UNDERGROUND MINE DRAINAGE QUANTITY AND QUALITY GENERATION MODEL

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ABSTRACT : This computer model is capable of simulating underground mine makewater ant its consequent discharge rates from adits. An additional feature is its ability to generate acid loads associated with the drainage. A hydrologic model using climatological data, watershed parameters, and mine operation information is used to calculate the amount of water passing to the geologic strata of the mine. As the water movement through the mine works is modeled, the acid generated is simulated by mathematical formulations describing the chemical productions and removal mechanisms. The component contributions are summed, with time preservation, and expressed as discharge rates and loads. The model is presented as a case study application to a coal mine in the U. S. A.

RESUME : Ce modèle est capable de simuler l'eau souterraine produite dans une mine et les vitesses des débits qui en résultent, en fonction des ouvertures des mines. Un aspect spécial de ce modèle est sa capacité pour générer les charges acides associées à ce drainage. Le modèle hydraulique utilise les données météorologiques, les paramètres de l'aquifère ainsi que les informations sur l'opération de la mine pour calculer la quantité d'eau qui s'écoule à travers les couches géologiques des mines. Pendant que le mouvement d'eau à travers la mine est modelé, l'acide générée est simulé par une expression mathématique qui exprime la production des acides et les moyens de s'en débarrasser. Les éléments qui contribuent sont ajoutés avec préservation du temps et exprimés comme vitesses des débits et charges. Ce modèle est présenté comme cas d'étude d'une mine dans la province d'Ohio aux Etats-Unis.

RESUMEN : Este modelo es capaz de simular el agua subterránea producida en una mina, y los caudales fluentes en función de la apertura de los huecos mineros. Una faceta adicional del modelo es su posibilidad de generar las concentraciones de ácido asociadas al drenaje. El modelo utiliza datos climáticos, parámetros del acuífero e información de las operaciones mineras, para calcular la cantidad de agua que fluye por las formaciones geológicas de la mina. Al mismo tiempo se simula la producción de ácido con formulaciones matemáticas que describen la producción y los mecanismos de remoción de sustancias químicas. Los diferentes componentes se suman, teniendo en cuenta el tiempo de contacto, y se expresan en forma de caudales y presiones. Se presenta una aplicación práctica a una mina de carbón en Ohio (U. S. A.).

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INTRODUCTION

Over the past decade researchers at The Ohio State University have developed high speed computer based mine drainage models. The models are designed to simulate the discharge flow rates and attendant acid loads emanating from coal mining operations. There are three models (underground, surface, and refuse pile) available and, although they are concerned with coal extraction and its associated pollution problems, they are basic enough to be altered to handle other mining operations. The underground or deep coal mine model is the topic of this paper.

The deep mine model is a hybrid of models for the hydrologic behavior of a watershed and for the generation of acid mine water. The basic operation of the model traces the disposition of water as it progresses through the hydrologic cycle with due concern for subsurface movements. The hydrology of the basin is simulated by a modified version of the Stanford Watershed Model. Climatological data, watershed and mine operation parameters are used to calculate the amount of water passing through the geologic strata associated with the mine complex. Through appropriate time delays controlled by the percolation of the makewater, quantities of water are transferred and stored in the aquifers bounding the active and/or abandoned mine. Subroutine hydraulics models then route the water into and through the mine complex, with attention given to travel lag times, to identified collection points for discharge through the adits.

If the water traversing the mine is subject to a pollutant loading, as is a common case in the coal mines of the Eastern U.S., it can be simulated by the acid generation portion of the model. The events of acid production and its removal are determined through the computer processing of their mathematical formulations applied to a prescribed micro-volume scheme representing the mine. The total minewater flow rate and quality is calculated by summing, with time preservation, the generation events in the micro-volume.

The quantities of water in any of the system components (surface runoff, infiltration, interflow, percolation, groundwater, mine aquifer storage, etc.) may be obtained via model output options. Standard outputs include flow rates in the receiving stream or watershed streamflow and mine adit discharges with their pollutant acid load rates, which occur in response to hourly precipitation input. Output may be tabular and/or graphical. The model continuously simulates the process and the more variable outputs, such as streamflow, may be optioned down to one-minute time frames; however, the normal outputs are as average daily values.

Several reports and papers have been published that adequately describe in detail the technical aspects of the model's conception, structure and operation. Two comprehensive project reports, Shumate, 1976 and Ricca, 1978, presenting the contract research performed for the U.S. Environmental Protection Agency are recommended reading for a thorough understanding and operating the models. These reports contain an extensive bibliography as well as the computer program details and user manuals.

In this paper the concepts of the model will be indicated by a brief treatment of their technical aspects. The nature of the model and its utility will be stressed and exemplified by its application to a deep coal mine complex located in West Virginia, U.S.A. The particular mine site was chosen by the U.S. Environmental Protection Agency's Extraction Technology Branch for an intensive monitoring program on drainage pollution. It consequently affords one of the more complete compilations of data needed to develop and validate mine drainage models. All data sources peculiar to the U.S.A. will be de-emphasized and general statements as to their nature will be used instead.

HYDROLOGIC MODEL

The Ohio State University version of the Stanford Watershed Model is a high-speed, digital computer model which provides a versatile, reliable tool capable of simulating the hydrologic behavior of a basin. This is accomplished through the integrated use of mathematical statements describing the hydrologic activities which occur within the hydrologic cycle. The model is programmed to work toward a complete balance between the volume of water entering the basin and the amount of water leaving the basin plus the water remaining as storage. This balance, which is computed during each water year and displayed at the end of that year, uses precipitation and initial soil moisture conditions as the input, and generates transpiration, evaporation, overland flow, interflow and groundwater flow as the output. During the modeling process, a continuous account is kept of the amount of moisture in all the activities of the hydrologic cycle. Figure 1 shows a schematic diagram of the moisture accounting process in the Stanford Watershed Model (SWM).

Data requirements for the SWM consist of a variety of inputs involving: measurable and physical watershed parameters, trial and adjustment factors, selected or assigned values; along with basic recorded data on precipitation, pan evaporation, and daily streamflow. These parameters are listed in Table 1 in their assigned Fortran computer language names along with a brief description, units, and sample value associated with the case study application discussed later. There are also input-output control options available which may be used to improve, extend or analyze a simulation effort.

