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THE U.S. GEOLOGICAL SURVEY COAL HYDROLOGY PROGRAM AND THE POTENTIAL OF HYDROLOGIC MODELS FOR IMPACT ASSESSMENTS

By W. Harry Doyle, Jr.

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METRIC CONVERSIONS

Inch-pound units used in this report may be converted to metric (SI) units by the following conversion factors:

Multiply inch-pound units	by	To obtain metric (SI) units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
acre	0.4047	hectare (ha)
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

THE U.S. GEOLOGICAL SURVEY COAL HYDROLOGY PROGRAM AND THE POTENTIAL OF HYDROLOGIC MODELS FOR IMPACT ASSESSMENTS

By W. Harry Doyle, Jr.

ABSTRACT

A requirement of Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977, is the understanding of the hydrology in actual and proposed surface-mined areas. Surface-water data for small specific-sites and for larger areas such as adjacent and general areas are needed also to satisfy the hydrologic requirements of the Act. The Act specifies that surface-water modeling techniques may be used to generate the data and information. The purpose of this report is to describe how this can be achieved for smaller watersheds. This report also characterizes 12 "state-of-the-art" strip-mining assessment models that are to be tested with data from two data-intensive studies involving small watersheds in Tennessee and Indiana. Watershed models are best applied to small watersheds with specific-site data. Extending the use of modeling techniques to larger watersheds remains relatively untested, and to date the upper limits for application have not been established.

The U.S. Geological Survey is currently collecting regional hydrologic data in the major coal provinces of the United States and this data will be used to help satisfy the "general-area" data requirements of the Act. This program is reviewed and described in this report.

INTRODUCTION

Hydrologic Impact of Public Law 95-87 -- Surface Mining Control and Reclamation Act of 1977

Surface mining of domestic coal in the United States increased from 120 million tons in 1955 to 406 million tons in 1978. In 1979 the production increased dramatically to almost 800 million tons. Past surface-mining practices involved little or no reclamation and thus caused environmental, social and economic impacts on the land and people near the mined areas. Legislation in 1977 by the 95th Congress produced comprehensive environmental regulations to protect the environment from the consequences of surface-mining operations. Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977 (SMCRA), was designed to ensure that in our haste to become energy self-sufficient we do not damage the environment and create conditions detrimental to society.

Purpose and Objective of Law

The purpose of Public Law 95-87 is defined in Sec. 102 items (a)-(m). Item (a) reflects the underlying purpose which is to:

> "establish a nationwide program to protect society and the environment from the adverse effects of surface coal mining operations."

Item (g) in Sec. 102 states that the Federal government will:

> "assist the states in developing and implementing a program to achieve the purposes of this Act;"

In Sec. 201 a new office in the Department of the Interior, the Office of Surface Mining and Enforcement (OSM), was established to assist the states.

Public Law 95-87 further specifies that any coal mining operator wanting to mine coal must submit an application for a permit before any surface-mining operations are conducted. The application for a permit is to include an evaluation of the prevailing hydrologic balance in the mine-plan and adjacent areas. Baseline conditions have to be established both onsite and offsite so that the potential impacts of mining can be determined. The objective of Public Law 95-87 is to minimize changes in the hydrologic balance that result from surface mining.

Required Surface-Water Information

Section 779.16 of the Regulations lists the minimum general surface-water characteristics that must be described in order to evaluate the prevailing hydrologic balance and to establish the baseline conditions.

Surface-water information shall include:

> "Minimum, maximum, and average discharge conditions which identify critical low flow and peak discharge rates of streams sufficient to identify seasonal variations; and water-quality data to identify the characteristics of surface waters in, discharging into, or which will receive flows from surface or ground water from affected areas within the proposed mine-plan area, sufficient to identify seasonal variations--"

Responsibility of Applicant

Section 507 (b)(11) requires that applications for a mine permit contain a

> "determination of the probable hydrologic consequences of the proposed mining and reclamation operations."

The responsibility for gathering data and making impact assessments is divided between the permit applicant and a regulatory authority. The regulatory authority will either be a state agency or the Office of Surface Mining and Enforcement. The mining-permit applicant is responsible for obtaining data that are needed to determine the hydrologic impacts both on and adjacent to the potential mining site. The regulatory authority or some government agency supplies the hydrologic data for the general area surrounding the mine site. Upon receipt of the permit application the regulatory authority is responsiblc for making an assessment of the cumulative impacts of all mining and anticipated mining in the area upon the hydrology of the area. For this purpose the regulatory authority would use the applicant's site and adjacent-area data as well as the general-area data.

For small scale operations, Sec. 507 (c) of Public Law 95-87 states that,

> "If the regulatory authority finds that the probable total annual production at all locations of any coal surface-mining operator will not exceed 100,000 tons, the determination of probable hydrologic consequences required by Sec. 507 (b)(11) and the statement of test

borings or core samplings required by Sec. 507 (b)(15) shall, upon the written request of the operator be performed by a qualified public or private laboratory designated by the regulatory authority and the cost of the preparation of such determination shall be assumed by the regulatory authority."

The program that provides the small operator with this assistance is the Small Operator Assistance Program (SOAP).

Geological Survey Responsibilities

Section 507 (b)(11) of Public Law 95-87 indirectly refers to the U.S. Geological Survey as a participant in implementing SMCRA. Sec. 507 (b)(11) states that hydrologic information about the general area prior to mining will be made available from an appropriate Federal or state agency. A memorandum from the Assistant Secretary-Energy and Minerals (July 5, 1979) established guidelines for OSM and Survey involvements under the mandate of Public Law 95-87.

An administrative report by the Systems Analysis Group of the Survey's Water Resources Division, January 1979, assessed Survey responsibilities under Public Law 95-87. The study pointed out that hydrologic information needs arise from six aspects of Public Law 95-87. These include:

1. The permitting process.--The responsibility for providing hydrologic information is shared by the regulatory authority and the permit applicant. The applicant is responsible for obtaining data and making impact determinations on the mine itself; the regulatory authority is responsible for providing the applicant

data on the general area prior to mining and also must make an assessment of "the probable cumulative impacts of all anticipated mining in the area upon the hydrology of the area and particularly upon water availability."

2. The abandoned mine program.--Hydrologic information is needed for developing priorities for Federally funded reclamation and for evaluating the effectiveness of the reclamation.
3. The Small Operator Assistance Program (SOAP).--Federal funds are provided to small operators to assist them in preparing their applications.
4. The enforcement area.--All enforcement monitoring is to be done by the coal mining operator.
5. Lands unsuitable for surface mining.--There are several reasons why lands may be unsuitable for surface mining. These include aquifer recharge, wetlands, natural hazards, and nonreclaimable land. The Systems Group study pointed out though, that the Survey's responsibility in this area is unclear.
6. Alluvial valley floors (AVF) west of the 100th meridian.--Public Law 95-87 requires that mining will not interrupt, discontinue, or preclude farming on AVF or damage surface or ground water quality of the AVF. Again as in 5 above, the Survey's responsibility is unclear.

A major conclusion of the report is that the Survey will have the major responsibility for collecting, analyzing, and disseminating the hydrologic information required by Public Law 95-87, especially for the "general-area" requirement.

Objectives of Study

The purpose of this study is to describe how surface-water modeling techniques can provide some of the hydrologic information requirements defined in Public Law 95-87. The investigation considered the following areas:

1. Identification and summary of Public Law 95-87 hydrologic data requirements.
2. How modeling can further enhance a data base to meet Public Law 95-87 requirements.
3. Characteristics of watershed models for making strip-mine assessments.
4. Data requirements of watershed models.
5. Review and evaluation of the Survey's Coal Hydrology Program to see if it meets the requirements of Public Law 95-87.
6. Other coal-related research and data collection activities.

ASSESSMENT MODELS FOR COAL MINING AREAS

Modeling Techniques and Compliance with Public Law 95-87

Mining operations affect the hydrologic balance in and around mined areas. Disturbed surface areas affect infiltration and thus, runoff characteristics. Sediment and water-quality transport processes change too. Public Law 95-87 requires that a determination of the probable hydrologic consequences of mining must be made for both on and off the mine-plan area before any surface-mining operations can begin. This assessment of the cumulative impacts of all active and anticipated mining in an area can be made only if there are sufficient hydrologic data. One way to obtain the data is through hydrologic data collection programs designed for sufficient areal coverage and that addresses mining impacts by measurement only. However, these programs are very expensive to implement and operate. Even with extensive hydrologic data collection programs, all potential mining areas cannot be sampled. Section 779.13 of the Regulations indicates that if hydrologic data are not available in the general area of a proposed mine site then,

> "the use of modeling techniques may be included as part of the permit application."

Modeling techniques are those tools that can be used to simulate a watershed's hydrologic response from some known stress. The tool may be a simple mathematical expression or one that attempts to describe most of the complex interrelated watershed processes. Mathematical modeling provides a powerful means by which to analyze and compare solution alternatives and thereby to reach a more rational course of action than might be otherwise possible (Baltzer, 1972).

