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Acid Mine Drainage Modeling of Surface Mining

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ABSTRACT

This computer model is capable of simulating the hydrology and acid mine drainage of watersheds which have experienced surface mining or contain refuse piles. A hydrologic model using climatological data, watershed parameters, and mine operation information is used to calculate the amount of water runoff, percolation through the site or pile, and subsurface drainage. As the water traverses the system it picks up the acid generated by a set of mathematical formulations describing the chemical productions and removal mechanisms occurring in various zones. The component contributions are summed, with time preservation, and expressed as discharge rates loads. The model is presented as a case study application to a surface coal mine in W. Virginia, U.S.A.

INTRODUCTION

Coal is a major source of energy in the United States. About half of the 3.2 trillion tons (1) of U.S. coal could be surface mined. Surface mining in geologic areas containing pyritic materials can cause concern over the generation of acid mine drainage.

Researchers at The Ohio State University have developed acid production simulation models for both deep mining and surface mining. When combined with a hydrologic simulation model, these total models will predict the minewater flow and its associated acid load. The detailed development of these models is presented in U.S. Environmental Protection Agency sponsored research reports (2,3). Attention in this paper will be directed towards the surface mine modeling portion of the research, in particular, the experiences the authors had in applying the model to a test watershed which had undergone extensive mining.

To accomplish this presentation, first a brief overview of the model will be discussed to acquaint the reader with its general structure; second, a description of the surface mine or refuse pile and the associated pyrite oxidation reaction will be reviewed; third, the data requirements for using the model will be listed; fourth, the model will be applied to a test site; and finally, the modeling results will be evaluated and discussed.

OVERVIEW OF THE MODEL

The total computer modeling for simulating surface mine and refuse pile drainage is accomplished by first generating hydrologic information by use of a hydrologic simulation model and then using that information as input for the acid mine drainage modeling. These models will be presented separately below with explanation on their linking.

Hydrologic Model

The Ohio State University version of the Stanford Watershed model (SWM) is a highspeed, 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 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).

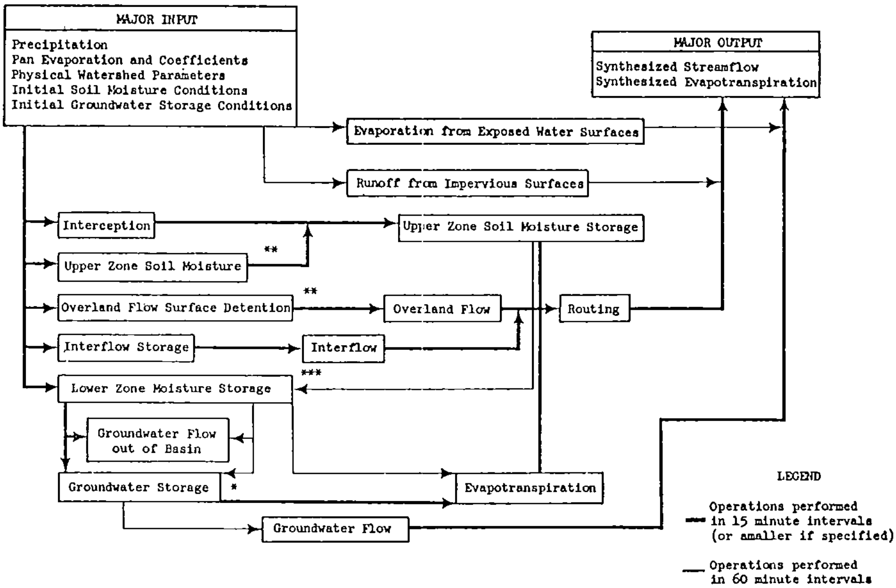

Figure No. 1: Moisture Accounting in the Stanford Watershed Model

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 I 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.