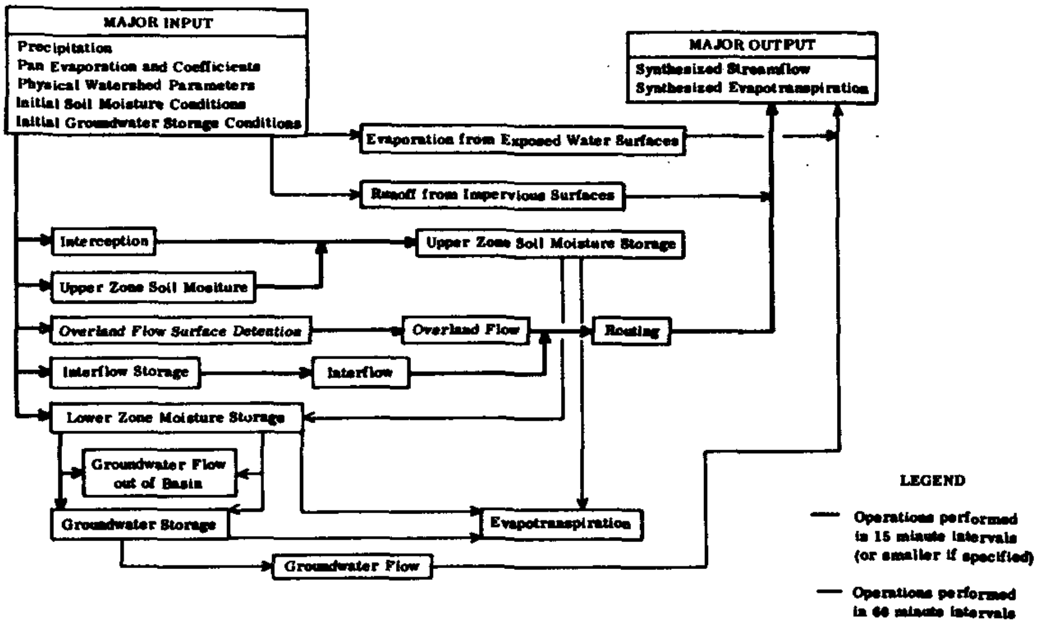

Figure 1 - Moisture Accounting in the Stanford Watershed Model

Of the two basic types of climatological data required by the SWM, precipitation is the more important and is usually more easily obtainable than evaporation because of the larger number of stations which record either hourly or storage gage daily values. Oftentimes precipitation data is not taken within the watershed, necessitating the use of records from stations outside the watershed. The decision on whether outside data may be used without modification depends on the proximity of the station to the watershed, how well the records reflect regional precipitation trends and how they compare with any incomplete records that may exist within the watershed. If unmodified records are inadequate or unrepresentative, then precipitation synthesizing techniques are employed.

The selection of evaporation data from an outside station is less critical than the choice of precipitation data due to the fact that daily evaporation varies to a lesser degree over a regional area. However, the fewer number of stations which record daily pan evaporation, combined with the suspension of daily recordings by many stations during the winter months, make adequate evaporation data difficult and sometimes impossible to obtain. This may be remedied in many instances by using records from outside stations and/or available local climatological data such as daily solar radiation, wind movement, dew point temperature, relative humidity and air vapor pressure to synthesize evaporation data.

Another type of climatological data is a grouping used as input to an optional subroutine that calculates snowmelt. The use of this subroutine improves the timing of runoff during winter and early spring; however, the amount of data needed to operate it is extensive and in most instances very difficult to locate or collect. Therefore, the subroutine is rarely used unless snowfall contributes a significant percentage to the total annual precipitation.

Table 1. Hydrologic Model (SWM) Input Parameters

MODEL PARAMETERS	PARAMETER DEFINITION AND UNITS*	CASE STUDY** VALUE
	Measurable Parameters	
TCONC	Time of concentration of watershed, min.	540.
TINC	Basin routing interval, min.	60.
A	Impervious fraction of watershed surface	0.0
AREA	Watershed drainage area, sq. mi. [$(km)^2$]	29.2
CHCAP	Index capacity of existing channel, cfs (m^3/s)	2000.0
ETL	Fraction of watershed in stream surface	0.002
IRC	Daily interflow recession constant	0.90
KK24	Daily baseflow recession constant	0.95
KSC	Streamflow routing parameter for low flows	0.85
KSF	Streamflow routing parameter for flood flows	0.934
L	Mean overland flow path length, ft. (m)	1900.0
SS	Average ground slope within watersheds, ft/ft. (m/m)	0.170
	Trial and Adjustment Parameters	
CB	Index controlling the rate of infiltration	0.50
CS	Index for estimating soil surface moisture storage	0.40
CY	Index for time distribution of moisture entering interflow	5.00
EDF	Index for estimating soil surface moisture storage capacity	1.00
EF	Seasonal factor adjusting infiltration and evaporation rates	1.00
EMIN	Minimum value of factor varying seasonal infiltration	0.50
GWS	Current value of groundwater slope index, in. (m)	0.10
LZS	Current soils moisture storage, in. (m)	2.00
LZSN	Soil moisture storage index, in. (m)	3.00
SGW	Groundwater storage increment, in. (m)	0.10
ATFLO	Parameter controlling adjustment of infiltration	10.0
ATCFS	Parameter controlling adjustment of infiltration	0.010
ATDR	Parameter controlling adjustment of infiltration	1.50
ATC2L	Parameter range adjustment of infiltration	0.250
ATC2U	Parameter range adjustment of infiltration	5.00
	Assigned or Selected Parameters	
EPXM	Maximum interception rate for a dry watershed, in./hr. (m/h)	0.18
K3	Soil evaporation parameter	0.20
K24E1	Groundwater evaporation parameter	0.80
K24L	Index for groundwater flow leaving the basin	0.20
KV24	Daily baseflow recession adjustment factor	1.00
NN	Manning's n for overland flow on soil surface	0.40
NNU	Manning's n for overland flow on impervious surface	0.012
RFC	Index for routing	6.00
UZS	Current soil surface moisture storage, in. (m)	0.0
VOLUME	Swamp storage and dry ground recharge, ac-ft. (m^3)	0.0
ETCORR	Adjustment factor for off-site evaporation data	1.0

Note: *The model is designed to operate with English units. SI units may be used with a data conversion program. The output units may be optioned in either system.
**English units values used for the Roaring Creek Study Watershed, West Virginia, U.S.A.

Physical data on the watershed concerning drainage areas, lakes, overland and stream flow characteristics, vegetative cover, etc. can be obtained from maps and aerial photographs. Soil moisture parameters are best evaluated with the aid of soil borings, well logs or a local geologic profile. Also a knowledge of the soil types and their moisture associated behavior is helpful.

Adequate streamflow data is essential to calibrate the hydrologic model. A minimum of three years of continuous average daily data is needed. Several isolated storm hydrographs are utilized to establish routing parameters and recession coefficients. Groundwater parameters describing percolation, water table fluctuations and slopes, and interbasin transfers, are determined through the aid of well records and boring logs.

Detailed instructions on how to acquire the requisite data, evaluate its suitability, and synthesize missing records are presented in the report and user manuals by Ricca, 1978.

The main role of the hydrologic model is to generate the quantities of moisture which will eventually percolate to supply the aquifers surrounding the underground mine workings. The daily amounts of percolation water are outputted as punched cards which in turn become input for the acid mine drainage model that follows.

DEEP MINE MODEL

The Deep Mine Model development began when the underground pyritic system was conceptualized by Smith, 1971 and has progressed to its current status as reported herein. The basic operation of the model consists of three steps. First, the model divides the deep mine system into micro-volumes. Then the events occurring in each micro-volume, involving oxidation and the mine's product removal mechanisms, are determined through the use of mathematical equations formulated to describe them. Finally, the total mine behavior is calculated as the sum of the events in each micro-volume. The schematic of Figure 2 offers a slightly more detailed description of the model operation.

