mine plan that follows.

Coal Exploration

Exploration holes were not drilled as part of the study. Therefore, the depth, extent, and mineralogy of the Buffaloville and unnamed coal seams were estimated from exploration holes near the permit area. Eight exploration holes would probably have provided the necessary information for the permit area, although no specific number of holes is required by the regulations. Sections 815.15 and 816.13 of the permanent regulations require that exploration holes be cased and sealed. Mine facilities and manmade features in the vicinity of the permit area that were assumed for this evaluation are portrayed in figure 32.

Information on ground-water levels, infiltration rates, subsurface flow, storage characteristics, and the quality of ground water are required by the permanent regulations (section 816.52) to "determine the effect of surface mining activities on the recharge capacity of reclaimed lands and on the quality and quantity of water in ground-water systems in the mine plan and adjacent areas." Again, no specific number of ground-water observation wells are legally required, but a minimum of four wells in the permit area was considered to be necessary by the authors. From an exploration hole drilled near the permit area, the authors determined that the unnamed coal seam (fig. 7) is a low-yield aquifer, that the Buffaloville coal seam is dry, and that the stratum immediately below the Buffaloville coal seam contains no acidic or toxic-forming materials or water. (See section "Bedrock Geology," subsection "Permit Area.") Although the four ground-water observation wells could not be drilled during the study, the authors assumed that an aquifer underlies the permit area at the unnamed coal seam and that a dry stratum capable of transmitting water exists at the Buffaloville coal seam. The authors also assumed that the stratum immediately below the Buffaloville coal seam, the lowest seam to be mined, contained no acidic, alkaline, or toxic-forming materials, nor water (section 779.14).

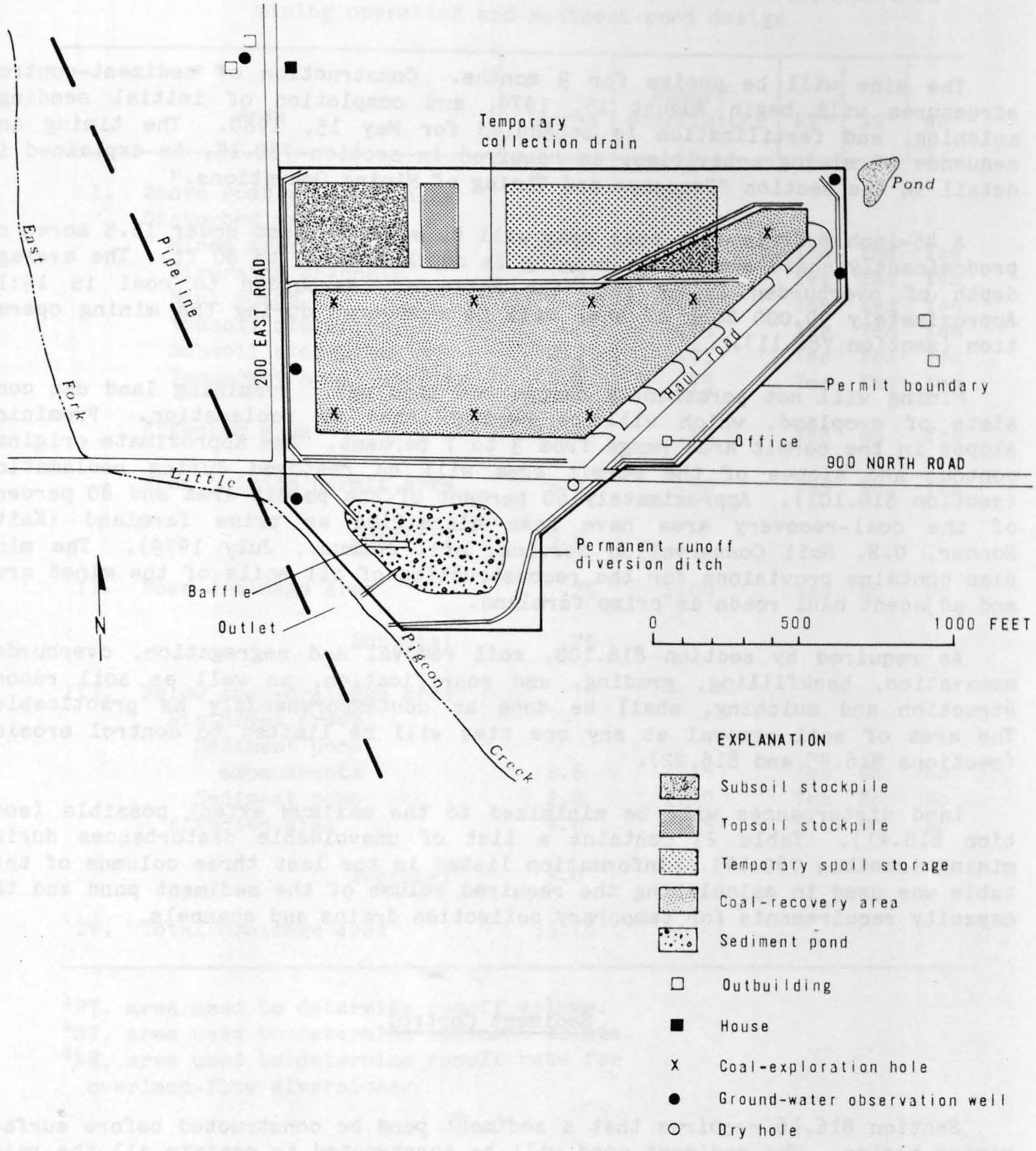


Figure 32. -- Mine facilities and manmade features in the vicinity of the permit area.

General Operational Information

The mine will be active for 9 months. Construction of sediment-control structures will begin August 15, 1979, and completion of initial seeding, mulching, and fertilization is scheduled for May 15, 1980. The timing and sequence of mining activities, as required in section 780.15, is explained in detail in the section "Sequence and Timing of Mining Operations."

A 45-inch Buffaloville coal seam will be surface-mined under 15.5 acres of predominantly shale overburden ranging in depth from 60 to 80 ft. The average depth of overburden is 67 ft. The ratio of overburden to coal is 19:1. Approximately 90,000 tons of coal will be recovered during the mining operation (section 780.11).

Mining will not permanently change the land use. Premining land use consists of cropland, which will be reestablished by reclamation. Premining slopes in the permit area range from 3 to 7 percent. The approximate original contour and slopes of the permit area will be restored during reclamation (section 816.101). Approximately 60 percent of the permit area and 80 percent of the coal-recovery area have been classified as prime farmland (Keith Sonner, U.S. Soil Conservation Service, oral commun., July 1979). The mine plan contains provisions for the reconstruction of all soils of the mined area and adjacent haul roads as prime farmland.

As required by section 816.100, soil removal and segregation, overburden excavation, backfilling, grading, and scarification, as well as soil reconstruction and mulching, shall be done as contemporaneously as practicable. The area of soil removal at any one time will be limited to control erosion (sections 816.45 and 816.22).

Land disturbances will be minimized to the maximum extent possible (section 816.41). Table 23 contains a list of unavoidable disturbances during mining (section 780.14). Information listed in the last three columns of this table was used in calculating the required volume of the sediment pond and the capacity requirements for temporary collection drains and channels.