How Models Will Be Used

The procedure often followed in watershed modeling begins with calibration of model parameters by using detailed physical and hydrologic watershed data at a gaged site. Initial model parameter values can be estimated from model runs with data from other data collection programs, laboratory studies, and literature reviews in which the models are referenced. Observed data at the specific site are used to adjust or "fine-tune" the initial model parameter values. Sensitivity tests on model parameters can also be performed by running the model and holding all parameters constant except the one being tested for sensitivity. A highly sensitive parameter produces significant changes in model output results when a range of parameter values are tested in the model. After calibration, to assure that the model is reliable and credible, it is verified with additional data from the site. The model should be capable of simulating a range of hydrologic events.

A calibrated and verified model for a specific watershed can be used to model ungaged watersheds with similar physical features. For modeling approaches to be useful elsewhere, detailed watershed data must be collected at a sufficient number of sites so that information from models calibrated and verified in one area can be transferred to ungaged sites in another area. This is usually accomplished with regionalization of model parameters by relating, through regression techniques, the model parameters to watershed physical parameters.

A proposed mine area has three time periods in which modeling techniques can be used. The first period is pre-mining; the second, active-mining; and the third, post-mining. During the post-mining period, final reclamation occurs. For large mining areas, various phases of each time period can occur concurrently but in different parts of the basin.

A model can be used during the pre-mining period to simulate baseline hydrologic information. This information provides design criteria for ponds, dams, and sediment control structures that may need to be constructed to regulate runoff quality and quantity during and after mining. Also these data can be compared to post-mining data to determine if reclamation is being accomplished. The second and third periods, during and after mining, are when the mine operators are required to collect hydrologic data at the mine sites. These data can be used for model calibration of different land-use scenarios corresponding to various stages of mining and reclamation operations.

Each time period can provide valuable data for adjusting model parameters that may vary with changes in land use. Model applications at ungaged sites or sites with little data will be more reliable as more is learned about model parameters and how they vary with land-use changes.

Types of Models Needed

Surface-water hydrologic information required both in and adjacent to mine-plan areas dictates the need for multipurpose flow and water-quality models that can be used on small and large watersheds. The models should also be capable of simulating channel transport processes so that the probable hydrologic consequences of surface mining can be determined at downstream locations.

Models vary in complexity from simple models with a few simulated processes to highly sophisticated models that contain many interactive processes. Constraints such as time, money, personnel, available data, and knowledge of the models are a few of the factors that influence the model-selection process. In general, the model choice should be the most accurate model consistant with the problem context.

Reference to two conceptual approaches that have been used in model development will give a range for comparing models. One approach referred to as "deterministic modeling" pertains to models whose development are based upon physical laws and measures of initial and boundary conditions and input (Overton and Meadows, 1976). The output from these models can be accepted with a high degree of certainty when input data are adequately described. In deterministic models the parameters are measurable watershed characteristics such as roughness and slope. This results in an improved capability to model in minimum data situations.

The second approach has been termed "parametric modeling" in which the model parameters are not necessarily defined as measurable physical quantities. Parameters and system responses are lumped together and parameter values may be the result of fitting the model output to observed hydrologic data with an optimization technique. These types of models can be used to assess the gross effects of land use on runoff whereas the more deterministic models have the capability of assessing the sensitivity of internal distributions of land use on runoff.

Models Selected For Evaluation

Researchers from a number of universities and Federal agencies are developing watershed models for strip-mine assessment applications. A review of their research resulted in the selection of 12 models (table 1) for testing and evaluation. These models were selected because they simulate the processes that are a part of strip-mining operations.

The different processes that are simulated by the models include:

(1) The generation of rainfall excess as a function of precipitation and extractions from precipitation such

Table 1.--Strip-mining assessment models being evaluated by the Survey

MODEL	REFERENCES
AGRICULTURAL RESEARCH SERVICE MODEL (ARS MODEL)	Smith, 1977
ANSWERS MODEL	Beasley and others, 1977
ARIZONA STATE MODEL (AS MODEL)	Berkas, 1978
COLORADO STATE UNIVERSITY MODEL (CSU MODEL)	Li, 1979
CREAMS MODEL	Knisel, 1980
TENNESSEE VALLEY STRIPMINE MODEL (TVA-HYSIM)	Bales, 1979 Betson, 1979
UNIVERSITY OF KENTUCKY MODEL (UK MODEL)	Haan and Barfield, 1978
UNIVERSITY OF TENNESSEE MODEL (UT MODEL)	Overton and Crosby, 1979
U.S.DEPARTMENT OF AGRICULTURE SEDIMENT LABORATORY MODEL (USDA MODEL)	Alonso and others, 1978
U.S. GEOLOGICAL SURVEY MODEL (USGS MODEL)	Leavesley, 1973
UTAH STATE UNIVERSITY MODEL (USU MODEL)	Jeppson, 1980
VIRGINIA POLYTECHNIC INSTITUTE MODEL (VPI MODEL)	Ross and others, 1977

as evaporation, transpiration, infiltration, detention storage, and so forth;

(2) Overland routing of flow quantity and quality; and

(3) Channel routing of flow quantity and quality.

Flow-quality transport processes include those for both sediment and water-quality constituents. Most all of the models cover flow-quantity and sediment transport and some include transport of water-quality constituents, too.

Past model development has been mainly oriented toward agriculture; more recently, models have been developed to simulate processes in urbanized areas. Most of the research has been conducted on small watersheds, some as small as laboratory-size plots. Therefore, most of the available watershed models are best applied to small watersheds with specific-site data. Extending the use of modeling techniques to larger watersheds remains relatively untested, and to date the upper limits for application have not been established.

Most of the strip-mining assessment models (table 1) are in the developmental stage, and some are in the pre-documented stage. The Gulf Coast Hydroscience Center is evaluating these models and recommendations as to which models can be used to best simulate surface-water characteristics, as required by Public Law 95-87, will be in the final report of this project.

General Data Requirements for Models

The following data are needed to test the 12 models:

1. Continuous measurement of rainfall;
2. Continuous measurement of runoff;

3. Continuous measurement of several water-quality parameters such as conductance, pH, and temperature;
4. Sediment discharge hydrographs for flood events;
5. Evaporation data;
6. Rainfall-simulation derived data to determine infiltration and soil erodibility parameters and to define soil detachment/transport processes; and
7. Watershed data on land use, channel geometry, and other physical parameters.

Since the number of processes that the models can simulate vary, not all of the above data are needed for testing each model. However, a complete evaluation of all the models cannot be made without all the data. Table 2 lists for the 12 models in table 1 their corresponding processes and some of the model characteristics. A brief description of each model is presented in the next section of the report.

Description of Models

The Agriculture Research Service Model (ARS MODEL) is a distributed deterministic model. This model predicts surface runoff and erosion, as well as sediment deposition in reservoirs for storm events. The hydrologic response of the watershed is simulated using a two-parameter infiltration model to compute runoff, which is subsequently routed overland using a kinematic wave model. Channel flow is also routed using a kinematic wave model. The erosion/sedimentation component considers erosion by both raindrop splash and overland flow. Raindrop erosion is expressed as a power function of rainfall intensity, local water depth, and other

Table 2.--Comparison of model processes and characteristics

PROCESSES and CHARACTERISTICS	MODEL											
	ARS MODEL	ANSWERS	AS MODEL	CSU MODEL	CREAMS	TVA-HYSIM	UK MODEL	UT MODEL	USDA MODEL	USGS MODEL	USU MODEL	VPI MODEL
Streamflow Processes	X	X	X	X	X	X	X	X	X	X	X	X
Distributed	X	X	X	X					X	X	X	X
Lumped					X	X	X	X				
Water-Quality Transport					X			X				
Sediment Transport	X	X	X	X	X	X	X	X	X	X		X
Channel	X	X		X	X		X	X	X	X		X
Overland	X	X	X	X	X	X	X	X	X	X		X
Model Characteristics												
Time Interval												
Continuous			X			X				X		
Storm event	X	X		X	X		X	X	X		X	X
Basin Representation												
Multiple element	X	X	X	X	X			X	X	X	X	X
Single element						X	X					

empirically determined parameters. Erosion by overland flow is expressed as a linear function of concentration deficit. There are six sediment transport laws programmed into the model, any of which can be used for a plane or channel. The ARS model does not treat sediment particle sizes individually in these situations. Water-quality simulations are not considered in the ARS model. Input data consists of the usual climatologic data, watershed geometry and physical characteristics, and other optimized and calibrated parameters.

The Areal Nonpoint Source Watershed Environment Response Simulation Model (ANSWERS) is a distributed deterministic model that can be used to predict runoff and erosion/sediment transport for agricultural watersheds. A tile drainage simulation process is included in the model. The hydrologic component describes surface runoff, subsurface flow, and channel flow in a system of square grids laid over the watershed. The model has an infiltration component and when the water content of the control zone exceeds field capacity, infiltrated water becomes subsurface drainage. The erosion component of ANSWERS is a modification of the Universal Soil Loss Equation. The overland erosion process has two soil detachment processes, one a rainfall detachment and the other an overland flow detachment. Channel erosion is assumed to be negligible so that only deposition is allowed in channel flow. Sediment transport, both overland and channel, is based on transport capacity. That is, when the transport capacity is exceeded, the amount of sediment in excess of the transport capacity is deposited.