The previous described hydrologic model (SWM) provides information to compute: water quantities involved in the mine drainage, the extent of inundation in the workings, and the generation and removal of pollutants, acid in this case, in the system. This information is linked to the acid production scheme and the combination produces a complete modeling system called the Deep Mine Model. The major point of linkage of the two is associated with subsurface flow and water storage in the region of the mine. The SWM calculates the amount of water infiltrating from the watershed above in 15-minute intervals. These values are processed through the subsurface and summed to yield the total daily moisture infiltrating to the groundwater, which is then transferred to the Deep Mine Model and used to determine daily aquifer moisture storage and daily mine-water flow. Once the amount of water flowing through the deep mine is defined, then the acid loads removed by leaching, inundation and gravity diffusion can be obtained. Program output consists of daily infiltration water reaching the

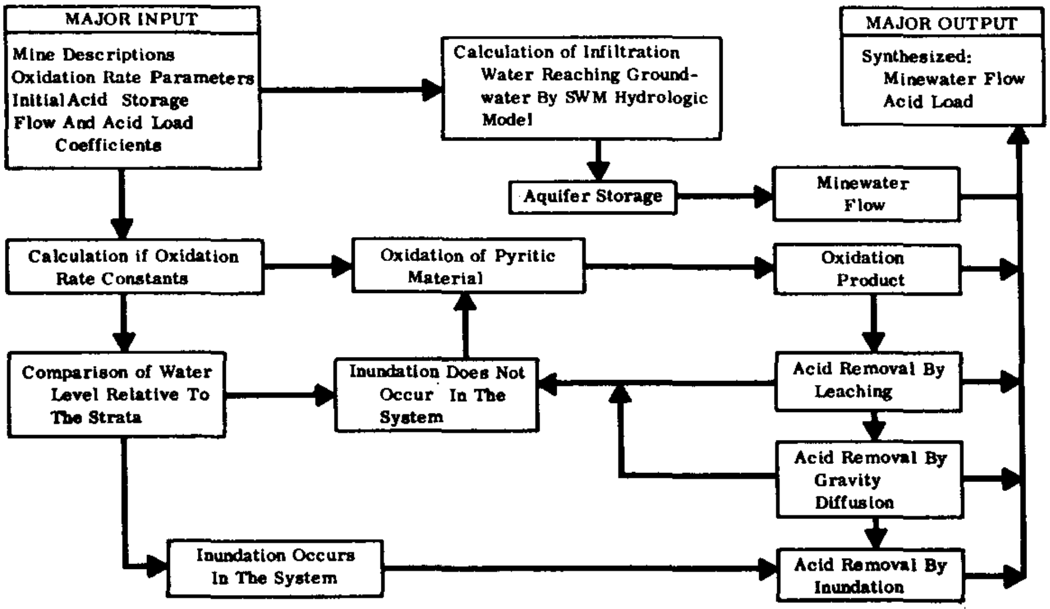

Figure 2 - Schematic of Acid Mine Drainage Model

mine aquifer, daily minewater discharge and acid load associated with each of the three removal mechanisms, and the total daily minewater discharge and acid load removal from the deep mine.

The potential complexity of a mining system and the use of elaborate models to simulate the mine flow and pollutant generation loads necessitate rather demanding data requirements or input information. This information should reflect the physical, climatologic, geologic and hydrologic characteristics of the watershed and should be representative of the coal mining system and its acid generation characteristics. Acid mine drainage sources have three basic characteristics to be simulated: the physical features of the pollutant source, the rate of pyrite oxidation in the source system, and the transport of acid products from the reactive sites by the mine drainage. The Deep Mine Model requires input information on: mine system descriptors, pyrite oxidation kinetics, pollutant products removal mechanism, and mine discharge quantity and quality records. Table 2 lists the input parameters by their Fortran Computer language names with a brief description, units, and a sample value used in the case study application presented later. In addition to these listed variables, there are parameters used to control the program and level of output generated.

Mine description data include information on areal extent and age of mine workings, surface watershed area, location of adits, mineral seam thickness and lengths, pyritic seams, and stratigraphy above the mine. Much of these data can be compiled from topographic and geologic maps, mine maps and operation records, and boring logs.

The pyrite oxidation data is of two types: those related to acid production characteristics of the strata, and those describing the mine conditions under which pyrite oxidation occurs. Values are needed for the chemical reaction

Table 2. Deep Mine Model Input Parameters

MODEL PARAMETERS	PARAMETER DEFINITION AND UNITS*	CASE STUDY** VALUE
	Deep Mine Physical Parameters	
IMINE	Number of mines involved	1
NFEET	Number of air-solid interface increments	1
NLAYER	Number of layers in the coal seam	20
NDEPTH	Number of depth increments in the model	15
DK	Length of depth increments, ft.(m)	1.0
DI	Length of air-solid interface increments, ft.(m)	1.473×10^6
ROCK TYPE	Liberal strata descriptors	COAL
TOP	Datum plane for top of coal seam, ft.(m)	98.57
ALT	Elevation of stratum relative to datum, ft.(m)	90.00-98.24
	Pyrite Oxidation Parameters	
REACT	Oxygen consumption rate of pyrite	2.55, 0.55
PYCON	Void fraction of the stratum	0.30, 0.005
STORE	Oxidation product storage array, $lbs/ft^3(kg/m^3)$	7.24, 1.95
TEMP	Mine temperature correction factor, none	0.15
FTGMOL	Volume occupied by one gram-mole of gas, $ft^3(m^3)$	0.79
CCPRFT	Constant to calculate pyrite reaction rate constant	28287.26
P	Mine pressure, psi (N/m^3)	454.0
GASC	Gas concentration under mine conditions	0.0856
DIFF	Gas diffusivity, $ft^2/day(m^2/d)$	99.965
	Oxidation Product Removal Parameters	
WSHED	Watershed area of the mine, sq. miles (km^2)	5.538
TANK	Mine aquifer storage, inches (cm)	0.158
CONFH	Constant relating minewater flow to aquifer storage	0.039
CONM, CONB	Constants in the relationship between head and storage	4.95, -2.013
FLOWMI	Min. flow for acid removal by flooding, gpd(ℓ/d)	2.268×10^6
HEADMI	Min. head needed for acid removal by leaching, in.(cm)	0.045
PER	Parameters for distance into coal strata that is inundated	1.50
WSLOPE	Hypothetical slope of the water level	0.10
COND	Constant in acid products removed by leaching	0.50
FRACT	Fraction of stored products removed by inundation	0.15
SOX	Initial total acid storage, lbs.(kg)	0.0
DIF	Base gravity diffusion constant	0.001
DTHETA	Time increment length, days	1.0

Note: *The model is designed to operate with English units. SI units may be used with a data conversion program. The output units may be optioned in either system.