Sediment Control

Section 816.46 requires that a sediment pond be constructed before surface mining begins. The sediment pond will be constructed to contain all the rainfall from a 24-h, 10-yr precipitation event, which was determined to be 4.5 in. In the construction, the bottom (foundation) of the sediment pond will be cleared of all organic matter; topsoil and subsoil will be stockpiled; and the foundation will be scarified. Fill material for the embankment of the sediment pond will be free of vegetation and coal wastes. The fill will be placed at the lowest part of the foundation and will be built up in compacted, horizontal layers.

Table 23.--Areas of disturbance and acreages in the hypothetical mining operation and sediment-pond design

Area	Acres	Runoff coefficient	RV[1]	SV[2]	RR[3]
I. Above road-drainage area					
Disturbed areas					
Mined areas	15.5	0.75	Yes	Yes	Yes
Diversion channels	1.0	.75	Yes	Yes	Yes
Haul roads	1.6	1.00	Yes	Yes	Yes
Topsoil stockpile	.8	.75	Yes	Yes	Yes
Subsoil stockpile	2.2	.75	Yes	Yes	Yes
Temporary spoil storage	4.9	.75	Yes	Yes	Yes
Affected area	14.0	.60	Yes	No	Yes
Area outside permit area	5.0	.50	Yes	No	Yes
Subtotal	45.0				
II. Road-drainage area	.75	1.00	Yes	No	No
Subtotal	.75				
III. Below road-drainage area					
Disturbed areas					
Sediment pond embankments	1.8	.75	Yes	No	No
Sediment pond	2.2	1.00	Yes	No	No
Affected area	4.0	.65	No	No	No
Subtotal	8.0				
IV. Total drainage area	53.75				

[1]RV, area used to determine runoff volume.
[2]SV, area used to determine sediment volume.
[3]RR, area used to determine runoff rate for overland-flow diversions.

The sediment pond will provide additional storage volume for sediment that will erode from upstream areas disturbed during mining. OSM's criterion of 0.1 acre-ft of storage for each upstream disturbed acre will be used in design of the sediment pond (section 816.46). Discharge from the sediment pond will be controlled by an outlet valve connected to an appropriately sized conduit. This valve will be manually operated to provide a detention time of at least 24 h for all rainfall events equal to or less than the design storm event (section 816.46). After sediment accumulates to 60 percent of the design sediment-storage capacity, the sediment pond will be dewatered, and the sediment will be removed for burial in the mine pit (section 816.46).

Preliminary calculations show that the sediment pond must have a volume of at least 15.8 acre-ft to meet the preceding criteria. This volume consists of 2.6 acre-ft of sediment storage, for an assumed maximum of 26 acres of disturbed land upstream from the sediment pond, and 13.2 acre-ft of runoff from all areas draining into the sediment pond. A runoff coefficient of 0.75 was used in calculating the runoff; therefore, the sediment pond should be capable of detaining runoff from storms larger than the design storm because the contribution to surface runoff within any given 24-h period will probably be less than 75 percent of the rainfall on the permit area.

Approximately 3,600 ft of temporary collection drains and channels will be constructed to transport runoff from some areas draining into the permit area (fig. 32). Temporary collection drains will be constructed to carry the peak runoff from a precipitation event with a 2-yr recurrence interval (section 816.43). The design flow rate, 28 ft^3/s, was determined by using the runoff coefficients, the areas noted in table 23, and a design rainfall intensity of 0.9 in./h.

A total of 2,500 ft of permanent overland-flow-diversion channels will be constructed on the east boundary of the permit area. The purpose of this channel is to divert the overland flow from 25 acres outside the permit area. Moreover, the channel will control erosion and prevent contact of runoff with potential acid or toxic-forming materials in the permit area. Permanent diversion channels will be constructed to carry the peak runoff from a precipitation event with a 10-yr recurrence interval (section 816.43). On the basis of a runoff coefficient of 0.5, an area of 25 acres, and a design rainfall intensity of 1.6 in. per hour, the authors estimated the magnitude of the 10-yr peak runoff event to be 20 ft^3/s.

After construction of the sediment pond, channels, and drains, all disturbed areas will be hand seeded with 15 lb of fescue (Festuca ayundinacea) and 8 lb of orchard grass (Poa chapmaniana) per acre. The seeded area will be mulched with 3 to 5 tons of straw per acre to provide a stable vegetative cover (section 816.45). All phases of the construction and the inspection of the sediment-control structures will be under the supervision of a registered professional engineer (section 816.49).

Topsoil Handling

Before any disturbance other than construction of sediment and water-control structures, stockpile and storage areas will be prepared. For the mine plan, topsoil will be considered as the top 9 in. and subsoil as the next 39 in. Topsoil from the subsoil stockpile site and the temporary spoil-storage site will be removed and will be stockpiled. Subsoil from the temporary spoil-storage site will also be removed and will be stockpiled. Topsoil and subsoil from cuts A and B (fig. 29) and the adjacent haul road (fig. 32) will then be segregated and will be stockpiled (section 816.22).

Vehicle traffic patterns will be controlled to prevent excess compaction of stockpiled materials. Both topsoil and subsoil stockpiles will be designed to promote stockpile stability and minimize erosion (section 816.23). Stockpiles will be hand seeded with 15 lb of fescue and 8 lb of orchard grass per acre and will be mulched with 3 to 5 tons of straw per acre to minimize erosion (section 816.23).

Mining

Mining operations are scheduled to begin on September 1, 1979. One bulldozer-loader team will work full time in removing topsoil and subsoil (13 h/acre), and overburden (254 h/acre), and in loading coal (15 h/acre). One dozer will work full time backfilling, rough grading, and compacting spoil delivered by trucks from concurrent overburden removal and in supplementary landscaping and haul-road construction. There will be two 10-h shifts per day, 7 days per week. Mining should proceed at a rate of 2 acres per month, and backfilling and soil reconstruction should lag no more than three cuts behind mining (section 816.101).

All rainfall or ground-water seepage entering the pit area will be pumped into the sediment pond. If necessary, the water will be neutralized before it is discharged into the sediment pond. To minimize the formation of acid and (or) toxic water, all seepage or rainfall entering the pit area will be pumped to the sediment pond at the completion of each shift.

Reclamation

Except for materials that must be stockpiled or stored, backfilling, grading, scarification, soil reconstruction, and mulching will be done concurrently with mining. Geological data from the minesite indicate that potential acid-forming strata lie 10 to 30 ft below land surface. (See section "Bedrock Geology.") These strata are much darker than the surrounding gray shale and, therefore, should be easily identified. Selective burial of the strata will be done as specified in section 816.103 and will not be a problem for a dozer-loader operation.

With the completion of coal extraction, materials from the stockpile and storage sites will be used to backfill and grade the final pit (section 816.71). The surface of the graded spoil will be scarified, and the soil horizons will be reconstructed with a uniform thickness of 39 in. of subsoil and 9 in. of topsoil (section 816.24). After reconstruction, the entire area will be worked with a hyperbolic subsoiler to correct any land surface that may have been compacted during soil reconstruction (section 816.51). Soil tests will determine the amounts of lime and fertilizer to be added.

A quick-cover crop of birdsfoot trefoil (Lotus americanus) (8 lb/acre), red clover (Trifolium pratense) (8 lb/acre), and orchard grass (4 lb/acre) will be sown in April and May 1980, and additional mulch will be added to reduce erosion, improve soil structure, and add nitrogen to the soil (sections 816.113 and 816.114). Erosion resulting in rills and gullies will be regraded and will be reseeded as discovered (section 816.106). The quick-cover crop will be left in place, and further soil amendments will be added as needed during three growing seasons.