The Arizona State Model (AS MODEL) has five basic components: evaporation, interception, soil moisture movement (infiltration and evaporation), surface-water runoff routing, and sedimentation. The model was developed for use in reclamation decisions on coal mine spoils in the southwestern United States. It can be used to estimate soil moisture, peak flows, runoff volumes, and erosion.

The AS MODEL is used in conjunction with a computer mapping model that fits a square grid to a watershed and produces a slope and aspect for each grid square. The surface runoff model requires that a watershed be divided into square elements. The elements are small so that topographic and vegetation features are uniform. Each grid square has a uniform slope so that water is routed along the slope parallel to the aspect. The values of slope and aspect for each square can be obtained from a contour map of the watershed by hand if a computer mapping model is not available.

The erosion process in the model occurs as rainfall detachment or flow detachment. Rain striking the soil surface causes soil detachment while overland flow causes erosion by flow detachment. The use of squares for overland flow segments allows erosion to be calculated for each square so that spatial variations can be determined.

The soil moisture movement routine continuously routes moisture through the soil, therefore, a soil moisture profile can be obtained at anytime. Antecedent moisture conditions are established so that accurate estimates of infiltration are possible. This results in a more accurate determination of the storm runoff hydrograph. A model limitation is that watershed area should be small (< 10 km^2) so that uniform slopes and aspects can be computed for each grid square.

The Colorado State University Model (CSU MODEL) is an unsteady overland flow and soil erosion model used to simulate runoff and sediment yield from small watersheds. The model is a single-event model based on the physical processes of water erosion and sedimentation in a watershed. The hydrologic component considers the physical processes of interception and infiltration in determining rainfall excess. The sediment component considers soil erosion by both rainfall splash and shear stress of overland flow. Raindrop erosion is expressed as a power function of rainfall intensity and an empirically determined erodibility factor. Erosion by overland flow uses a detachment coefficient characteristic of the soil type. The routing of water and sediment is accomplished by a kinematic wave model both for overland and channel flows. Data requirements consist of climatological data, watershed geometry, physical characteristics, and soil information data. These data are entered via a square grid system.

The Chemicals, Runoff, and Erosion from Agriculture Management Systems Model (CREAMS) is a physically based continuous simulation model. CREAMS estimates runoff erosion/sediment transport, and plant nutrient and pesticide transport from small field-sized areas. CREAMS is structured in three separate components: 1. Hydrologic; 2. Erosion/Sedimentation; and 3. Chemical. The hydrologic component includes models for infiltration, soil moisture accounting, and evapotranspiration. These processes are modeled on a day to day basis, if rainfall records are available. When rainfall records are not available, the watershed hydrologic response is estimated using the Soil Conservation Service (SCS) curve number procedure. The main processes in the erosion/sedimentation component are overland flow, channel flow, and impoundments. Sediment detachment is computed using a modified Universal Soil Loss Equation. The chemical component consists of plant nutrient and pesticide submodels. The nutrient submodel is an accounting and transport model used to simulate nitrogen and phosphorus losses from fields. Transport is treated in both solution and sediment phases.

The Tennessee Valley Authority Strip Mine Model (TVA-HYSIM) was specifically designed for ease of application in land-use planning studies within the Tennessee Valley. TVA-HYSIM is a continuous simulation model that employs a regionalized lumped parameter approach. The model consists of four linked components. It is driven by a stochastic rainfall generator component that simulates a daily rainfall distribution for the continuous streamflow component. The streamflow component determines storm runoff as well as performs a basic soil moisture accounting. This component considers the individual processes of interception, evapotranspiration, and infiltration to determine streamflow and precipitation excess. These processes are simulated using long-term regionalized averages in conjunction with empirical relationships. The third component of TVA-HYSIM is a regionalized unit hydrograph that is used to distribute the rainfall excess across the storm hydrograph. The fourth component simulates the erosion/sedimentation process. Erosion is approximated using a modified Universal Soil Loss

Equation. The sediment is then distributed across the storm hydrograph using an instantaneous unit sediment graph approach. Data requirements consist of climatological statistics, watershed characteristics and physical data, averaged soil and sediment data, and land-use data. The approach is to use an "interactive" input terminal, wherein the computer prompts the user for information.

The University of Kentucky Model (UK MODEL) is currently under development. This model, which should be available in early 1981, specifically will describe the hydrology and sedimentology of strip mining. The UK MODEL, will have a component to simulate the erosion process; but, water-quality transport will not be modeled.

The University of Tennessee Model (UT MODEL) has three components consisting of a storm hydrograph simulator, a watershed pollutant load simulator, and a site erosion simulator. The storm hydrograph simulator (TENN-II) has as input a real time or design rainfall hyetograph. Rainfall excess is computed using the Curve Number model developed by the Soil Conservation Service. A unit response function is simulated from watershed characteristics and rainfall excess. The unit response function is convoluted with the rainfall excess hyetograph to produce the outflow hydrograph. The site erosion simulator (ERODE-I) simulates the time distribution of soil mass transport rates at the end of a mining site per unit width for a real storm or a design storm rainfall time distribution. The watershed pollutant load simulator (LOAD-I) simulates the load rate curve and hydrograph (pollutograph) associated with storm hydrographs. Selected watershed characteristics are used to generate a load modulus. The load modulus allows linkage of the pollutograph and storm hydrograph.

The U.S. Department of Agriculture Sediment Laboratory Model (USDA MODEL) consists of two components. The first component describes the hydrology of the basin while the other component describes the associated erosion and sedimentation processes. Water and sediment are routed using the kinematic wave solution techniques of the continuity, momentum, and flow resistance equations. Watersheds can be described in detail as overland and channel segments. The model simulates the processes of interception, infiltration, runoff, detachment, transport, and deposition of sediment. There are several restrictions to the model applicability. Streamflows are to be ephemeral; subsurface flow and ground water movement are not significant; and the kinematic wave approximation for flow routing must be valid.

The U.S. Geological Survey Model (USGS MODEL) is a modular design program package with each component of the hydrologic cycle defined by a model module. A distributed-parameter approach is used with basins being divided into subunits on the basis of slope, aspect, altitude, vegetation type, soil type and snow distribution. Basins are divided so that an accounting can be made for temporal and spatial variations of basin physical and hydrologic characteristics, climatic variables, and system responses. A basin subreach is considered homogeneous and produces a single hydrologic response unit (HRU). The total system response is determined by weighing individual HRU's and computing from them a total system response.

There are four components of the model. These are the climatic, land phase, snow, and sediment components. The model can simulate individual storm events and also a continuous daily mode between storms. There is no water-quality component, only sediment. The ground water component being considered is a lumped-type reservoir system that will be within the land-phase components. In the future the ground water component will be changed and water quality will be added to the model.

The Utah State University Model (USU MODEL) is a composite hydrologic model consisting of several submodels linked together to simulate watershed hydrology both on and below the watershed surface. The submodels are a ground water model, an unsaturated flow model, an overland flow model, and an evapotranspiration model. The ground water submodel receives recharge in the form of percolation from the unsaturated flow model. The ground water model supplies the water table levels to define the lower boundary of the unsaturated model. Seepage effluent from this submodel is input into the overland flow model. The unsaturated flow model accounts for water movement between the ground surface and the water table. The submodel is based on the one-dimensional vertical flow solution for each element in the watershed. The overland flow model solves the kinematic wave equations for flows along the watershed's surface. The watershed surface is described by a cascade of overland flow planes and channels. Plant transpiration and surface evaporation as a function of roots penetration, meteorological elements, species of plants, stage of plant growth, and a soil-water parameter are computed by an evapotranspiration model. Presently there is no water-quality component in the USU MODEL, but future plans do include incorporating a water-quality transport component.

The Virginia Polytechnic Institute Model (VPI MODEL) is a finite-element numerical model that routes overland and channel flows in a watershed. Inputs to the model that drive the streamflow processes are soils, land use, topographic descriptors, and rainfall. The various processes of infiltration, canopy interception, seasonal vegetative growth, and depression storage are components in the hydrologic part of the model.

The model can also be used to determine overland and channel sediment transport and erosion processes. Overland sediment yield is a function of soil detachment by rainfall and overland flow. Soil detachment by raindrop impact and overland flow is estimated from empirical relationships. The total soil detached is compared to a computed potential transport capacity rate. If the soil detached is greater than the transport capacity, the amount in excess is deposited. The amount of detached soil less than the transport capacity is routed through the element. The sediment transport in the channel is computed from a sediment continuity equation that was adapted to the finite-element technique for routing storm-water runoff.

The model is spatially responsive and therefore requires a large data base and excessive amounts of computer memory to store the data. It is time consuming to prepare spatially variable data sets. However, new advances in interactive computer techniques such as pattern recognition, and advances in data collection such as remote sensing are minimizing these liabilities.