**English unit values used for Roaring Creek Study Watershed, West Virginia, U.S.A.

rates, diffusivity and concentration of oxygen through the stratum, and temperature and pressure at the coal seam faces. Oftentimes many of these data are very difficult to obtain because of no prior evaluation of the coal seam. Two alternatives to ascertain the information arise; either collect samples of the coal and surrounding strata and perform a laboratory analysis for the values, or select intial values for the parameters and, by trial and error substitution, find values which provide the most suitable acid load simulation results.

Parameters associated with the pollutant product removal data fall into two categories: those in the minewater generation process and those that aid in the description of the removal mechanism. The major data of this group are: the daily water infiltrating and percolating to the mine aquifer (these values are generated by the hydrologic model), and the factors controlling the hydraulics governing the transfer of water from storage in the surrounding aquifers into the mine workings.

Minewater quantity and quality data is collected to provide some means of analyzing the success of the model simulations and to aid in determining a few of the input parameters. The more accurately and frequently the flows at the adits are monitored the more successful will be the application of the model.

Explicit instructions on data acquisition for the Deep Mine Model are available in the report and user manuals by Ricca, 1978.

CASE STUDY APPLICATION

The Hydrologic Model has been successfully applied to several watersheds in the Eastern coal fields of the U.S. The Deep Mine Model has had only a limited application due to the lack of sufficient hydrologic and mine drainage data being collected simultaneously. The only test site that the authors could find that had reasonably complete simultaneous data sets for the model pair was at Elkins, West Virginia. This site was under study by the U.S. Environmental Protection Agency from 1964 to 1969. One aspect of their investigation was to monitor the site climatology and drainage from the deep and strip mines within the Roaring Creek and Grassy Run Watersheds. Thus, partial records of minewater quantity and quality were available, as well as much of the other pertinent information on the physical and geological aspects of the area, and the nature and extent of the coal mining activities. Although not all the input data needed for modeling was collected either completely or consistently, enough information was compiled, by synthesizing missing pieces, to apply the models. The following describes the experiences of this application.

Location

The Roaring Creek watershed is located in east-central West Virginia, within the Eastern coal fields of the United States. It covers 75.6 square kilometers (29.2 square miles) and is drained by Roaring Creek, a stream within the drainage system of the Ohio River basin. Figure 3 shows the location of the study area in West Virginia and the continental United States, and also depicts

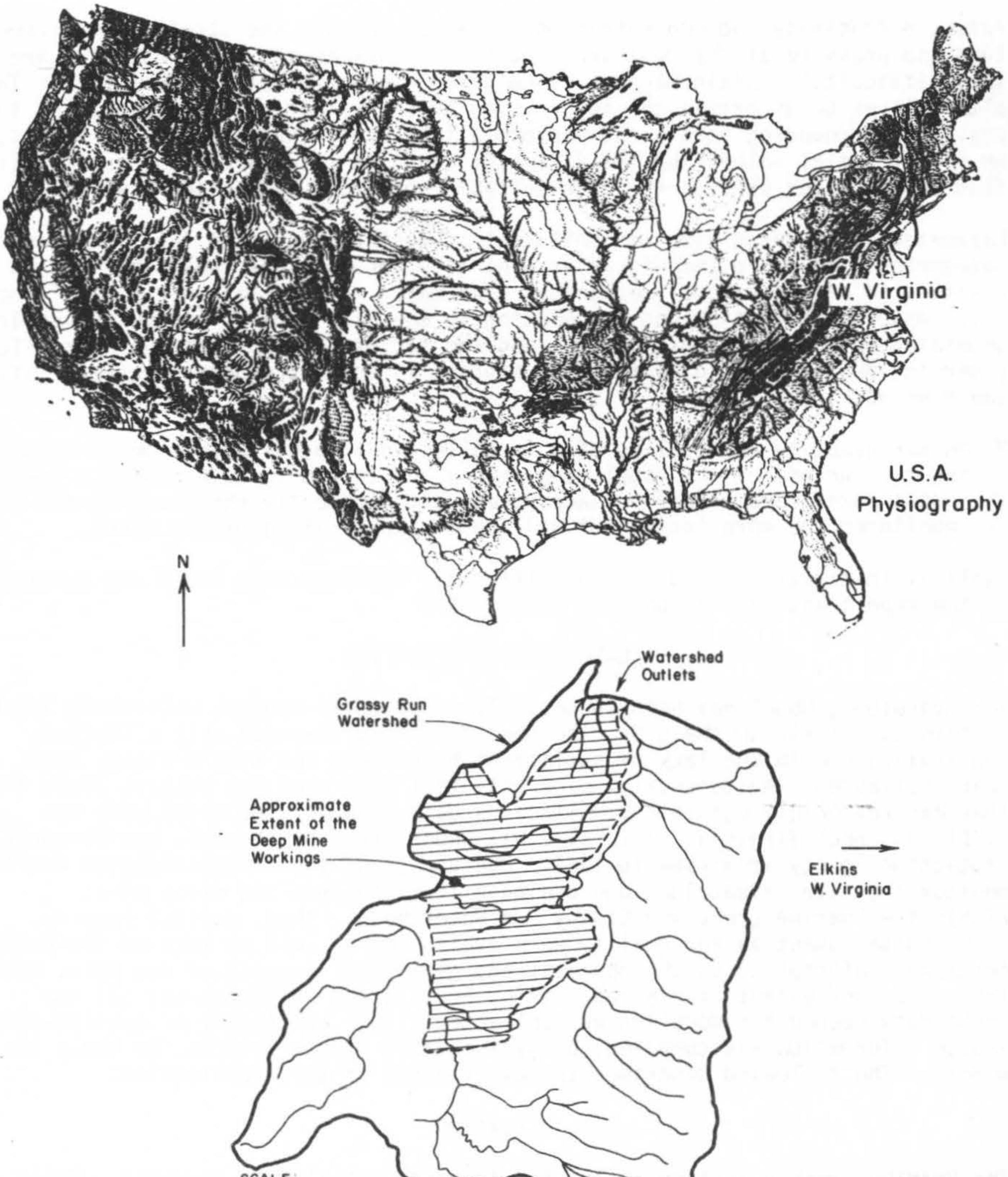

Figure 3 - Roaring Creek Watershed, Elkins, West Virginia

the Roaring Creek watershed. The topography of the area ranges from rolling foothills in the west to mountainous terrain in the east. The ground cover is predominantly hardwood forest, with a few clearings along Roaring Creek and at higher elevations.

Climate

The climate of the area is of the continental mountainous type, with cold winters and mild summers. Average yearly precipitation is 1.186 meters (45.92 inches). The vast majority of this precipitation comes from intense thunderstorms occurring during the summer months or large-scale, low-intensity, cyconic-type storms that occur in the early spring. Snowfall within the area is of moderate significance, with an average of about 1.19 meters (47 inches) per year, usually deposited during the period from November to April.

Geology

The Roaring Creek watershed is composed of two distinct physiographic areas which reflect the respective weathering characteristics and structures of the underlying rocks. The western two-thirds of the watershed consist of gently dipping beds of moderately resistive shales and sandstones which form broad, flat uplands separated by narrow V-shaped valleys carved by tributaries of Roaring Creek. The topography of the eastern one-third of the watershed is dominated by mountainous cliffs and flatiron-like ridges carved from moderately dipping sandstone and conglomerate sandstone. A syncline separates the two physiologic regions, and influenced the establishment of the main direction of drainage for the watershed.