After a satisfactory cover crop has been established, the temporary collection drains and sediment pond will be regraded and revegetated (section 780.25). Because most of the post-mining land use will be cropland, soybeans will be planted as a row crop. As specified in section 816.116, revegetation success will be achieved when 2 consecutive years average annual crop production is equivalent to or higher than the projected pre-mining productivity of 32 bushels per acre (Williamson and Shively, 1973, p. 40-41).

Monitoring

To ensure compliance with OSM regulations and NPDES permit conditions, the mine operator will monitor sediment-pond effluent weekly and, if necessary, ground-water wells in adjacent areas. Additional observation wells will be drilled and will be monitored as specified by the Regulatory Authority (sections 816.52 and 780.21).

Sequence and Timing of Mining

The timing and sequence of mining through the three major phases of surface mining--site preparation, mining, and reclamation--are described in the log that follows (sections 780.11 and 780.18). This information is an essential component of a subsequent part of this report in which hydrologic impacts are described. (See section "Estimated Impacts of the Hypothetical Mining Activity.")

8-15 to 8-31-79: (17 days)	Sediment-pond area cleared and scalped, soils stockpiled, foundation scarified. Pond basin excavated, fill used to construct embankments. Channels and ditches excavated, soils stockpiled. All sediment control structures seeded and mulched. Stockpile and storage areas prepared.
9-1 to 9-7-79: (7 days)	Soils from cuts A and B (fig. 29) and adjacent haul road removed, segregated, and stockpiled. Stockpiles graded and seeded.
9-8 to 10-9-79: (32 days)	Overburden from cut A removed and transported to temporary spoil-storage area. Coal loaded and removed from cut A.
10-10 to 10-12-79: (3 days)	Haul-road construction for access to cut B completed (soils stockpiled earlier). Overburden excavated and backfilled in cut A.
10-13 to 11-23-79: (42 days)	Overburden excavated from cut B, backfilled and graded in cut A. Coal removed from cut B. Graded spoil in cut A scarified.
11-24 to 11-26-79: (3 days)	Haul-road construction for access to cut C completed. Soils removed, reconstructed, and mulched in cut A; excavated overburden backfilled in cut B.
11-27-79 to 1-14-80: (49 days)	Soils removed and segregated from cut C. Soil horizons reconstructed on scarified spoil in cut A. Reconstructed soil mulched. Overburden removed from cut C and backfilled, graded, and scarified in cut B. Excess spoil not used for backfilling will be temporarily stored. Coal removed from cut C.
1-15 to 1-17-80: (3 days)	Haul road constructed for access to cut D. Soils removed, reconstructed, and mulched in cut B; excavated overburden backfilled in cut C.
1-18 to 3-14-80: (57 days)	Soil removed from cut D and soil horizons reconstructed and mulched on cut B. Overburden removed from cut D and backfilled, graded, and scarified in cut C. Excess spoil stored. Coal removed from cut D.
3-15 to 3-17-80: (3 days)	Haul road constructed for access to cuts E and F. Soils removed, reconstructed, and mulched in cut C; excavated overburden backfilled in cut D.

3-18 to 4-19-80: (33 days)	Soil removed from cuts E and F and reconstructed on cut C. Soil mulched in cut C. Overburden removed from cuts E and F and backfilled in cut D. Coal removed from cuts E and F.
4-20 to 5-15-80: (26 days)	Final part of cuts D, E, and F, and haul road backfilled with spoil from storage areas. All remaining spoil graded and scarified. Soil horizons reconstructed from stockpile areas. Remaining areas mulched. Entire reconstructed area worked with subsoiler. All disturbed area seeded and fertilized.
9-1-80:	Regraded, seeded, and fertilized as necessary.
5-1-81:	Regraded, seeded, and fertilized as necessary.
9-1-81:	Reseeded and fertilized as necessary.
5-1-82:	Temporary collection drain and sediment pond regraded and seeded. Reconstructed area tilled for row crop soybeans.

ESTIMATED IMPACTS OF THE HYPOTHETICAL MINING ACTIVITY

The primary function of this section is to project the extent of impact of the hypothetical mining activity on the hydrologic environment of East Fork Little Pigeon Creek. Previous sections of this report have shown that parts of the creek have been affected by mining. Data from other streams in southwestern Indiana were used in part to determine the extent of impacts from past as well as current mining operations. The condition of the other sites ranges from severely affected to unaffected by mining. Figures 14 and 33 show the location of the sampling sites, and tables 19 and 24 list some of the data collected for the basins.

On the basis of the preceding information and field observations, three broad categories of impaction have been established for streams highly, moderately, and minimally impacted. The highly impacted category is illustrated by sampling sites 26 and 27 (fig. 33). The pH at the two sites was low (4.0 to 6.4), and methyl-orange acidity was moderate to high (10 to 140 mg/L, table 25). Total iron and manganese concentrations (mostly dissolved) were high (3.0 mg/L to 7.5 mg/L and 22 to 49 mg/L, respectively, table 24). Sulfate concentrations were correspondingly high (1,500 to 3,000 mg/L) as were specific conductance measurements (2,300 to 3,300 µmho/cm, table 24). The high concentration of cations plus anions (71.2 meq/L at site 27, table 17) is typical of water in the highly impacted category.