Testing and Evaluation of Models

Current WRD projects in Tennessee and Indiana will generate comprehensive data sets for testing and evaluating the models (table 1). Studies in Kentucky, Illinois, Montana, North Dakota, Pennsylvania, Virginia, West Virginia and several other states will provide data for further model testing and evaluation.

Tennessee New River Basin Study - The New River Basin, Tennessee, is representative of small watersheds in eastern Tennessee that have undergone a transition in basin watershed outflow and suspended sediment responses as a result of strip-mining. Coal mining activity in the basin has also affected both water quality and quantity.

The long history of mostly unregulated mining activities in the New River basin has produced two distinctly different sediment loads. One is a large load of fine grain suspended sediment that is being produced in response to current land-disturbing activities. The other is a large supply of coarse material consisting mostly of coal which moves as bedload.

Sediment transport of suspended particles and bedload material provide a major mechanism by which chemical constituents move through a watershed hydrologic system. Current data collection and modeling efforts in the basin by the University of Tennessee, U.S. Geological Survey, and other agencies (Betson, 1979; Crosby, 1979) are concerned primarily with the sediment production from small first-order basins (< 5 mi^2). Little attention has been given to routing the sediment and associated chemical constituents downstream and no modeling has been done to examine the downstream movement and effects of bedload.

The objectives of the study are to test the 12 models on small mined and unmined watersheds in the New River Basin. An evaluation will be made of the models and a generalized model selected or adapted for use in calibration and simulation of flow, sediment, and water-quality processes from small mined and unmined watersheds that are tributary to Smoky Creek near Hembree, Tenn. Smoky Creek is one of six major tributaries to the New River (fig. 1). In addition, a cumulative impacts analysis of Smoky Creek basin (17 mi^2) will be made using a channel transport and flow routing model linked with a watershed model.

Past and current data on flow, sediment, and water-quality constituents will be used in model calibration and verification analyses. New data to be collected will include water-quality constituents mentioned in Public Law 95-87. Detailed watershed analyses at several sites in or near the Smoky Creek basin will determine the probable hydrologic consequences of mining. Also, an analysis will be made to assess cumulative impacts of surface mining on water quality and quantity for a part of the basin or a "general-area" as specified in Public Law 95-87.

Indiana Watershed Study - There are coal deposits underlying nearly 6,500 mi^2 in southwestern Indiana. In the last 50 years almost 100,000 acres (about 156 mi^2) in this area have been disturbed by surface mining, either directly by coal removal or indirectly by spoil deposition (Powell, 1972). Figure 2 shows the location of surface-mined lands in southwestern Indiana.

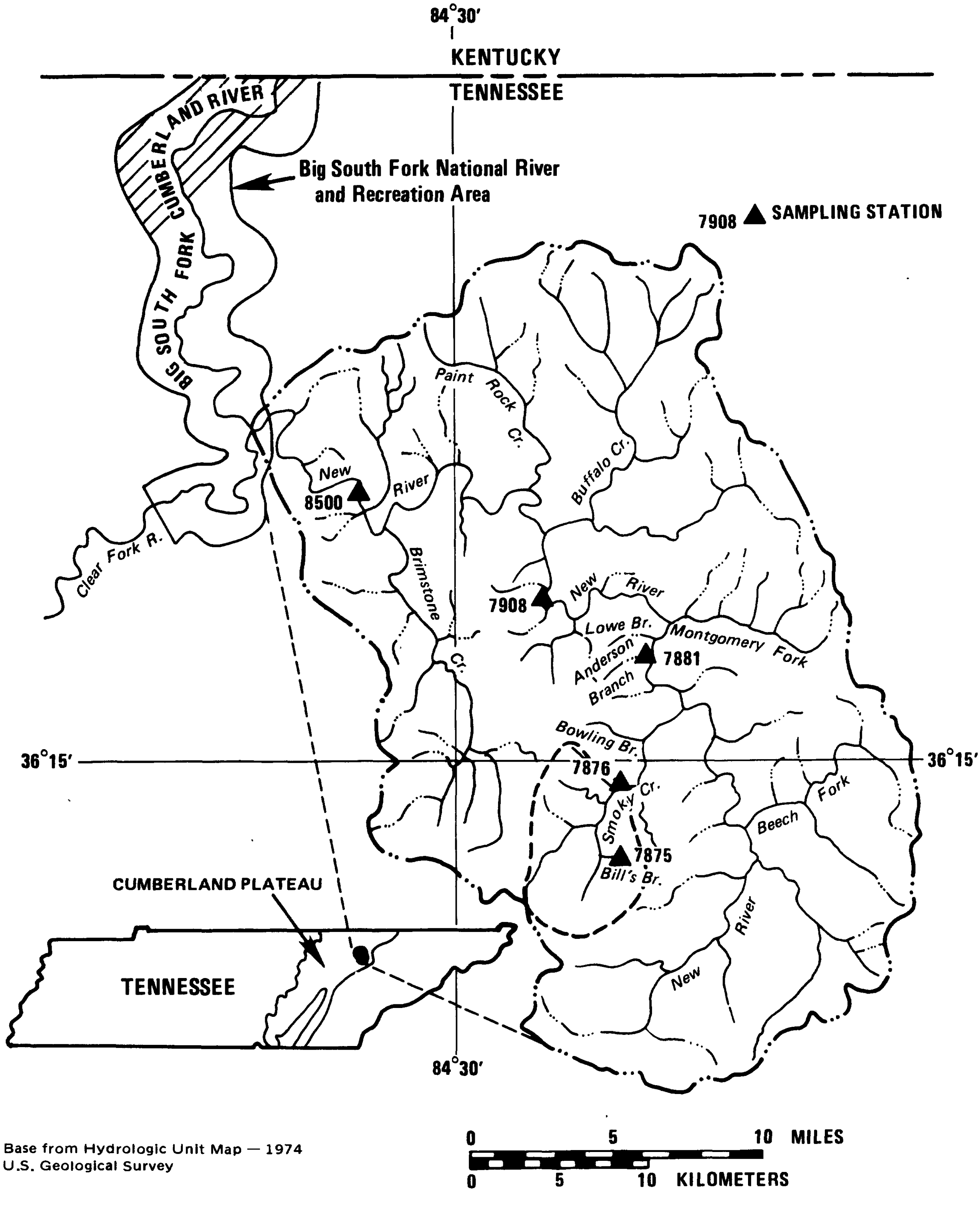

Figure 1.--Location of New River Basin and sampling stations.

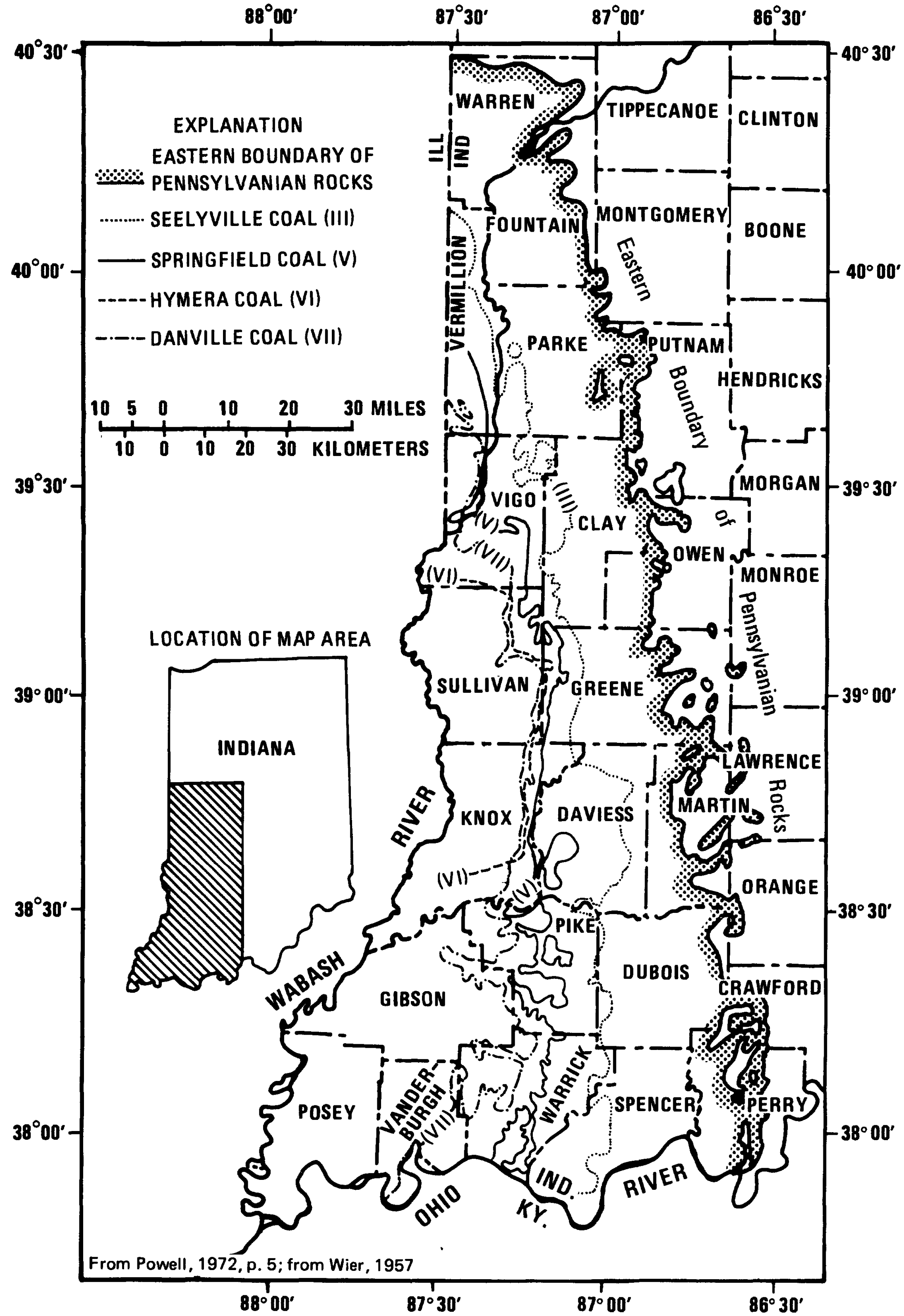

Figure 2.--Southwestern Indiana - Distribution of strip-mined land as of June 1972. Adapted from Powell, 1972.