Coal and Mining Activities

Three economically important coal seams exist within the Roaring Creek watershed; the Kittanning seam is the most extensively mined. Removal of this coal seam produced a massive underground mining complex of approximately 1200 hectares (3000 acres) which extends into the adjacent Grassy Run watershed. In addition, surface mining of the seam outcrop surrounding the deep mine complex resulted in more than 400 hectares (1000 acres) of additional disturbed land in the watershed.

Hydrologic Model Application

The Hydrologic Model (SWM) is first applied to generate input for the Deep Mine Model. After it is calibrated and is deemed to be successfully simulating the watershed hydrologic behavior, specific information on the water percolating to the aquifers surrounding the mine complex is generated as punched card output. Also, having established the watershed hydrographs permits one to see the impacts of the mine drainage pollutants on the receiving streams.

Climatological Data

Precipitation data for the Roaring Creek watershed was obtained through the use of statistical analysis techniques which combined the hourly precipitation records existing at two weather stations located outside the watershed with existing hourly and daily data taken in the watershed. Evaporation data was acquired through a combination of recorded and synthesized information.

Streamflow Data

Average daily streamflow data for Roaring Creek was taken from the United States Geological Survey (USGS) publication of Water Resources Data for West Virginia. The Environmental Protection Agency provided detailed hydrograph data needed to determine several streamflow routing and recession parameters required by the SWM.

SWM Inputs

The major SWM input parameters evaluated for the Roaring Creek watershed are listed in Table 1. Determination and/or adjustment of values for most of the parameters followed guidelines and procedures recommended by Ricca (1978). Special computational efforts were required in the case of K24L, the fraction of groundwater lost via inter-basin transfer. Due to the orientation of the mined coal seam and the extensive nature of the deep mine complex, some of the minewater originating in the Roaring Creek basin discharged into the adjacent Grassy Run watershed. Analysis of this moisture transfer involved the use of recorded minewater discharge data within the Grassy Run watershed and mine maps depicting the areal layout of the deep mine complex.

After the initial values of the input parameters were determined, the data was assembled for use. To enhance the utility of the model and reduce the cost of operation, the SWM source deck was compiled on disk and all evaporation, precipitation, and recorded streamflow data were transferred onto 9-track magnetic tape. These measures reduced the amount of input data on cards to essentially those parameters shown on Table 1, plus required program and input/output control data.

Hydrologic Modeling Experience

Analysis of the results of the initial run of the SWM for the Roaring Creek watershed indicated a severe undersynthesis of streamflow in the winter months followed by an equally harsh oversynthesis in the summer months. Also, a net increase in soil moisture storage occurred in each of the four water years being modeled. In order to improve these situations, different values of several trial and adjustment parameters were tried following the sensitivity guidelines. Parameter changes progressed until satisfactory simulation results were obtained.

Hydrologic Modeling Results

The simulation results for water-year 1968-69 represent the average success achieved during the hydrologic modeling effort. Results were generated in both tabular and graphical form. Selected output presented in this paper include plots of the recorded and simulated streamflow hydrographs for Roaring Creek (Figure 4), and the daily infiltration water reaching the groundwater (Table 3), which is the key hydrologic input data for the Deep Mine Model. Additional output includes tables of recorded and simulated daily streamflows; monthly and yearly summaries of streamflow, precipitation, and evaporation; end-of-the-month values for certain key parameters; the balance of all water in the basin throughout the water year; the daily correlation coefficient; and the daily soil moisture status.

The results of the hydrologic modeling effort indicated that the overall seasonal patterns of the recorded stream hydrograph were reasonably well simulated; however, only moderate success was met in reproducing individual streamflows. In general, monthly streamflow volumes indicated a moderate undersynthesis of streamflow occurring in the spring, and a definite oversynthesis in the summer and early autumn. From mid-autumn through the winter, an oversynthesis of streamflow volumes occurred, with most of the excess contained in peaks. Also, some simulated peaks in this period were out of phase with their recorded counterparts. The spring undersynthesis may be associated with annual spring thaw activities which cannot be completely modeled by the SWM. Possible explanations for the summer and fall oversynthesis are: the local rain storms which occur in the summer and fall seasons may not be properly represented by synthesized precipitation data; the evapotranspiration values used for this period are too small; and the actual soil moisture may be considerably lower than the modeled volume. In the winter, snowfall and its associated complications are the probable source of simulation difficulties. While the SWM is capable of handling this problem, the large amounts of data required to do so were not available. Lastly, the inability of the SWM to account for some of the total yearly moisture could be attributed to the interception of surface runoff by openings and fractures leading into the deep mine system, and the subsequent transfer of this moisture out of the watershed via underground routes not indicated on the old mine maps.

Deep Mine Model Application

A segment of the large deep mine complex extending beneath the Roaring Creek watershed and the adjacent Grassy Run basin served as the subject of modeling with the Deep Mine Model. This segment encompasses approximately one-third of the total complex area; it was selected after investigation of the EPA's minewater discharge monitoring network and the available deep mine maps which indicated that the majority of minewater emanating from this segment discharged into a tributary of Roaring Creek, and was not diverted through inter-basin transfer to Grassy Run. Figure 4 locates the underground mine in the watershed and Figure 5 shows the entire mine complex and the segment selected for modeling.