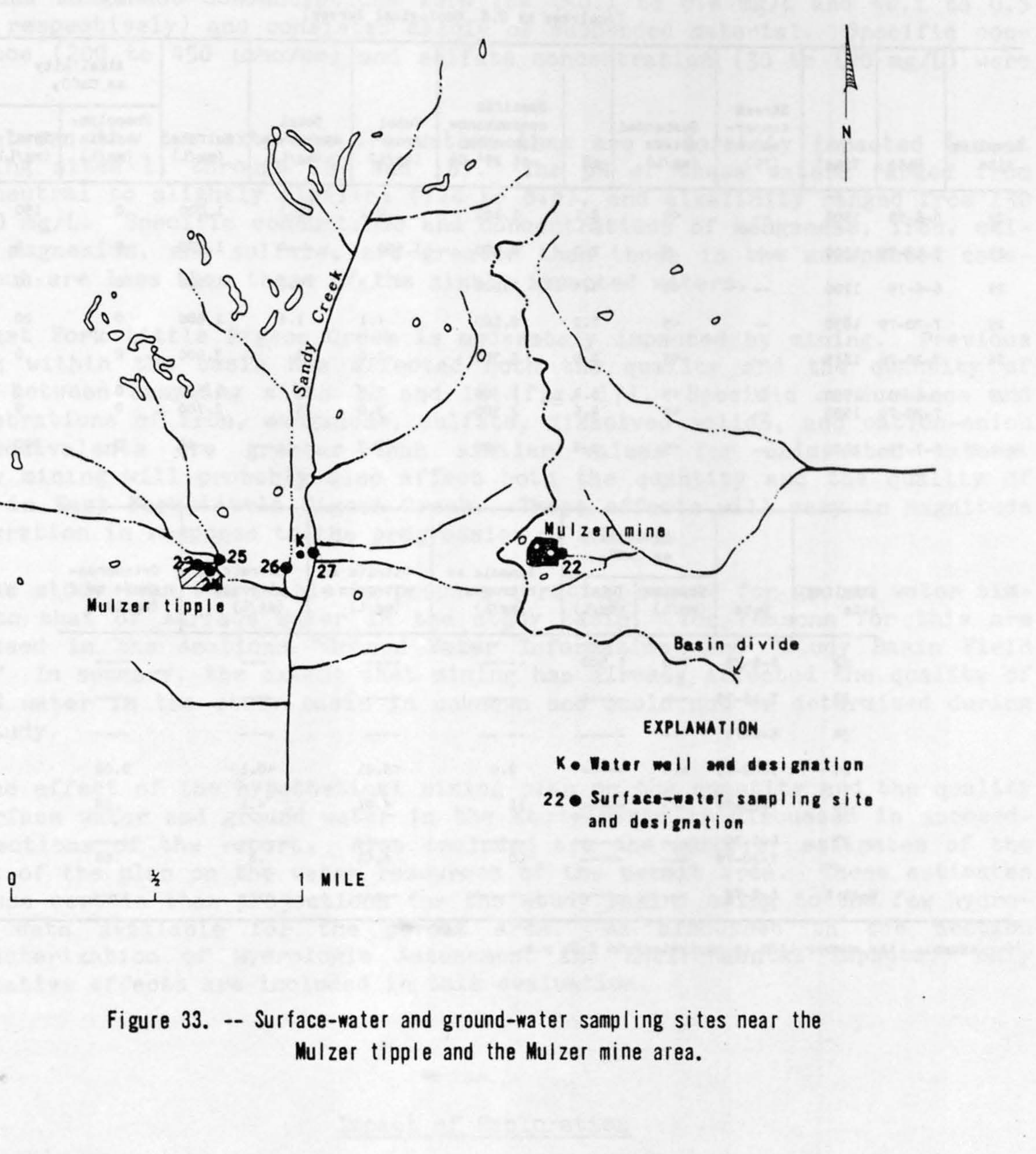


Figure 33. -- Surface-water and ground-water sampling sites near the Mulzer tipple and the Mulzer mine area.

Table 24.--Field analyses of surface water and ground water near Liberal, Ind.

[Analyses by U.S. Geological Survey]

Sampling site	Date	Time[1]	Stream temperature (°C)	Suspended solids (mg/L)	pH	Specific conductance (µmho/cm at 25° C)	Total iron (mg/L)	Total manganese (mg/L)	Sulfate (mg/L)	Alkalinity as $CaCO_3$		Methyl-orange acidity (mg/L)
										Phenolphthalein (mg/L)	Total (mg/L)	
22	6-8-79	1400	--	<5	8.1	1,800	0.1	<0.1	1,000	0	150	0
23	7-18-79	1300	--	5	2.2	4,900	1,600	----	1,000	0	0	3,500
24	6-6-79	1700	--	<5	4.4	2,000	.2	5.0	1,000	0	<10	10
25	7-20-79	1830	--	<5	7.2	2,100	<.1	1.6	1,000	0	20	0
26	7-20-79	1845	--	<5	4.0	3,300	7.0	49	3,000	0	0	140
27	6-6-79	1730	27	<5	6.4	2,300	7.5	22	1,500	0	0	-----
	7-20-79	1900	--	<5	4.6	2,700	3.0	26	2,700	0	0	10
Well K	6-7-79	1600	--	<5	7.4	600	1.3	--	<5	0	290	0

Sampling site	Date	Hardness as $CaCO_3$		Ammonia as nitrogen (mg/L)	Nitrite as nitrogen (mg/L)	Nitrate as nitrogen (mg/L)	Orthophosphate as P (mg/L)
		Calcium (mg/L)	Total (mg/L)				
22	6-8-79	760	1,500	-----	----	----	----
23	7-18-79	---	-----	-----	----	----	----
24	6-6-79	---	-----	-----	----	----	----
25	7-20-79	---	-----	2.5	<0.01	<0.1	0.08
26	7-20-79	---	-----	11	<.01	<.1	.08
27	6-6-79	---	-----	-----	----	----	----
	7-20-79	---	-----	10	<.01	.8	.06
Well K	6-7-79	---	-----	------	----	-----	-----

[1]For example, the number 1400 is equivalent to 2:00 p.m.

In contrast with the highly impacted category, the minimally impacted category includes waters such as those at sampling sites 8, 9, 10, and 17 (table 16), which had no methyl-orange acidity, varying alkalinities (20 to 150 mg/L), and near-neutral to slightly alkaline pH values (7.1 to 8.8). Total iron and manganese concentrations were low (<0.1 to 0.6 mg/L and <0.1 to 0.5 mg/L, respectively) and consisted mainly of suspended material. Specific conductance (200 to 450 µmho/cm) and sulfate concentration (30 to 120 mg/L) were low.

Between the two extremes are waters that are moderately impacted (as at sampling sites 11 through 16, and 18). The pH of these waters ranged from near neutral to slightly alkaline (7.4 to 8.8), and alkalinity ranged from 130 to 230 mg/L. Specific conductance and concentrations of manganese, iron, calcium, magnesium, and sulfate, are greater than those in the unimpacted category but are less than those of the highly impacted waters.

East Fork Little Pigeon Creek is moderately impacted by mining. Previous mining within the basin has affected both the quality and the quantity of water between sampling sites 11 and 18 (fig. 17). Specific conductance and concentrations of iron, manganese, sulfate, dissolved solids, and cation-anion milliequivalents are greater than similar values for unimpacted waters. Future mining will probably also affect both the quantity and the quality of water in East Fork Little Pigeon Creek. These effects will vary in magnitude and duration in response to the progression of mining.

The study team was unable to prepare a rating scheme for ground water similar to that of surface water in the study basin. The reasons for this are discussed in the sections "Ground Water Information" and "Study Basin Field Data." In summary, the extent that mining has already affected the quality of ground water in the study basin is unknown and could not be determined during the study.

The effect of the hypothetical mining plan on the quantity and the quality of surface water and ground water in the study basin is discussed in succeeding sections of the report. Also included are the authors' estimates of the effect of the plan on the water resources of the permit area. These estimates are less certain than projections for the study basin, owing to the few hydrologic data available for the permit area. As discussed in the section "Characterization of Hydrologic Assessment and Environmental Impacts," only qualitative effects are included in this evaluation.

Impact of Exploration

Premining activities will be limited to coal exploration. Drilling of exploration holes should not adversely affect the quantity or the quality of ground water because all coal-exploration holes will be cased and will be sealed. Most of the pyritic and reactive material brought to the surface by drilling will probably remain on the site. However, small quantities may be transported to the headwaters of East Fork Little Pigeon Creek by surface runoff. The influx of this material will probably not markedly affect ambient water quality or present (1979) in-stream or off-stream uses of the water. In summary, the effect of the exploration phase of the hypothetical mining activity on the quality of both the surface water and ground water in the permit area and study basin should be minimal.

Impact of Mining

This phase of the hypothetical mining activity consists of removing topsoil, overburden, and the Buffaloville coal seam. The time frame for these activities is from September 1979 to April 1980.