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

Table No. I: Hydrologic Model (SWM) Input Parameters

MODEL PARAMETERS	PARAMETER DEFINITION AND UNITS*	CASE STUDY* VALUE
	Measurable Parameters	
TCONC	Time of concentration of watershed, min.	540.
TNIC	Basin routing interval, min.	60.
A	Impervious fraction of watershed surface	0.0
AREA	Watershed drainage area, sq. mi.	29.2
CHCAP	Index capacity of existing channel, cfs	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.	1900.0
SS	Average ground slope within watersheds, ft/ft.	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 moisutre 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.	0.10
LZS	Current soils moisture storage, in.	2.00
LZSN	Soil moisture storage index, in.	3.00
SGW	Groundwater storage increment, in.	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.	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.	0.0
VOLUME	Swamp storage and dry ground recharge, ac-ft.	0.0
ETCORR	Adjustment factor for off-site evaporation data	1.0

*Values used for the Roaring Creek Study Watershed, West Virginia, U.S.A.

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, the 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.

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, et al. (3).

The main role of the hydrologic model is to generate the surface and interflow components of the watershed which will eventually be subjected to acid generation sources. The daily amount of these waters are outputted which in turn become input for the acid mine drainage model that follows.

SURFACE MINE-REFUSE PILE MODEL

Both surface mining and deep mining tend to produce waste materials that are accumulated in refuse piles near the mine sites. Due to the chemical nature of the wastes involved, refuse piles generally tend to be acid producers. It was with this phenomena in mind that Johnson (4) originally developed the Refuse Pile Model. Johnson's model relies on the Stanford Watershed Model for overland flow, interflow, and groundwater flow data. Using these hydrologic inputs and using the characteristics of the refuse pile itself, the Refuse Pile Model simulates a continuous accounting of the flow and of the acid produced, removed, and stored. However, this model failed to simulate acid production in surface mines or in refuse piles covered by a layer of inert material. Maupin (5) adapted Johnson's model to include strip mines and covered refuse piles. To do this, Maupin developed three subroutines, two of which effectively eliminated the constant acid production used by Johnson. This adaptation proved to be particularly effective since it did not change the original linking to the Stanford Watershed Model. It is Maupin's Combined Surface Mine-Refuse Pile Model (SMRPM) that is the subject of this application.

A refuse pile is basically composed of materials that have been mined with the coal. These materials usually include clays, shales, and low grade coals, and often have a high pyritic content. Since refuse piles are generally close to the actual mining operation, their shape is affected by the terrain of the mining area. In mountainous country, steep-sided piles are often found due to the dumping of material over existing steep slopes. Very broad, flat topped piles are often found in flat or gently rolling terrain. Ponds of water may sometimes be found on the larger flat-topped piles.

Most refuse piles may be divided into three distinct zones. The three zones of a typical refuse pile are illustrated in Figure 2. The first of these zones is the outer mantle. In this zone, most of the fine material (clays, powdered shales, and coal dust) have been removed by precipitation. The absence of fines produces a very porous soil