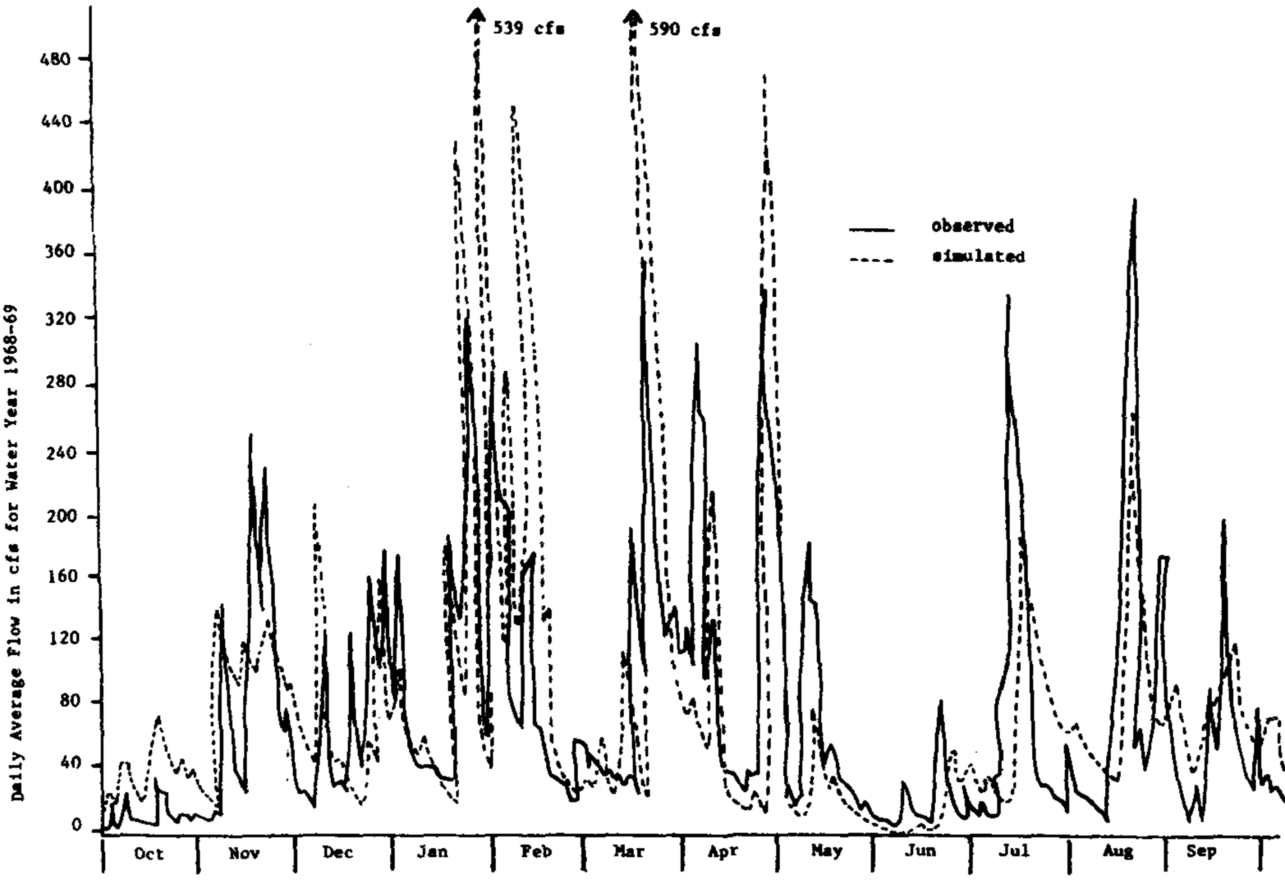

Figure 4 - Plot of Recorded and Simulated Streamflow

Table 3. Daily Infiltration Water Reaching the Groundwater, inches

DAILY INFILTRATION WATER REACHING GROUNDWATER

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT
1	0.0	0.000	0.000	0.032	0.026	0.011	0.001	0.0	0.0	0.0	0.0	0.0
2	0.0	0.000	0.000	0.023	0.010	0.006	0.000	0.0	0.0	0.0	0.0	0.0
3	0.0	0.000	0.013	0.016	0.018	0.003	0.001	0.0	0.0	0.0	0.0	0.0
4	0.0	0.016	0.155	0.010	0.024	0.002	0.001	0.0	0.0	0.0	0.0	0.0
5	0.0	0.000	0.001	0.008	0.013	0.001	0.001	0.0	0.0	0.0	0.0	0.0
6	0.122	0.106	0.001	0.007	0.008	0.000	0.016	0.0	0.0	0.0	0.0	0.205
7	0.007	0.244	0.000	0.005	0.014	0.000	0.009	0.0	0.0	0.0	0.0	0.000
8	0.000	0.046	0.000	0.013	0.013	0.0	0.004	0.0	0.0	0.0	0.0	0.193
9	0.000	0.004	0.0	0.042	0.033	0.010	0.001	0.0	0.0	0.011	0.0	0.081
10	0.000	0.002	0.0	0.019	0.022	0.000	0.000	0.0	0.0	0.022	0.197	0.003
11	0.0	0.001	0.113	0.012	0.039	0.000	0.000	0.0	0.0	0.029	0.021	0.002
12	0.0	0.000	0.000	0.009	0.018	0.012	0.001	0.0	0.0	0.057	0.014	0.001
13	0.0	0.0	0.000	0.007	0.010	0.037	0.000	0.0	0.0	0.147	0.008	0.000
14	0.0	0.261	0.000	0.003	0.007	0.009	0.000	0.0	0.0	0.008	0.004	0.000
15	0.0	0.001	0.000	0.001	0.004	0.010	0.0	0.0	0.013	0.003	0.001	0.000
16	0.0	0.000	0.000	0.001	0.002	0.001	0.0	0.0	0.009	0.001	0.060	0.0
17	0.0	0.040	0.000	0.000	0.001	0.000	0.0	0.0	0.000	0.000	0.002	0.0
18	0.076	0.160	0.039	0.016	0.000	0.000	0.0	0.0	0.000	0.0	0.024	0.0
19	0.089	0.002	0.038	0.032	0.000	0.0	0.0	0.0	0.0	0.0	0.190	0.0
20	0.000	0.001	0.002	0.006	0.000	0.0	0.0	0.0	0.0	0.0	0.395	0.171
21	0.000	0.000	0.001	0.024	0.000	0.0	0.0	0.0	0.0	0.0	0.028	0.212
22	0.000	0.000	0.023	0.006	0.000	0.0	0.001	0.0	0.0	0.0	0.015	0.001
23	0.0	0.000	0.002	0.004	0.001	0.0	0.012	0.0	0.0	0.0	0.007	0.000
24	0.0	0.039	0.001	0.003	0.004	0.0	0.006	0.0	0.0	0.0	0.003	0.000
25	0.027	0.001	0.001	0.002	0.018	0.013	0.000	0.0	0.0	0.0	0.001	0.034
26	0.004	0.000	0.003	0.002	0.008	0.007	0.000	0.0	0.0	0.0	0.000	0.000
27	0.014	0.000	0.035	0.001	0.011	0.005	0.0	0.0	0.0	0.0	0.000	0.000
28	0.022	0.000	0.057	0.000	0.030	0.001	0.0	0.0	0.0	0.0	0.0	0.012
29	0.000	0.0	0.022	0.028		0.000	0.0	0.0	0.0	0.0	0.0	0.001
30	0.000	0.0	0.014	0.019		0.003	0.0	0.0	0.0	0.0	0.0	0.000
31	0.000		0.013	0.015		0.000		0.0		0.0	0.0	