Ground-water quantity in the permit area will be affected by mining in several ways. Most significant will be the truncation of the aquifer at the unnamed coal seam. Water in this aquifer in the vicinity of the permit area will intercept the highwall and the working area. The water will be pumped out of the pit into the sedimentation pond. The resulting effect of this action will be twofold. First, a small fraction of the water in the aquifer at the unnamed coal seam will be lost from the aquifer. The proposed mining activity will probably not cause draining of the aquifer updip from the permit area but will merely remove part of the flow in the aquifer downdip from the permit area. Second, water entering the pit from the truncation of the aquifer at the unnamed coal seam may cause some discharge from the sediment pond to East Fork Little Pigeon Creek. However, this discharge may not materialize because the entire flow into the sediment pond from the truncation may evaporate. If water flows from the sediment pond to the creek, the authors assume that the quality of the water will be similar to that at well G (fig. 30, tables 21 and 22). The quality of the water at well G is better than that at site 11 along the creek, so the discharge will probably not adversely affect the quality of East Fork Little Pigeon Creek.

Infiltration rates in the permit area will change during the mining phase. Within the 15.5 acres of disturbed area, infiltration rates should decrease in the reclaimed parts of this area, owing to soil compaction. In contrast, infiltration rates for areas filled with overburden but lacking soil will probably increase.

Local geology indicates that a water mound may form under the cast overburden (fig. 34). This mound may induce flow into the potential water-bearing stratum at the Buffaloville coal seam. Although water was not detected in the stratum during exploration, water induced into the stratum would flow downdip and away from the permit area. The loss of water from the aquifer at the unnamed coal seam and the introduction of water into the potential water-bearing stratum at the Buffaloville coal seam will not adversely affect any potential uses of ground water in the permit area. There are no wells in either aquifer

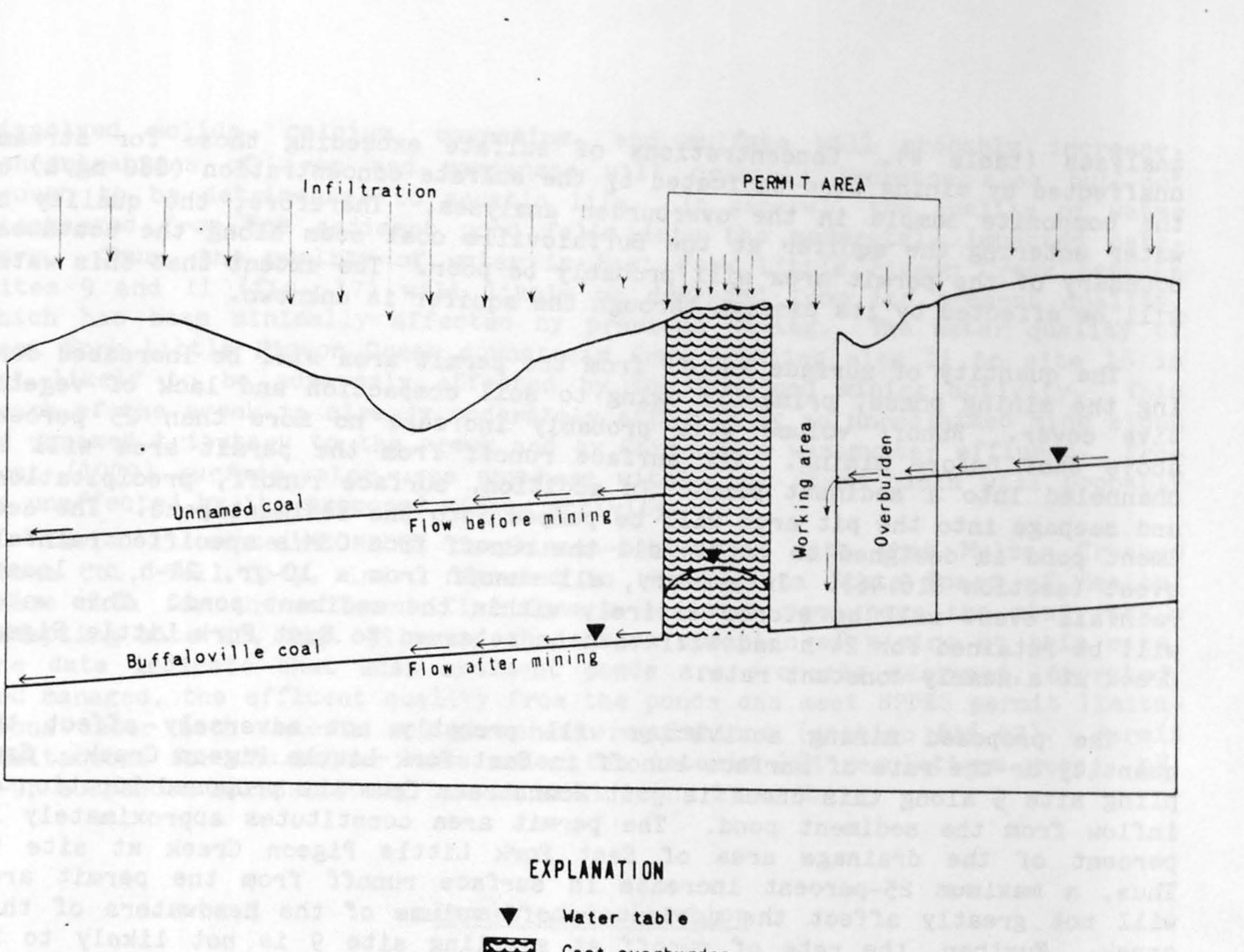


Figure 34.-- Generalized diagram showing changes in ground-water flow patterns resulting from mining.

downdip from the permit area. The disturbance to the aquifer at the unnamed coal seam in the permit area, in comparison to the overall extent of this aquifer, suggests that the quantity of water downdip from this aquifer will be only minimally affected by the proposed mining activity.

The proposed activity will probably not affect Chrisney Lake, the public water supply of Chrisney. The geologic section in figure 8 shows that this lake lies just above the unnamed coal seam, if the seam is assumed to be continuous. The authors were initially concerned that the proposed mining activity might adversely affect the quality of the lake. Further study indicated, however, that the proposed activity would affect ground-water quality in the aquifer at the Buffaloville coal seam but not in the aquifer at the unnamed coal seam. The quality of water at the Buffaloville coal seam is unknown but may be estimated from the analysis of the composite sample of the overburden analyses (table 4). Concentrations of sulfate exceeding those for streams unaffected by mining were indicated by the sulfate concentration (880 mg/L) of the composite sample in the overburden analyses. Therefore, the quality of water entering the aquifer at the Buffaloville coal seam along the southwest boundary of the permit area will probably be poor. The extent that this water will be affected by its passage through the aquifer is unknown.

The quantity of surface runoff from the permit area will be increased during the mining phase, primarily owing to soil compaction and lack of vegetative cover. Runoff volume will probably increase no more than 25 percent above that before mining. All surface runoff from the permit area will be channeled into a sediment pond. In addition, surface runoff, precipitation, and seepage into the pit area will be pumped into the sediment pond. The sediment pond is designed to retain all the runoff from OSM's specified rainfall event (section 816.46). In summary, all runoff from a 10-yr, 24-h or lesser rainfall event will be stored entirely within the sediment pond. This water will be retained for 24 h and will then be released to East Fork Little Pigeon Creek at a nearly constant rate.