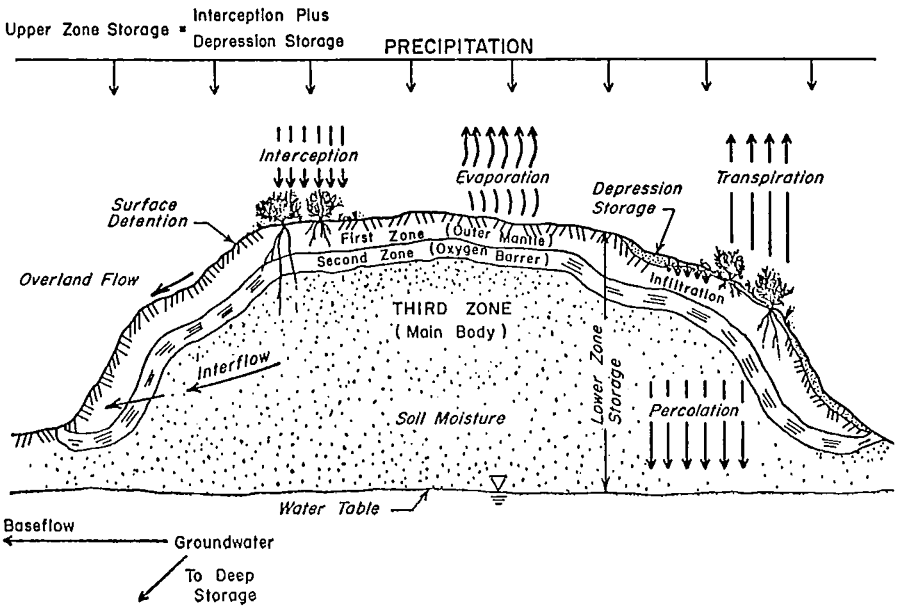

Figure No. 2: Hydrologic Cycle on a Refuse Pile

in which the pyrite is readily exposed to both oxygen and water. Therefore, pyrite oxidation will occur rapidly and acid products will form. These acid products generally inhibit the formation of any vegetative cover. The second zone is composed of clays and other fine materials that have become tightly packed due to rain action. This zone, although very thin and containing some discontinuties, exhibits a low permeability and forms an effective water and gas barrier. This barrier tends to prevent significant pyrite oxidation from occurring at lower levels of the pile. Due to the barrier forming second zone, the main body of the pile is subject to little weathering or pyrite oxidation.

Reclaimed refuse piles are often covered by a layer of inert material as illustrated in Figure 3. Since this type of reclamation will cause a refuse pile to behave in a fashion similar to that of a reclaimed surface mine, both reclaimed surface mines and refuse piles are modeled by the surface mine option of the SMRPM. However, active surface mines lack this layer of inert cover and are, therefore, modeled by the refuse pile option of the SMRPM.

In a refuse pile, oxygen and water are readily available

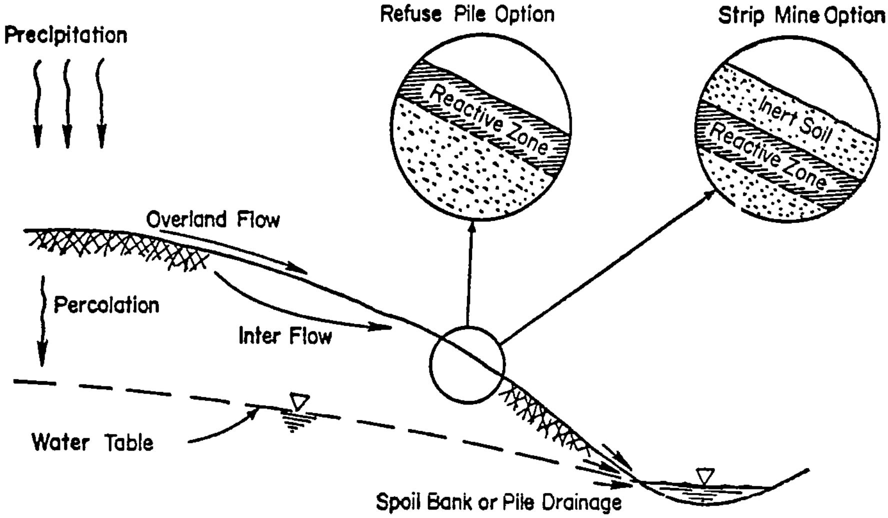

Figure No. 3: Illustration of the Refuse Pile and Surface Mine Options

only in the outer mantle. Since both are required for pyrite oxidation, it can be seen that the only significant acid production will take place in the outer mantle. The chemical reactions and equations governing acid production from pyritic sources are discussed in detail in the research reports (2,3). It will suffice here to identify the major pollutants from these reactions as sulfates, ferrous iron, and sulfuric acid. It is the acid production that is of concern in this model.

The use of models to simulate the complexities of mine drainage and pollution generation load necessitates rather demanding data requirements or input information. This information should reflect the physical, climatological, geologic and hydrologic characteristics of the watershed and should be representative of the coal mining operation 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 SMRPM requires input information on: mining operation physical parameters, pyrite oxidation parameters, acid removal parameters, and mine site discharge quantity and quality records. Table II lists the input parameters by their Fortran computer language names with a brief description, units, and sample value used in the case study application presented later. In addition to these listed variables, there are adjustment factors, and parameters to control the program and level of output generated.