Surface mining of coal in Indiana has significantly altered the hydrologic system in mined and nearby unmined areas. Watershed drainage areas, slopes, soil properties, lake storage, and the course and slope of streams have been drastically altered by surface mining.

The objectives of the study are to determine the changes in surface-flow and quality characteristics resulting from varied land use and altered surface topography. Other project objectives include an analysis of the ground water system and the exchange between the ground water and surface water systems to determine how they too have been affected by mining activities.

The models will be tested and evaluated on three types of sites that either have the highest potential for mining or have already been mined. The three types of sites are:

1. Homogeneous unmined agricultural sites;
2. Unmined sites with mixed land-uses -- forest, pasture, and agricultural uses; and
3. Previously mined, unreclaimed sites.

The third type represents areas that will have additional mining operations as a result of new mining equipment and technology developed since the area was previously mined.

The Indiana study provides a different physiographic setting for model testing. As compared to the New River Basin where altitudes are 1,800 to 2,400 feet, in Indiana they are uniformily around 500 feet. The two areas are also different topographically, and different surface-mining practices are used. Mountain-top removal and contour mining are methods used in Tennessee while in Indiana most mining is flatland or area mining that involves stripping away the overburden down to the coal seam.

Other Studies - A significant data base for coal-mined areas in Kentucky, Illinois, Montana, North Dakota, Pennsylvania, Virginia, West Virginia and several other Survey districts is being created. Flow, rainfall, and water-quality information are some of the data being collected. These data can be used to calibrate models and evaluate the effects of coal mining. Liaison has been established with field and research projects throughout the Survey.

REVIEW OF THE SURVEY COAL HYDROLOGY PROGRAM

Prior to enactment of Public Law 95-87, the Survey had previous involvement in coal hydrology in connection with Federal lands. The Bureau of Land Management (BLM) requested in FY 1974 that the Geological Survey assist in several hydrologic problems associated with coal mining on Federal coal lease areas in the Western States. In fiscal year 1975, $1.2 million was available to the Survey to investigate the relationships between coal development and water resources on Federal lands. In 1976, $2.6 million was provided for a study of large-scale ground water withdrawals from the Madison Aquifer in support of coal development in the Northern Great Plains. By FY 1977, funding for the Survey coal hydrology program totaled $8.2 million. However, the program was still essentially limited to the Western United States. With the enactment of Public Law 95-87, the coal hydrology program became nationwide in scope.

Public Law 95-87 places heavy emphasis on the effects of mining and reclamation on water resources. The increases in the budgets for FY 1979 and FY 1980 are mostly for hydrologic support to Public Law 95-87. This section of the report summarizes and evaluates the data collection part of the Coal Hydrology Program that has been implemented in 30 Survey districts to meet the requirements of Public Law 95-87. Figure 3 shows the major coal provinces in which the 30 states are located.

Types of Programs Implemented

The Survey Coal Hydrology Program consists of two parts: First, hydrologic data collection having a broad coverage pattern designed to provide a basis for characterizing the general-area hydrology, and; second, in pilot-basin areas, detailed specific-site studies to be used to develop and evaluate techniques and models to aid in making determinations of probable mining impacts and cumulative impacts.

Network Program Station Types

As part of the first objective, the Survey has implemented a coal hydrology network in 30 states. There are two station types in the program: (1) regular, permanent continuous record surface-water gaging stations, and (2) miscellaneous or synoptic surface-water data sites. Special categories of the first type are trend and reference stations.

Trend stations are located in areas disturbed by mining and provide hydrologic information that can be used to detect broad trends that occur as a result of mining and reclamation. Reference stations are hydrologically isolated from any significant land-use

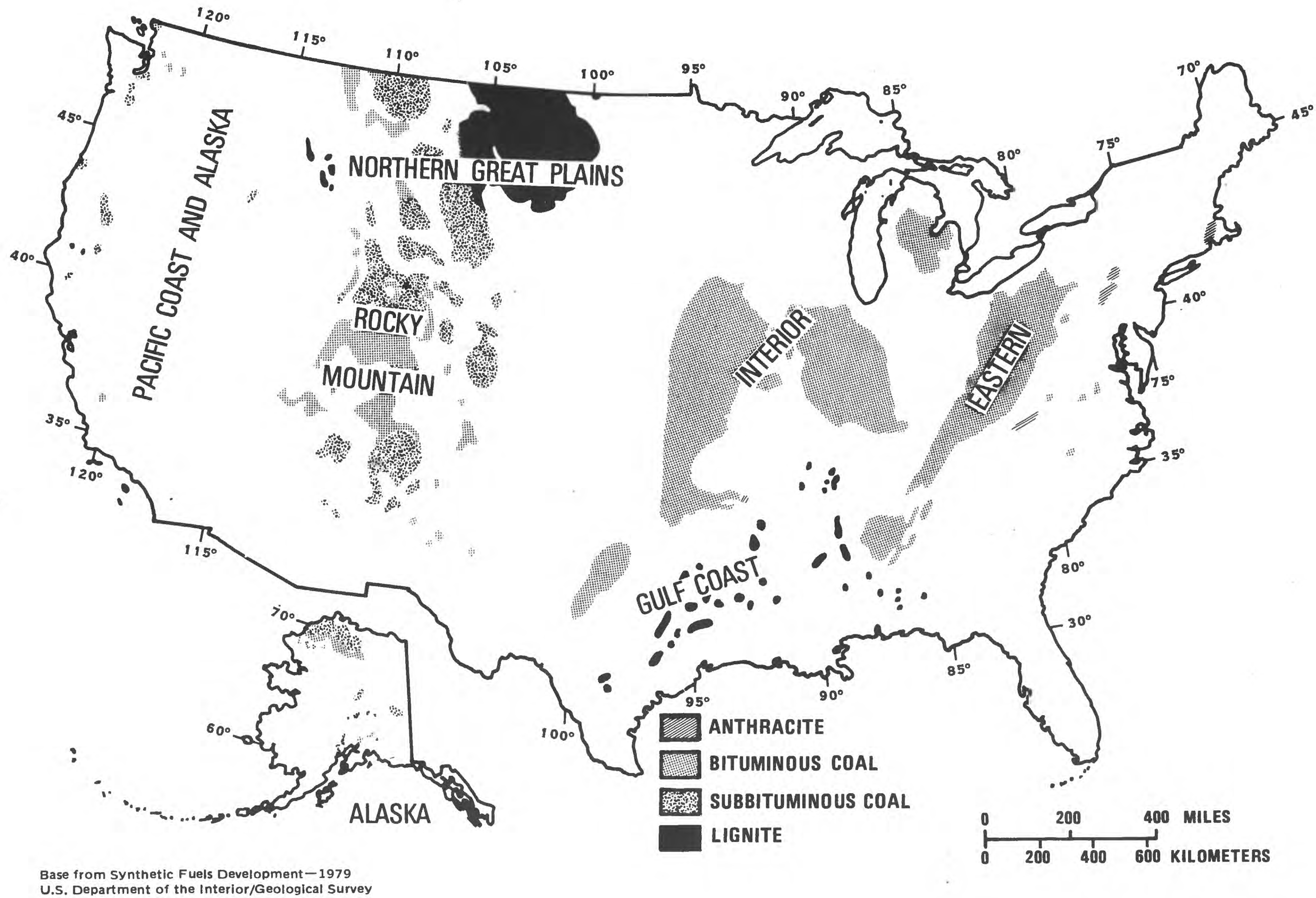

Figure 3.--Coal provinces of the United States.

disturbances. Baseline information can be collected at reference stations and, together with trend station data, used to assess the impacts of land-use activities such as coal mining.