The proposed mining activities will probably not adversely affect the quantity or the rate of surface runoff in East Fork Little Pigeon Creek. Sampling site 9 along this creek is just downstream from the proposed location of inflow from the sediment pond. The permit area constitutes approximately 15 percent of the drainage area of East Fork Little Pigeon Creek at site 9. Thus, a maximum 25-percent increase in surface runoff from the permit area will not greatly affect the ambient runoff volume of the headwaters of this creek. Further, the rate of runoff at sampling site 9 is not likely to be increased by the proposed mining activity but, rather, will probably be decreased slightly in response to the storage characteristics of the sediment pond. Discharge from the sediment pond will be released at a nearly constant rate and will be delayed about 24 h, in comparison to premining runoff characteristics. Neither rate nor volume of flow along the lower reaches of East Fork Little Pigeon Creek are likely to be affected markedly by surface runoff during mining.

The sediment pond will nearly eliminate any flooding potential from the mining activity for rainfall events less than or equal to the design storm event and will also mitigate the runoff volume and peak flow rate for precipitation events greater than the design event.

A review of the geologic section near the permit area (fig. 7) shows that ground-water movement is stratigraphically beneath East Fork Little Pigeon Creek. The proposed mining activity should not affect the quantity of base flow. The headwaters of the creek upstream from sampling site 5 (fig. 17) will probably not contain any streamflow during low flow as it did in July 1979.

Surface-water quality in the permit area will probably be affected during mining. The quality of water in the sedimentation pond will probably be similar to that of the sediment pond at the Crooks mine (sampling site 8, table 16) and certainly no worse than that of the sediment pond at the Kelco mine (sampling site 1, table 16). Specific conductance and concentrations of dissolved solids, calcium, magnesium, and sulfate will probably increase. Concentrations of iron and manganese will probably increase also but not enough to be detrimental to aquatic life. In general, the quality of water discharged from the sediment pond falls into the moderately impacted category. Thus, the quality of water in East Fork Little Pigeon Creek between sites 9 and 11 (fig. 17) will likely be degraded from its present quality, which has been minimally affected by previous mining. The water quality of East Fork Little Pigeon Creek downstream from sampling site 11 to site 18 is not likely to be adversely affected by the proposed mining activity. This reach of the creek is already moderately affected by an unreclaimed mine along an unnamed tributary to the creek and by Chrisney's wastewater effluent. Present (1979) surface-water uses anywhere within the study basin will probably be unaffected by the proposed mining activity.

Table 25 contains NPDES compliance-monitoring data that Mulzer Crushed Stone Co., Tell City, Ind., reported to the Indiana State Board of Health. These data for the effluent flow from a sediment pond near the study basin (sampling site 22, fig. 33) span the entire duration of mining at this site. The data indicate that when sediment ponds are properly designed, operated, and managed, the effluent quality from the ponds can meet NPDES permit limitations under both interim and permanent regulations (section 816.42). Permit limitations for the Mulzer mine under the interim OSM regulations were: pH, 6-9; suspended solids, 90 mg/L; and total iron, 12 mg/L.

Impact of Reclamation

For discussion, the period of reclamation is considered to be the time between the cessation of mining (May 15, 1980) and the time when the entire permit area is reconstructed and revegetated. The length of the time will probably be at least 18 months, although a longer period may be required to reestablish vegetation in the disturbed area.

In the terminal phase of reclamation, surface runoff from the permit area will be about the same as that before mining began. Thus, the higher rates and volume of runoff during the mining phase should taper off, owing to the mulching of the area and the establishment of vegetation.

The well-developed fragipan in the permit area before the beginning of mining will be removed by the mining activity. Removal of this fragipan, which is about 2 ft below land surface, will allow increased drainage on the site during and after reclamation and should permit the planting of a greater variety of crops than had been possible previously. The magnitude of this change in the drainage property of the soils in the permit area is not known.

The quality of surface runoff should improve during the reclamation period, and the degraded water quality of the mining phase should gradually improve to a quality similar to that in the premining period. The primary causes for the improved water quality will be (1) burial of all spoil material with soil, (2) mulching the reconstructed surface with straw, and (3) regrowth of vegatation.

Table 25.--National Pollution Discharge Elimination System compliance-monitoring data for the Mulzer sediment pond

[Data obtained from Indiana State Board of Health]

Date	Effluent flow (Mgal/d)	pH	Suspended solids (mg/L)	Total iron (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Acidity as $CaCO_3$ (mg/L)
7-14-77	0.1	7.2	4	0.01	21	5
7-22-77	.1	7.2	30	.01	14	6
8-5-77	.1	6.7	6	0	18	4
8-12-77	.1	6.5	6	.04	20	3
8-18-77	.1	6.5	8	.07	27	4
8-26-77	.1	6.5	8	.01	16	1
9-2-77	.1	6.9	9	<.01	25	6
9-8-77	.1	7.0	6	<.01	45	8.5
9-15-77	.1	7.0	7	<.01	34	7
9-23-77	.1	6.7	8	<.01	34	25
9-29-77	.1	---	3	<.01	174	19
10-5-77	.1	7.1	5	.10	90.5	4.5
10-11-77	.1	7.3	10	.03	14.5	11
10-19-77	.1	7.3	8	.02	100.5	4.2
10-28-77	.1	6.7	9	.27	14	.3
11-4-77	.1	7.0	13	.30	69	11
11-11-77	.1	7.4	1	.02	55	4
11-17-77	.1	6.5	30	.03	5	7
11-23-77	.1	6.4	2	.10	8	6
12-77			No discharge			
1-78			No discharge			
2-23-78	.1	6.8	7	1	18	7
3-7-78	.1	7.3	27	.10	71.5	7
3-21-78	.1	7.4	23	.02	65	3
3-30-78	.1	7.4	7	.01	66	5.5
4-4-78	<.1	7.2	4	.01	263	13
4-12-78	<.1	5.25	4	.05	8.4	3.5
4-18-78	<.1	6.4	3	.09	11.2	3.7
4-27-78	<.1	6.5	10	.38	21	4.7
5-78			No discharge			
6-78			No discharge			
7-11-78	<0.1	6.5	<1	<0.01	10	1.5
7-22-78	<.1	6.7	8	.17	11.5	<.5
8-23-78	<.1	6.9	10	<.1	17.5	6

Table 25.--National Pollution Discharge Elimination System compliance-monitoring data for the Mulzer sediment pond--Continued

Date	Effluent flow (Mgal/d)	pH	Suspended solids (mg/L)	Total iron (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Acidity as $CaCO_3$ (mg/L)
9-13-78	<.1	6.2	6	<.01	11.2	3
9-18-78	<.1	6.3	19	<.01	16.8	7
10-3-78	.1	6.7	1	.01	70.7	3.0
10-11-78	.1	6.6	1	.08	18.4	.5
10-18-78	<.1	6.5	2	.04	21.7	2
10-25-78	<.1	6.5	2	.03	22.4	4
11-1-78	.1	7.3	13	.05	98	5.5
11-16-78	.1	6.5	9	.08	10.5	3.5
11-28-78	.1	6.4	6	.15	9.8	3.0
12-14-78	.1	6.1	4	.04	4.2	1.5
12-24-78	.1	6.2	4	.04	4.9	.5
1-79		No discharge				
2-7-79	.1	6.7	5	.85	273	24
2-14-79	.1	6.8	12	.58	168	38
2-21-79	.1	6.3	4	.58	274	9.0
2-28-79	.1	6.7	5	.58	286	27
3-1-79	.5	6.5	17	1.4	54.6	2.0
3-8-79	.5	6.7	13	1.4	56.7	1.5
3-15-79	.5	6.7	28	1.5	53.2	1.5
3-23-79	.5	6.6	26	1.5	49.0	7.0
3-29-79	.5	6.6	8	.8	60.9	1.0
4-3-79	.5	7.5	1	.01	392	19
4-11-79	.5	7.6	1	.01	378	18
4-18-79	.5	7.6	1	.01	414	15
4-26-79	.5	7.5	1	.01	381	21
5-9-79	.1	7.8	7	.1	175	11
5-15-79	.1	7.8	8	.08	185	12
5-24-79	.1	7.9	9	.01	187	10
5-31-79	.1	7.9	10	.01	185	11