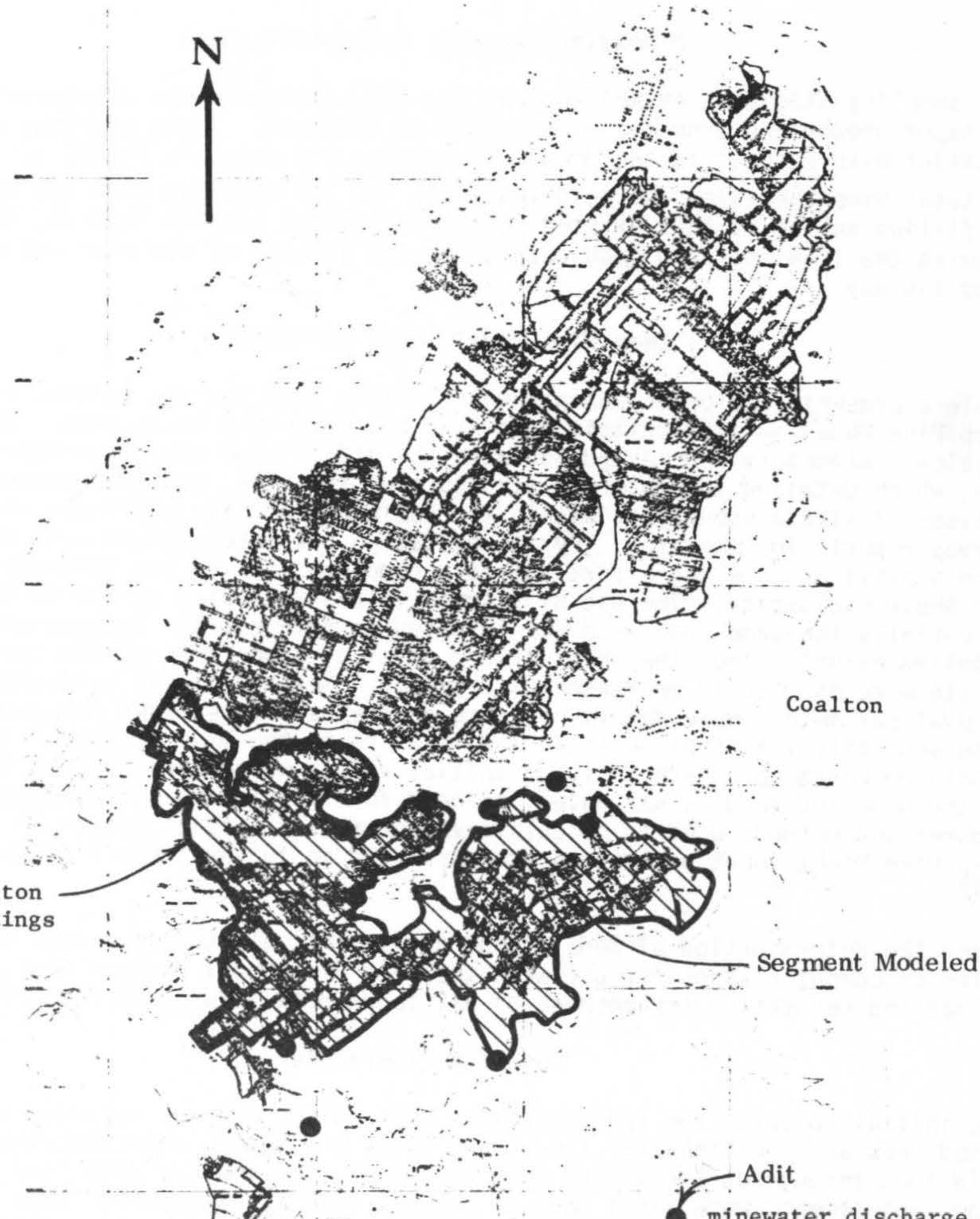

Figure 5 - Roaring Creek Deep Mine Complex

Minewater Quantity and Quality Data

Ten sampling stations, established by the EPA, monitored the minewater discharges of major proportion from the mine section of interest. These stations and their location with respect to the deep mine complex are shown in Figure 5. A record of total minewater flow and acid load data for the modeling area was obtained by filling any voids that existed in the individual station records, and then summing the flow and acid load data collected at each of the stations on each sampling day.

Deep Mine Model Input Parameters

Table 2 presents the principal parameter values used for the initial run of the Deep Mine Model in its application to the selected mine study area. Deep Mine physical parameters were evaluated with the aid of mine maps, furnished by the EPA, which detailed the internal structure of the mine, and documented observations of strata sub-layers within the unmined coal seam published in geologic survey reports for the area. Pyrite oxidation parameter values were taken from a previous modeling effort due to a complete lack of the information needed for their evaluation. The use of assumed values was based on the fact that essentially the same coal seam was involved in both earlier and present modeling efforts; thus the chemical and physical properties of the coal bearing strata were assumed to be reasonably similar. Several of the oxidation product removal parameters were determined through the use of recorded minewater flow data and daily values of moisture infiltrating to the mine aquifer. The remaining parameters were assigned initial values which were subject to change if the modeling results warranted the need for fine-tuning adjustments. Procedures and methods used to calculate and/or assign initial values to all the Deep Mine Model input parameters are described in further detail by Hemmerich, 1976.

After the determination of model input parameters, all required data was compiled on computer cards for use with the Deep Mine Model program deck. The format and sequential arrangement of all input data is presented by Ricca, 1978.

Modeling Experience

The initial computer run indicated poor correlation between recorded and simulated peak and low minewater flow occurrences and severe oversimulation of acid load throughout the entire modeled period. To improve acid load simulation, adjustments were first made to product removal parameters. When these were found to be inadequate, it was decided to adjust key pyrite oxidation and deep mine physical parameters. A reasonable reduction of these parameters produced simulated acid loads that were in the general range of recorded data. The parameter adjustments appear justified when considering the probable extent of deterioration of the mine's internal structure and the seasonal flushing of acid products out of the system during the more than half-century existence of the mines.

Further examination of the simulated minewater flow results leads to the identification of a time lag between simulated and recorded minewater discharges. It was theorized that the time lag was associated with the movement of moisture through the mine overburden and then through the mine system itself. Approximations of the moisture travel time through these two media were made using geologic field information and the results of minewater movement dye tests conducted by the EPA. Details of the computational techniques are discussed by Ricca, 1978; it is sufficient at this point to say that the total computed time lag was very close to the observed temporal displacement of simulated minewater flow events from the recorded data. After the justification of the time lag existence, a time delay feature applied to the infiltration to the mine aquifer and travel through the workings was incorporated into the Deep Mine Model.

Deep Mine Modeling Results

The simulation results for water year 1968-69 represent the better simulation success experienced during the modeled period. The total results of the modeling effort were generated in both tabular and graphical form. Output selected for presentation in this paper consists of the plots of recorded and simulated minewater flow and total acid load (Figures 6 and 7). Additional output includes tables of the daily infiltration water reaching the groundwater (as supplied by the SWM); the daily infiltration water corrected for a time delay; the average daily synthesized minewater flow and daily total synthesized acid load; the daily synthesized acid load removed by inundation, leaching, and gravity diffusion; and monthly and annual summaries of synthesized infiltration water, minewater flow, and acid load removal.

Examination of Figure 6 indicates that the simulated minewater flow follows the general trends established by the recorded data to a relatively adequate degree. Keep in mind that the simulated plot is on an average daily basis and the recorded flow spot points are instantaneous samples. Existing problems include the coordination of peak and low discharge periods and an undersimulation of total yearly flow volume. One possible explanation for these problems is the interception of surface runoff by the deep mine system. The Deep Mine Model in its present structure is unable to account for this additional moisture and the timing problems it creates. Another explanation involves a possible misrepresentation of natural minewater discharge conditions by combining the readings from all major effluent points into one lump sum discharge record. Because the Deep Mine Model can only simulate discharge from a single opening, unification of the flow records from each adit was necessary. However, this restriction in the model would tend to dampen out inherent timing differences between the effluent points, the result being that the recorded peaks of the cumulative record would be more drawn out, lower, and less sharp than the simulated, and less accentuated than the peaks recorded at each discharge point.