Synoptic data sites are miscellaneous sites that provide "filler" data to the regular, trend and reference station data. They are normally located on first-order streams and provide small drainage area data (< 5 mi^2) in proximity to actual or potential coal mining. The synoptic network is flexible with new sites being added and old ones dropped as system evaluations dictate. The nature of the synoptic sampling program reflects the nature of coal mining activities as mines open and close frequently in the Eastern and Interior Coal Provinces. The purpose of the synoptic sampling program is to provide data that together with the permanent station data can be used to appraise "general-area hydrology" more effectively than permanent station data alone.

Pilot-Basin Study Areas

These studies are on small watersheds that represent mined and unmined areas. There are ongoing studies of this kind funded by various Federal and state programs, in several districts such as Kentucky, Illinois, Montana, North Dakota, Pennsylvania, Virginia, and West Virginia. Studies like those in Indiana and Tennessee (referenced in the second section of this report) are just beginning. All these studies are more data intensive than any of the broad national data network activities described above containing permanent and synoptic data stations. Rainfall, runoff, sediment and water-quality data are recorded at small intervals. Rainfall simulation tests and determination of land-use data and basin and channel characteristics are a part of the studies. As a whole these studies offer the best opportunity to test some of the modeling techniques that will be used to assess strip-mining activities and its impact on the environment.

Variability in District Programs

The types of coal-monitoring programs implemented in the 30 districts vary. An intensive review of the Tennessee and Indiana Districts provided information about their programs. Contacts were also made with the other districts so that information about each district's program were a part of the program evaluation. Table 3 is an overview of the coal monitoring program in the various states.

The Eastern districts have implemented coal-monitoring networks that consist of synoptic, trend, and reference stations. Most of the districts have a large number of synoptic sites as a major part of their network. Other districts have few or no synoptic sites and rely on reference and trend stations for the hydrologic data. Most districts have intensive data collection programs at pilot-basin study sites.

Many new stations were added to those that existed to yield what is referred to as the coal-monitoring network; their selection processes are very important. Selection of sites for new stations should follow scientific guidelines with new stations being added if needed and old ones dropped if warranted.

A brief description of the method used by Indiana to select sites will illustrate one systematic approach of designing a coal-monitoring network. The District used maps from the Indiana Bureau of Reclamation and the Indiana Geological Survey showing coal outcrops, past and present mining operations and coal production,

Table 3.--Overview of the Survey coal hydrology program.

States	Number of miscellaneous sites and sampling frequency per year	Number of continuous sites and sampling frequency per year	Number of pilot-basin studies	Percent of national coal-related funding*	Mining activity	Analysis contemplated	Modeling contemplated	Program reshaping	Request for data	Year program began	Year first report available
ALABAMA	82 / 3	27 / 12	3	3	Yes	Descriptive data report	Yes	Rotate synoptic sites	Numerous	1978	1980
ALASKA	15 / 4	1 / 6	0	-	Yes	Descriptive data report	No	Field collection terminated in 1978	Some	1975	1980
ARKANSAS	8 / 4	2 / 4	0	1	Yes	Interpretive report	GW only	Event sampling	Some	1977	1979
ARIZONA	- / -	2 / -	4	-	Yes	Interpretive report	Yes	None	-	1973	1981
COLORADO	- / -	15 / 12	13	14	Yes	Statistical interpretive report	Yes	Yes	Numerous	1976	1980

*Includes funding from all Federal and State cooperative programs.

Table 3.--Overview of the Survey coal hydrology program--Continued

States	Number of miscellaneous sites and sampling frequency per year	Number of continuous sites and sampling frequency per year	Number of pilot-basin studies	Percent of national coal-related funding*	Mining activity	Analysis contemplated	Modeling contemplated	Program reshaping	Request for data	Year program began	Year first report available
GEORGIA	23/2 / 4/12	3 / 12	0	< 1	Yes	Descriptive data report	No	Rotate synoptic sites	None	1979	1981
ILLINOIS	109 / 3	7 / 12	8	5	Yes	Interpretive	Yes	Reshape synoptic program	None	1979	1980
INDIANA	300 / -	- / -	21	7	Yes	Interpretive statistical	Yes	Reduce to 21 intensive sites	Few	1979	1980
IOWA	15 / 4	5 / 12	0	< 1	Yes	Basic data report, statistical	No	Emphasize event sampling	None	1977	1979
KANSAS	20 / 4-12	4 / 12	6	1	Yes	Interpretive, basic data, statistical regression	Yes	Event sampling	Yes	1979	1981

*Includes funding from all Federal and State cooperative programs.

Table 3.--Overview of the Survey coal hydrology program--Continued

States	Number of miscellaneous sites and sampling frequency per year	Number of continuous sites and sampling frequency per year	Number of pilot-basin studies	Percent of national coal-related funding*	Mining activity	Analysis contemplated	Modeling contemplated	Program reshaping	Request for data	Year program began	Year first report available
KENTUCKY	230 / 4	30 / 9	†5	8	Yes	Interpretive	Yes	Reduce to baseline stations and synoptic network	Some	1976	1980
LOUISIANA	5 / During storms	10 / 4-12 1 daily	8	< 1	No	Basic data report	GW modeling	None	None	1977	1981
MARYLAND	37 / 3	8 / 12	4	1	Yes	Interpretive	Yes	Some	Few	1979	1980
MICHIGAN	52 / 3	- / -	32	< 1	No	Interpretive reports	Yes	No	None	1980	1982
MISSISSIPPI	15 / 1	3 / 2	2	< 1	No	Interpretive	Yes	No	None	1980	1984

*Includes funding from all Federal and State cooperative programs.
†Rainfall-runoff data in coal areas, part of a statewide network of rainfall-runoff stations. There are 29 sites with QW and sediment data, but none have rainfall information.

Table 3.--Overview of the Survey coal hydrology program--Continued

States	Number of miscellaneous sites and sampling frequency per year	Number of continuous sites and sampling frequency per year	Number of pilot-basin studies	Percent of national coal-related funding*	Mining activity	Analysis contemplated	Modeling contemplated	Program reshaping	Request for data	Year program began	Year first report available
MISSOURI	25 / 3	8 / 12	8	1	Yes	Interpretive	Yes	Yes--more intensive sampling	Yes	1979	1980
MONTANA	30 / 9-12	20 / 9-12	1	13	Yes	Interpretive and descriptive	Yes	Yes	Yes	1974	1976
NEW MEXICO	21 / 2-4	22 / 4-12	1	2	Yes	Descriptive and interpretive data reports	Yes	Yes	Yes	1978	1980
NORTH DAKOTA	- / -	33 / 12	3	1	Yes	Descriptive data reports	Yes	No	Yes	1978	1981
OHIO	311 / 2	4 / 12	4	6	Yes	Descriptive data and interpretive reports	Yes	Yes, reduce synoptic network to permanent‡	State university and Forest Service	1979	1980

*Includes funding from all Federal and State cooperative programs.
‡Program reshaping to also include increasing the sediment program in Ohio.

Table 3.--Overview of the Survey coal hydrology program--Continued

States	Number of miscellaneous sites and sampling frequency per year	Number of continuous sites and sampling frequency per year	Number of pilot-basin studies	Percent of national coal-related funding*	Mining activity	Analysis contemplated	Modeling contemplated	Program reshaping	Request for data	Year program began	Year first report available
OKLAHOMA	5 / 12	16 / 6-12	6	2	Yes	Descriptive and interpretive data reports	Yes	No	Only from BLM to date	1979	1980
OREGON	- / -	- / -	0	< 1	Yes, exploration only	Interpretive	No	No	None	1980	1981
PENNSYLVANIA	360 / 2 high and low	24 / 8-9	7	7	Yes	Descriptive and interpretive data reports	Yes	Rotate synoptic to get better coverage	Some	1979	1980
TENNESSEE	82 / 3	17 / 12	2	5	Yes	Descriptive and interpretive data reports	Yes	Yes	Yes	1979	1980
TEXAS	- / -	- / -	4	1	4 mine sites to date	Descriptive data and interpretive reports	Yes	Yes	None	1979	1981

*Includes funding from all Federal and State cooperative programs.

Table 3.--Overview of the Survey coal hydrology program--Continued

States	Number of miscellaneous sites and sampling frequency per year	Number of continuous sites and sampling frequency per year	Number of pilot-basin studies	Percent of national coal-related funding*	Mining activity	Analysis contemplated	Modeling contemplated	Program reshaping	Request for data	Year program began	Year first report available
UTAH	56 / §	16 / 12	0	2	Yes	Descriptive and interpretive reports	No	Yes	Yes	1978	1980
VIRGINIA	100 / 3	15 / 8-12	0	3	Yes	Descriptive data reports	No	Yes	Yes	1979	1980
WASHINGTON	- / -	10 / 12	0	< 1	Yes	Descriptive data reports	No	No	None	1980	1981
WEST VIRGINIA	‖315 / 2	42 / 12	6	7	Yes	Descriptive and interpretive data reports	Yes	Δ	Yes, many	1979	1980
WYOMING	- / -	31 / 12	27	10	Yes	Descriptive and interpretive data reports	Yes	Yes	Yes	1975	1979
TOTALS	2218	375	175								

*Includes funding from all Federal and State cooperative programs.