Some of the fertilizer and lime applied during reclamation will probably be dissolved by surface runoff and will eventually be discharged to East Fork Little Pigeon Creek. This nutrient-rich discharge will be temporary and should be eliminated before the end of the reclamation period. The runoff of nutrients from the permit area during reclamation will not likely degrade downstream quality more than that already degraded by farming in the study basin and by the discharge of even larger quantities of nutrients from the sewage-treatment plant at Chrisney.

The movement of ground water through the permit area should remain as described for the mining phase. The aquifer at the unnamed coal seam will remain truncated, and induced flow should continue in the aquifer at the Buffaloville coal seam. The acid-producing strata in the permit area will be selectively buried and should not affect ground-water quality more than the premining stratum affected it. The amount of water recharged through the disturbed area is not known specifically but should equal or exceed the amount recharged before mining.

Impact of Post Reclamation

The study team foresees only two long-term impacts of the hypothetical mining activity. First, the 15.5-acre truncation of the aquifer at the unnamed coal seam will remain, and coincident deep infiltration and induced flow to the aquifer at the Buffaloville coal seam will continue. Second, the removal of the fragipan during soil reconstruction will result in improved drainage of water at the permit area and possibly additional infiltration of water to the underlying aquifer. Neither of these long-term impacts are likely to affect the area adversely. Further, present water uses should not be affected by the proposed mining activity.

DISCUSSION

Two specific objectives were delineated at the formulation stage of the hydrologic evaluation. First, the study team was to prepare an example report of a hydrologic assessment required by OSM's regulations as part of a mine-permit application. The results of this work are presented in other sections of this report. To the fullest extent possible, completion of the hydrologic evaluation was based on guidelines in the pertinent sections of the permanent regulations, which were published in the Federal Register (1979) and are referenced throughout this report.

The second objective was to determine what information is required to understand the hydrologic setting of the permit area and the study basin. A hypothetical mining site was the focus for the completion of this second objective. Similar evaluations completed elsewhere throughout the United States will likely identify information needs that are different from those presented here because of regional variations in hydrology, geology, climate, soils, topography, mining practices, and data-collection programs. An important aspect of this second objective was to determine the availability and suitability of hydrologic information for completing a surface coal-mining-permit application. Because the hypothetical mine-site is in southwestern Indiana, the conclusions pertaining to the second objective are specific for Indiana only and may not apply to other States in OSM Region III.

Limitations

Although given substantial agency support and resources, this investigation was not without certain constraints that affected the scope of the hydrologic evaluation for the hypothetical minesite. Most of the constraints resulted from the prototype nature of the project, whereas others resulted from the short time frame and the budget within which the study was completed. Constraints in the first category are best illustrated by the inability of the study team to drill a matrix of exploration holes at the permit area that would provide an accurate understanding of areal geology, coal resources, and ground water. Because the hypothetical minesite was being farmed, the exploration holes and observation wells deemed necessary by the study team and required by sections 779.14 and 816.52 of the permanent regulations could not be drilled. As an alternative, the geology and the ground-water hydrology of the permit area were synthesized with data from nearby wells and observation holes. This alternative is unique to the nature of this prototype project and should not be a significant problem in the preparation of an actual permit application, where mining companies have access to the permit area for obtaining the data.

The permanent regulations require the completion of compaction tests on each stratum (section 779.14) and the determination of the mineralogical characteristics of aquifers, overburden, and spoil (section 816.52). Neither of these tests was completed as part of the hydrologic evaluation because of a lack of equipment. Again, completion of the tests should not be a major problem for a mining company who presumably could rely on commercial laboratories for completing them.

The study team was not able to collect complete hydrologic information for Little Pigeon Creek watershed into which the study basin drains. The authors consider this watershed to be part of the "general area" for the hypothetical mining activity (section 770.5). Additional hydrologic data would be needed before the "probable cumulative impacts" of the hypothetical mining activity on the quantity and the quality of surface-water and ground-water systems in the basin could be assessed. Little if any hydrologic information is available for Little Pigeon Creek. The collection of these data would have doubled the scope of the investigation and was not practical because of the time and budgetary constraints for the project.

The permanent regulations also require that water-quality and water-quantity data be included in the hydrologic assessment in sufficient detail to characterize seasonal variations within the proposed mine plan and adjacent area (section 779.16). Because both surface-water and ground-water hydrologic data were non-existent for the study basin before the start of the project, the study team collected most of the needed information during two visits to the study basin in the summer of 1979. Similar visits in the autumn, winter, and spring would be needed in order to meet the Office of Surface Mining's requirement to characterize the seasonal variation in water quality and quantity within the mine plan and adjacent areas. Such sampling was not envisioned, nor was it possible, as part of the study, which was completed within 3 months. The authors used data from nearby basins to synthesize some of the required seasonal information; namely, data for surface runoff, rainfall, evaporation, evapotranspiration, water temperature, and suspended-sediment load. However, seasonal information for surface-water quality, except suspended solids and temperature, and for ground-water quantity and quality could not be synthesized because historical records on these topics were not available in the vicinity of the study basin.

Regulatory Language

Only one of the five members of the study team had previous experience with the permanent regulations. Thus, a period of acclimation to the mining and regulatory language was required by most members. Particularly troublesome was the terminology and proper usage of the numerous types of "areas" used in the regulations. (The term "area" is more specifically defined in OSM guidelines, U.S. Department of the Interior, 1980.) These terms include "adjacent area," "affected area," "disturbed area," "general area," "permit area," "mine-plan area," "reference area," and "upland area." Definition of the "general area" created considerable concern to the study team at the onset of the project. Specifically, section 779.13 of the permanent regulations requires that: "...each permit application shall contain a description of the geology, hydrology, and water quality and quantity of all lands within the proposed mine-plan area, the adjacent area, and the general area." With respect to hydrology, the general area is defined as "the topographic and ground-water basin surrounding a mine-plan area which is of sufficient size, including areal extent and depth, to include one or more watersheds containing perennial streams and ground-water zones and to allow assessment of the probable cumulative impacts on the quality and quantity of surface and ground water systems in the basin" (section 770.5). Further, a perennial stream is defined as "a stream or part of a stream that flows continuously during all of the calendar year as a result of ground-water discharge or surface runoff" (section 701.5). Thus, the description of the general area's geology, hydrology, and water quality and quantity can encompass a considerable drainage basin in locations that do not have sustained base flows from ground water. Most streams in southern Indiana typically do not flow for extended periods during summer and autumn. Strict compliance with the regulatory language for

Section 779.13 would have required the study team to evaluate the hydrology, geology, and quality and quantity of waters within East Fork Little Pigeon Creek watershed (study basin), Little Pigeon Creek watershed, and at least a part of the Ohio River (fig. 14). Such an undertaking far exceeded the resources available for this project and therefore the authors decided to confine the hydrologic evaluation to the study basin only. The requirement for a mining company to complete a hydrologic assessment on all the areas mentioned would increase the cost and time necessary to complete the hydrologic assessment for the permit application.