As in the case of minewater discharge, the simulated acid load follows the trends in recorded data reasonably well. However, total yearly acid removal was over simulated, and a few problems with the correlation of recorded and

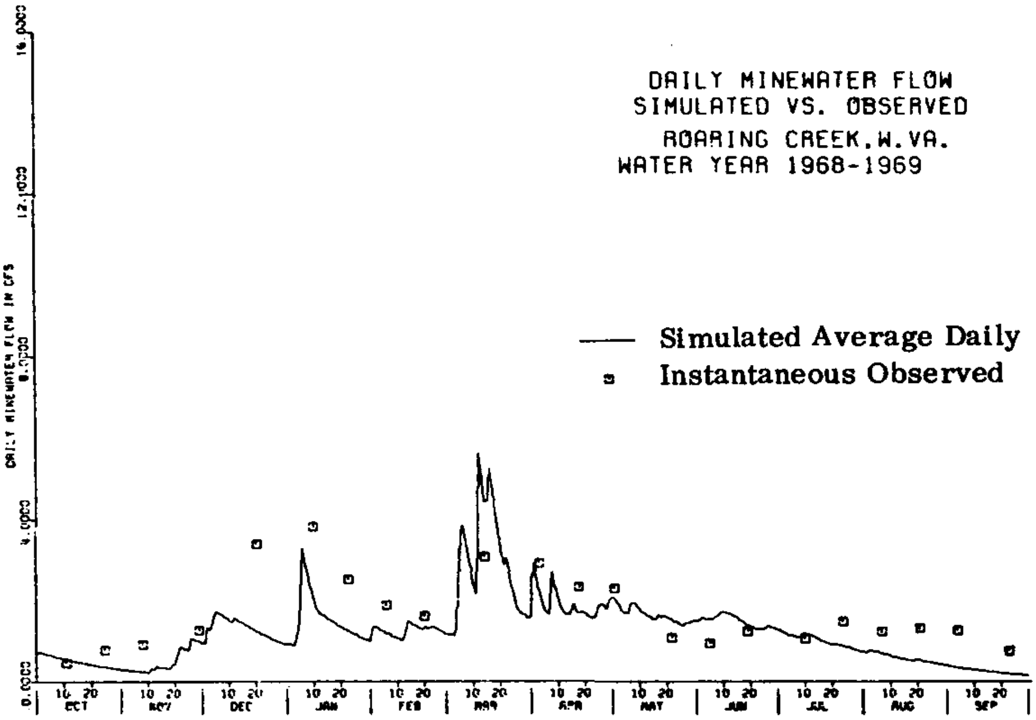

Figure 6 - Simulated and Recorded Minewater Flow Plots

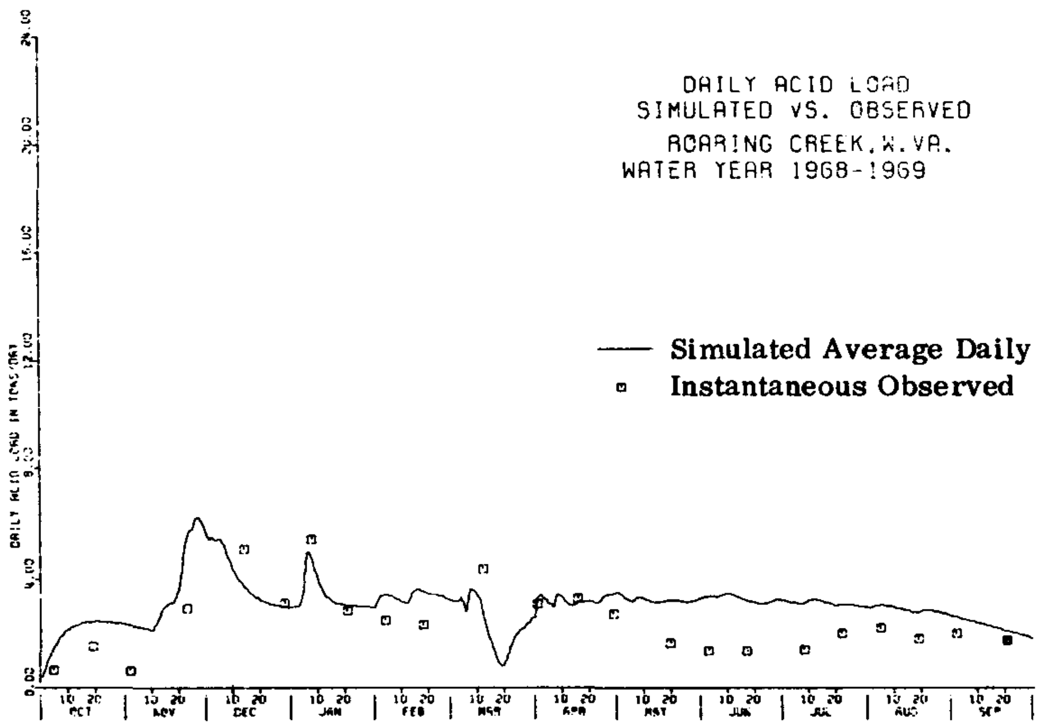

Figure 7 - Simulated and Recorded Acid Load Plots

simulated acid loads do exist. The tabular output indicated that leaching was the primary removal mechanism of acid products; since the main avenue of moisture entry into the mine is by infiltration through fractures in the overburden, the domination of leaching appears to be justified. Acid removal by inundation and gravity diffusion was relatively small throughout the entire water year. Causes or sources of the major problems in the simulated acid load results were difficult to interpret, basically due to the approximate nature of several input parameters describing acid production and removal. Efforts to further improve simulation were suspended once adequate results were obtained.

CONCLUSION AND RECOMMENDATIONS

The model application experience presented herein was only the second attempt at verifying its performance. The authors feel that the model is capable of performing well and that any shortcomings experienced can basically be associated with the completeness or consistency of the data employed. It takes several years of intensive effort to collect a complete data package on a deep mine drainage study. The one used herein was the best known to be available. As a consequence of this application, the deficiencies in data collection schemes surfaced. A paper was presented by Ricca, 1976 on data deficiencies in mine drainage modeling. Not only were the problems encountered discussed, but detailed recommendations were listed for future mine drainage data collection endeavors. Some of the salient recommendations are:

1) collect hydrologic and mine drainage quality and quantity data in the same time frame,
2) monitor climatologic events within the watershed; precipitation hourly and evaporation, daily. If snow is prevalent, collect snowmelt data,
3) gather information on the soil characteristics of the watershed and perform field tests on the overburden material,
4) analyze pyrite oxidation characteristics of the material comprising the mined coal seam and overburden,
5) acquire mine maps and operation techniques, and
6) locate and monitor major surface water diversions into the mines and/or transfers of water within the mine complex.

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