§Two base flow samples per year at each site and one water-quality sample per year at 12 of the 56 sites.

‖As of 10/1/80 number of sites will be 250.

ΔReduce number of synoptic sites. Sample remaining sites more intensively.

plus Geological Survey data on land use and water quality to select 300 stream sites. At the 300 sites, specific conductance, temperature, and pH were collected. These data allowed the effects of coal mining on water quality to be estimated and 84 of the 300 sites were selected for additional investigation.

Most coal-mining activities occur in southwestern Indiana and the 84 sites were chosen in order to adequately define the change in water quality due to different land uses, glaciated provinces, and physiographic units (Renn and others, 1980). Statistical analyses of the data from the 84 sites allowed the 84 sites to be reduced to 21 sites. An increased sampling frequency (monthly) was implemented at the 21 sites. The result was a better definition of the complete seasonal cycle of hydrologic events. Through further data analyses the 21 sites have finally been reduced to seven continuous recording stations witn five reference sites (two forested or natural and three agricultural) and two trend sites (active mining on both). The seven sites will provide data to adequately define the baseline hydrologic information as required by Public Law 95-87 for general areas in Indiana.

Section 779.16 (b) of the OSM Permanent Program Regulations requires that seasonal variations in water quantity and quality have to be identified within the proposed mine plan and adjacent areas. This includes minimum, maximum, and average discharge conditions that define critical low flow and peak discharge rates of streams. The water-quality information must include at least determinations for:

1. Total dissolved solids;
2. Total suspended solids;
3. Acidity;
4. pH;
5. Total and dissolved iron; and
6. Total manganese.

The regulatory authority can also require that any other relevant information be collected.

The frequency of data collection at synoptic sites for most states (table 3) during FY 79 was three to four samples per site. At permanent stations the frequency was 9 to 12 times per year. The water quality information includes the core requirements stated in the preceding paragraph plus additional information on metals, bottom materials, common constituents, minor elements, macro-invertebrates, and so forth.

As an illustration of sampling frequency and constituents sampled, two district programs are highlighted--the Pennsylvania coal study and the Arkansas lignite study.

Table 4 shows the comprehensive state-wide sampling plan for Pennsylvania including sampling frequency. This sampling plan is typical of northeastern states. Figure 4 shows the Arkansas lignite sampling network located in southern Arkansas (Terry and others, 1979). The sampling station network is located in a potential lignite mining area. Constituents shown in table 5 are sampled quarterly and annually and include an extensive array of chemical, physical and biological parameters.

Table 4.--Sampling parameters and frequency for coal-hydrology network in Pennsylvania

Sampling Frequency	Synoptic Sites	Trend Stations	Reference Stations	Other Continuous Record Stations
Once only	B,C,D	D	D	B,D,F
Annually	E	B,C,E,F	B,C,E,F	C
2-3X annually	A	-	-	-
6-9X annually	-	A	A	A
Other	-	G	G	-

LIST A

dissolved iron
total iron
dissolved manganese
total manganese
dissolved sulfate
pH
conductivity
temperature
discharge
suspended sediment
acidity
alkalinity
residue on evaporation at 180°C

LIST B

bottom materials
arsenic
cadmium
cobalt
copper
iron
lead
manganese
mercury
selenium
zinc

LIST C

Coal separation of bottom materials

LIST D

Detailed laboratory identification of benthic invertebrates

LIST E

Field identification of benthic invertebrates

LIST F

total arsenic
total barium
total cadmium
dissolved calcium
dissolved chloride
total chromium
total copper
cyanide
dissolved flouride
noncarbonate hardness
total lead
dissolved magnesium
total mercury
nitrite and nitrate as N
total phosphorus as P
total phosphorus as PO_4
dissolved potassium
total selenium
dissolved silica
total silver
total hardness
sodium and potassium
dissolved sodium
percent sodium
total zinc

LIST G

Daily and storm suspended sediment (beginning late in FY 80)

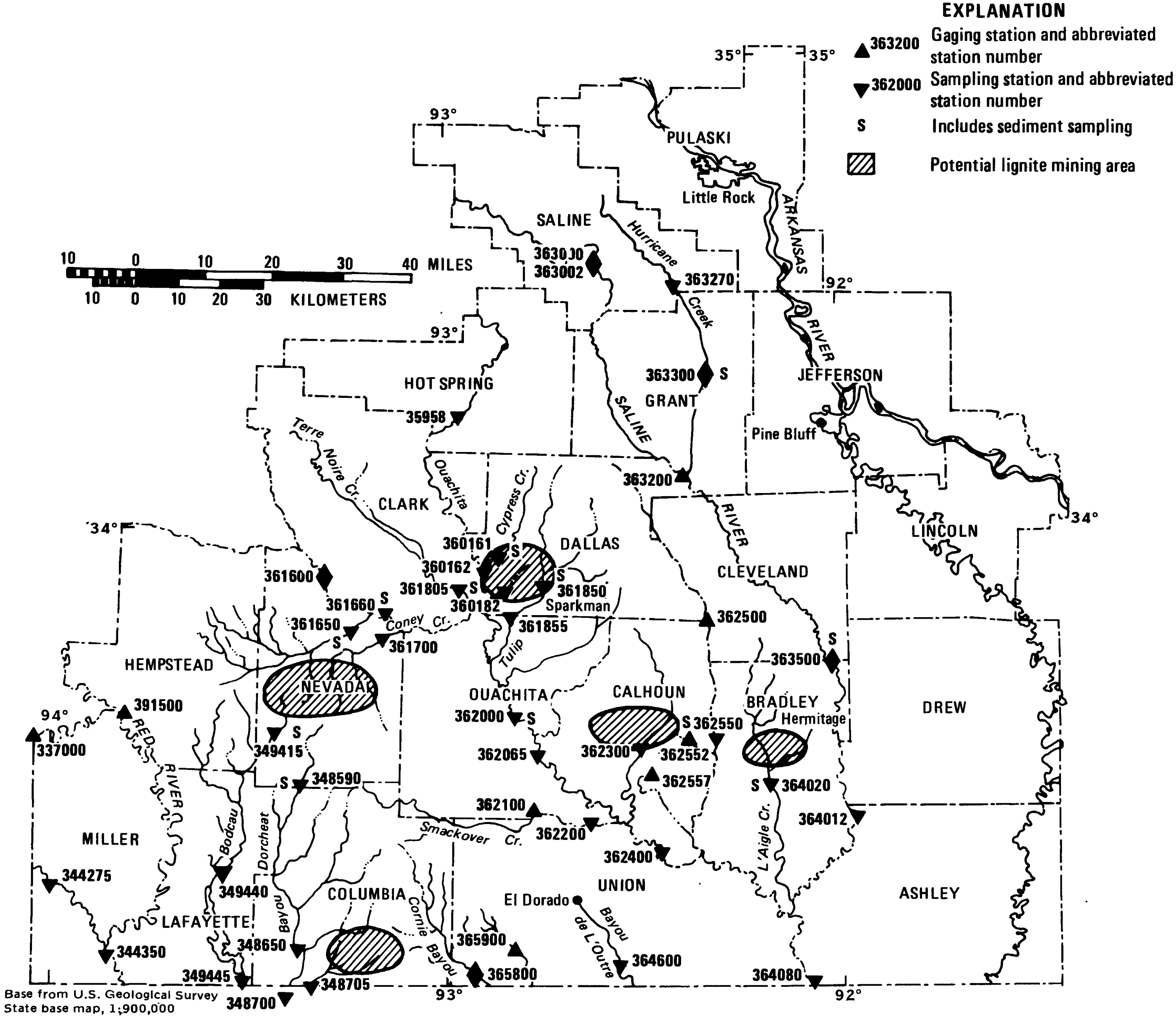

Figure 4.--Arkansas lignite coal-hydrology network.

Table 5.--Sampling parameters and frequency for coal-hydrology network in Arkansas

Field Determinations (quarterly)

- discharge, instantaneous
- specific conductance
- temperature
- pH
- dissolved oxygen
- calculate DO percent saturation

Laboratory Determinations (quarterly)

Nutrients--phosphorus, total as P
- nitrite + nitrate as N, total
- nitrogen, organic as N, total
- ammonia as N, total
- phosphorus, dissolved as P
- orthophosphate, total as P

Trace elements, total

arsenic	mercury
cadimium	selenium
chromium	zinc
cobalt	barium
copper	silver
lead	iron
manganese	

Organics--carbon, dissolved organic (DOC)
- carbon, total organic (TOC) by addition
- carbon, suspended organic (SOC)

Common constituents

pH	magnesium, dissolved
alkalinity, total ($CaCO_3$)	potassium, dissolved
calcium, dissolved	silica, dissolved
chloride, dissolved	SAR
residue, dissolved @ 180°C	sodium, dissolved
flouride, dissolved	sulfate, dissolved
iron, dissolved	turbidity, (NTU)
manganese, dissolved	

Suspended sediment
- in mg/l
- percent coal

Laboratory Determinations (annual)

Benthic organisms

Radiochemical--gross alpha, total BTM
- gross beta, total BTM
- RA_{226}, total BTM
- Uranium, total BTM

Trace metals in bottom material

The extent of sampling programs in the various states exceed minimum surface water-quality information requirements of Public Law 95-87. However, there is a significant variation in program objectives depending on area of the country and level of mining activity. The northeastern states rely mainly on synoptic monitoring with an emphasis on seasonal sampling. In the arid, western states, sampling networks are generally of the continuous station type and are situated in the actual or potential mining areas. Thus, in general, sampling frequency and constituents sampled are dependent on frequency of streamflow and on the importance of particular constituents.