Characterization of Hydrologic Assessment and Environmental Impacts

The hydrologic assessment of the study basin, and in particular the hydrologic characteristics of the permit area, was prepared from both synthesized information from nearby basins and on-site measurements completed as a part of the investigation. Responsibility for collecting and reporting information about geology, hydrology, soils, land use, mining permits, and associated activities is fragmented among many agencies in Indiana. The individuals, companies, and agencies that were contacted to obtain information about Spencer County and in particular East Fork Little Pigeon Creek watershed are listed in table 26. Although not difficult to complete, the procurement and associated workup process proved to be time consuming and required about 6 man months to complete. A mine-permit application will probably require a similar commitment of manpower to collect, review, synthesize, and document information that may be applicable to the mine-plan area. Considerably more effort will be required if similar information for the "general area" must be prepared by the applicant.

Most of the information compiled from the various sources listed in table 26 was suitable for its intended use in the investigation. However, some of the information was neither accurate nor sufficient in detail to be of value in synthesizing the hydrologic setting for the study basin. For example, the generalized geologic sections reported on interim mine-permit applications were too simple and contained insufficient detail to permit their use in developing an understanding of the location and the movement of ground water in the study basin.

A review of information for the completion of the hydrologic evaluation revealed inadequate or nonexistent technical information for Spencer County on the following topics:

(1) Sub-surface geology, especially the spatial extent of the Buffaloville and the unnamed coal seams.

(2) Mineralogy and lithology of strata down to the Buffaloville coal seam.

(3) Presence, depth, areal extent, movement, and yield of aquifers at the Buffaloville and the unnamed coal seams.

Table 26.--Sources of information used in completion of the hydrologic evaluation

[IGS, Indiana Geological Survey; DNR, Indiana Department of Natural Resources; ISBH, Indiana State Board of Health; NOAA, National Oceanic and Atmospheric Administration; USGS, U.S. Geological Survey; USDA, SCS, U.S. Department of Agriculture, Soil Conservation Service; SPSA, State Planning Services Agency; PDR 15, Planning Development Region for area 15]

Type of information	Source
A. Geology	
Surficial deposits	IGS, Bloomington, Ind.
Bedrock	Do.
Water-well records	DNR, Indianapolis, Ind.
Oil and gas-well records	Do.
Coal depths	IGS, Bloomington, Ind.
B. Soils	
Soil series and association	USDA, SCS, Indianapolis, Ind.
Land use, major agricultural crops	Do.
Percolation tests	Health Officer, Spencer County, Rockport, Ind.
C. Hydrology and water resources	
Streamflow data	USGS, Indianapolis, Ind.
Sediment data	Do.
Surface-water-quality data	Do.
	ISBH, Indianapolis, Ind.
Ground-water-quality data	DNR, Indianapolis, Ind.
	Health Officer, Spencer County, Rockport, Ind.
	Homeowners, near Chrisney, Ind.
Sediment pond	ISBH, Indianapolis, Ind.
	Mulzer Crushed Stone Co., Tell City, Ind.
Weather data	NOAA, Asheville, N.C.
	Evansville Airport, Evansville, Ind.
Chrisney Lake	City officials, Chrisney, Ind.
Chrisney sewage-treatment plant	Operator and city officials, Chrisney, Ind.
	ISBH, Indianapolis, Ind.

Table 26.--Sources of information used in completion of the hydrologic evaluation--Continued

Type of information	Source
D. Mapping and photography	
Topographic maps	IGS, Bloomington, Ind.
Aerial photographs	USGS, EROS Data Center, Sioux Falls, S. Dak.
Land-use maps	PDR 15, Jasper, Ind.
Plat maps	County Seat, Rockport, Ind.
Soil maps	USDA, SCS, Indianapolis, Ind.
County road maps	County Seat, Rockport, Ind.
Geology and coal maps	IGS, Bloomington, Ind.
E. Coal-mining activities	
Sediment pond	ISBH, Indianapolis, Ind.
Past mining permits	DNR, Division of Reclamation, Jasonville, Ind.
Past mining activities	Homeowners near Chrisney, Ind., and Mulzer Crushed Stone Co., Tell City, Ind.
F. Regulations	
Long-range plan	SPSA, Indianapolis, Ind.
Present usage	PDR 15, Jasper, Ind.

(4) Presence and spatial extent of toxic-forming, acid-forming, or alkaline-forming stratum near the Buffaloville and the unnamed coal seams.

(5) Location of recharge zones for aquifers presently used for domestic and livestock supply.

(6) Quality of ground-water aquifers within 300 ft of land surface.

(7) Quality and quantity of surface waters.

(8) Historical uses of water.

The lack of historical data base for the preceding topics not only hampered the construction of the present hydrologic setting but greatly impeded any rigorous attempt to ascertain the extent to which water quantity and quality have already been impacted by manmade activities, especially by mining activities. In particular, ground-water-quality data were nonexistent.

The void of data on the water resources of Spencer County also adversely affected the study team's attempts to project the effects of the proposed mining activities on the hydrologic environment of the permit area and the study basin. Effects on the quantity, movement, and quality of ground water were most difficult to project. In general, the projected impacts to both ground water and surface water could only be made on a qualitative basis and not on a quantitative basis as originally envisioned by the study team.

In general, information for adequately describing the surface-water hydrology of the study basin and, to a lesser extent, of the permit area was available. In contrast, information for adequately describing surface-water quality and the quality and the quantity of ground water was unavailable, and, therefore, some of this information was obtained from field measurements during two visits to the study basin. This supplemental, data-gathering effort was adequate for describing ambient, surface-water quality in the study basin and for projecting the probable effect(s) of the hypothetical mining activity on surface-water resources. Attempts to gather data on the quantity and the quality of ground water on site in the study basin were less fruitful and resulted in only a partial understanding of these characteristics. A better understanding of the study basin's ground-water resources can only be determined from a comprehensive assessment that would probably take hundreds of thousands of dollars and several years to complete.

In general, the authors' ability to characterize the hydrology of the permit area was limited because of insufficient data. Further, the authors were unable to locate much information from previous hydrologic studies on extremely small watersheds such as the permit area (less than 100 acres). However, these two problems are not perceived as major obstacles in an actual permit application, where access to the proposed mining site should be easily obtained and data to delineate seasonal changes in the quantity and quality of surface water and ground water can be collected on site.

Projecting the concurrent and post-mining effects of the hypothetical mining activity could only be attempted on a gross qualitative basis owing to: (a) lack of historical data on the water resources of the study area and nearby basins; (b) meager information for small mining operations typical of southwestern Indiana, obtained in the literature search for the investigation; (c) lack of demonstrated methodologies for projecting the effects of small mining operations; and (d) the general lack of experience in Indiana with the type and extent of reclamation envisioned under the OSM regulatory program. Substantial additional research would be needed before reliable quantitative projections could be made of the hydrological changes that result at small coal-mining sites during the various phases of mining.

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