Program Evaluation

Public Law 95-87 sets forth certain requirements as a part of the permit application. The Permanent Regulations specify in more detail required hydrologic information. The amount and type of data to be collected are defined as well as where and when the data are to be collected and by whom. There exists some confusion about definitions when the terms "adjacent areas" and "general areas" are referenced. The term adjacent is defined as "having a common border" while general is defined as "involving or applicable to the whole". If these definitions are considered then adjacent areas share common borders with the mine-plan areas while general areas would be the area that a set of hydrologic data information would apply as a whole. This would not establish any particular area size requirement but would at least allow some differentiation between one general area and another.

The first objective of the Survey coal monitoring programs is to provide sufficient data and information describing the general-area hydrologies. The permit applicant is required by law to provide the mine-plan and adjacent-area information with the regulating authority being responsible for general-area data as well as for making the cumulative impact assessment.

The present Survey coal hydrology monitoring programs consist of 2,218 miscellaneous sites, 375 continuous sites, and 175 pilot-basin study sites. Thirty states have been surveyed by Survey personnel and sites selected that will produce general-area hydrologic information. The Survey districts are preparing a series of 62 coal hydrology reports that will bring together data from the different data-collection networks and give a broad interpretation and description of baseline hydrology. Each report is designed to be useful to mine owners and operators and consulting engineers by presenting information about existing hydrologic conditions and identification of sources of hydrologic information (Harkins and others, 1980). The format of the report makes it easy to use. General hydrologic information about a single water-resources related topic is presented in a line of text and associated illustrations.

Other more interpretative reports are being released that describe mining-related hydrology unique to the many and varied conditions existing nationwide in the coal areas. Therefore, data are being widely collected and interpretative reports prepared that will adequately satisfy Public Law 95-87 requirements to describe the general-area hydrologies. However, these reports have revealed a need for techniques and methodologies to regionalize and interpret the water-quality, sediment, and flow data now being collected as well as to extend such information to other areas where little data are available.

A U.S. Geological Survey report (Lystrom and others, 1978) presents techniques and methodologies that can be used to predict annual loads of certain water-quality constituents including sediment as a function of physiographic, land use, and climate for the Susquehanna River Basin in Pennsylvania and New York. One significant finding from the study was that dissolved solids increased directly with the increase in basin area overlying coal deposits. More studies like this are needed as an aid where there is little baseline information.

The present Survey Coal Hydrology Program has been developed and implemented efficiently throughout the 30 districts. The program data seem adequate to define "general-area" baseline hydrology in areas where data are collected. The 62 coal hydrology reports and the numerous other more interpretative reports will assist in interpreting baseline hydrology. In areas where little information and data are available, regression techniques are a possibility for extending the data base. Such methodologies can also be of considerable aid in better interpreting data where it is being acquired.

The 175 pilot-basin study sites (table 3) vary as to watershed size, type and frequency of data being collected, and so forth. For example, one of the Alabama pilot-basin study sites covers 5,000 mi^2, whereas other sites are 1 mi^2 or less. Some of these sites could be used to support modeling studies that would aid in the development of techniques and methodologies to synthesize specific-site and adjacent-area hydrologic information. The development of these techniques and methodologies are presently being investigated in a second part of this project.

OTHER PROGRAMS IMPLEMENTED TO MEET REQUIREMENTS OF PUBLIC LAW 95-87

U.S. Geological Survey is the principal Federal water-data agency. It collects and disseminates about 70 percent of the water data currently used by Federal, state, local and private groups to develop and manage our water resources. U.S. Geological Survey developed the large-scale computerized system WATSTORE which stores and retrieves water resources data. There are also other agencies and groups that are involved in collecting coal hydrology data and performing coal related research.

Sections 801-804 of Public Law 95-87 provide for funding of university coal research laboratories. Sections 901-908 provide funds for 1,000 energy resource graduate fellowships in coal research.

University Programs

The second section of this report referenced model development being conducted by researchers at some of the universities, other agencies, and within the Survey. The University of Tennessee, TVA, and U.S. Geological Survey have been investigating the hydrology of the New River Basin in Tennessee for several years. An extensive data base for water quality and quantity, land-use information, and basin characteristics have been collected. Research is expected to continue during the next few years. In addition to research by the University of Tennessee, the University of Kentucky, Utah State University, Colorado State University and Virginia Polytechnic Institute are among major universities focusing on coal problems and applicable models.

Tennessee Valley Authority

The Tennessee Valley Authority (TVA) has collected hydrologic and basin characteristics data from over 100 sites in coal-mining areas. These data have been used in conjunction with the development and testing of the TVA-HYSIM model (Betson, 1979).

U.S. Forest Service Coal Monitoring Program

The U.S. Forest Service, Berea, Kentucky is also involved in a sampling program in the Appalachian area extending from Alabama to Pennsylvania. Over 400 first-order streams (15-300-acre drainage basins) have been sampled during the past 2 years by the U.S. Forest Service. During the next 3 to 5 years the U.S. Forest Service will continue to collect data at about 60 sites. The sites will be instrumented to collect 5-minute streamflow data. Besides Survey data collection efforts, this is the only other known program that is collecting data over a large area to characterize the hydrology of coal mining areas.

A problem encountered by the author during this evaluation was the difficulty in determining who are involved in coal hydrology research programs and who are collecting hydrologic data in coal mining areas. As coal mining permit applications are prepared, all available hydrologic water-quality and quantity data are to be supplied to the applicant. Sec. 201 (c) (8) of Public Law 95-87 states that OSM shall

> "develop and maintain an Information and Data Center on Surface Coal Mining, Reclamation, and Surface Impacts of Underground Mining, which will make such data available to the public and the Federal, regional, State, and local agencies conducting or concerned with land-use planning and agencies concerned with surface and under-ground mining and reclamation operations."

The difficulty in locating information about data and research programs makes it imperative that a system be established to supply all available information and data when requested by a user. Redundant, expensive and unnecessary data may be collected if a data base is not established. A coordinated effort with other agencies and researchers should be considered. For example, supplementing the data collection network of the U.S. Forest Service would provide much needed information at low cost.

SUMMARY AND CONCLUDING REMARKS

Public Law 95-87 requires definition of baseline hydrology for proposed mining sites. The three areas where hydrologic data are needed are:

1. Specific-site area (mine-plan area);
2. Adjacent area (next to the mine-plan area); and
3. General area.

The mining permit applicant for most cases is responsible for obtaining data for all areas except the general area. General-area data are the responsibility of the regulatory agency or a designated appropriate Federal or state agency. To date, the Survey has been the primary agency responsible for collecting general-area data.

The Coal Hydrology Program that the Survey has developed and implemented in 30 districts will provide information that can be used to define general-area baseline hydrology in areas where data are collected. The network established by the program is one that should continually be updated for this purpose. The 62 coal hydrology reports will assist in interpreting baseline hydrologies. Regression techniques are a valuable tool to use in analyzing collected data and in areas with little information and data, they may be used to extend the data base.

Baseline hydrologic information at specific-site and adjacent areas can be obtained through intensive data collection programs designed for sufficient areal coverage and that assess mining impacts by measurement only. Another, less expensive method, is by the use of models together with operator-collected data. Models can be used to simulate hydrologic baseline characteristics and the impacts of mining at specific sites, and on a larger scale, the cumulative impacts in general areas.

This report documented 12 "state-of-the-art" strip-mining assessment models that are being evaluated. Pilot-basin sites, like those in the Tennessee and Indiana studies, will provide data and offer the opportunity to test modeling techniques and methodologies.

OSM has stated that there is a need for surface and ground water quantity and quality data in small upland watersheds less than 50 mi^2 (U.S. Dept. of the Interior, 1980). They also state that there is a need for a highly efficient system of determining the adequacy of existing data, recommending data needs, accessing data, and transferring this information to State Regulatory Authorities to determine additional data requirements for operators to meet permit requirements.

The Survey has been involved in developing and implementing data collection programs for coal hydrology. In the BLM program, which began in FY 1974, the Survey investigated the relationships between coal development and water resources on Federal lands. In the present program the Survey is the major supplier of general-area hydrologic data. In the future the Survey might be asked to supply additional data and the techniques necessary to simulate specific-site and adjacent-area hydrologic information.

There are six major coal provinces in the United States. Specific-site data need to be collected at a significant number of representative sites within each province. Specific-site data can be used with surface-water models to simulate information at ungaged sites. With the potential ability to simulate information at any ungaged mining site, the specific-site and adjacent-area information required by Public Law 95-87 can be provided.

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