Table No. II: Surface Mine Model (SMRPM) Input Parameters

MODEL PARAMETERS	PARAMETERS DEFINITION AND UNITS	CASE STUDY* VALUE
	Physical Parameters	
AREA	Total Watershed Drainage Area, sq. ft.	25938000.
Z1	Inert Layer Thickness, ft	0.0
Z2	Pyrite Layer Thickness, ft	3.0
A1	Acid Producing Area, sq.ft.	5706360.0
	Pyrite Oxidation Parameters	
A	Pyrite Reactivity (Frequency Factor of Arrhenius Form), hr^{-1}	4.00×10^8
DEOR	$\Delta E/R$ of Arrhenius Form, hr	1.27×10^4
DO	Depth Washed by Direct Runoff, ft	0.500
DOZ	Diffusivity of Inert Layer, ft^2/hr	0.0448
DOZA	Diffusivity of Pyrite Layer, ft^2/hr	0.0448
P	Total Atmospheric Pressure, atm	1.0
R	Gas Law Constant, $atm.ft^3/{}^0R.lb.mole$	0.7302
SOLACD	Solubility of Acid Products, mg/ℓ	20000.
T	Temperature, ${}^0R$	508.43
XA1	Mole fraction of Oxygen in Atmosphere	0.208
	Acid Removal Parameters	
EXADIR	Initial Weight of Acid Dissolved in Direct Runoff Storage, lb.	0.0
EXAINT	Initial Weight of Acid Dissolved in Interflow Storage, lb.	0.0
EXALZ	Initial Weight of Acid Dissolved in Lower Zone Storage, lb.	0.0
EXAUZ	Initial Weight of Acid Dissolved in Upper Zone Storage, lb.	0.0
AMTACU	Initial Weight of Acid Adsorbed in Upper Soil, lb.	1000.0
AMTACL	Initial Weight of Acid Adsorbed in Lower Soil, lb.	1000.0
CO	Exponent Affecting Leaching of Acid by Direct Runoff	0.25
CEU	Exponent Affecting Leaching of Acid by Water Entering Upper Zone	0.05
OFF	Constant Affecting Leaching of Acid by Direct Runoff	1.00
UZF	Constant Affecting Leaching of Acid by Water Entering Upper Zone	0.10
IFF	Constant Affecting Leaching of Acid by Interflow	1.00
LZF	Constant Affecting Leaching of Acid by Water Entering Lower Zone	1.00
	Water Quality and Quantity Data	
FWR	Recorded Minewater Data, cfs	-----
ACR	Recorded Acid Load from Mine, tons/day	-----

*Values used for the North Branch of Flatbush Fork Study Watershed, West Virginia, U.S.A.

Mine and watershed description data include information on the total watershed area, the areal extent of the acid producing regions, the thickness of the pyrite layer, and the thickness of the layer of inert cover, if any. These data may usually be compiled from topographic maps, mine maps, and boring logs.

The pyrite oxidation data is of two types: those related to the conditions under which oxidation takes place and those related to the rate at which oxidation occurs. Values are needed for the pyrite reactivity, the diffusivity of oxygen through the stratum, the solubility of the acid products, and the temperature and pressure at the pyrite layer. Often, many of these data are difficult to evaluate due to the lack of prior analysis of the coal seam or pyritic material. However, two alternatives are available to acquire the necessary data; either samples of the acid producing materials may be collected for laboratory analysis to assign values, or initial parameter values may be assigned and adjusted by trial and error substitution until most suitable acid load simulation is obtained.

The acid removal parameters may also be divided into two categories: those dealing with the initialization of acid loads in various storage locations and those affecting the actual removal of oxidation products. These parameters are reported by Maupin (5) to be adjustment factors which must be re-evaluated until the best fit to recorded data is obtained.

Minewater quality and quantity data are required as input to the SMRPM for the purpose of providing a means of analyzing the success of a simulation effort. Accurate and frequent monitoring of minewater quantity and quality will provide the data necessary to achieve an accurate calibration of the model.

Detailed instructions on data acquisition for the SMRPM are available in the report and user manuals by Ricca, et al. (3).

CASE STUDY APPLICATION

The Hydrologic Model has been successfully applied to several watersheds in the Eastern coal fields of the United States. However, the Surface Mine-Refuse Pile Model had had only limited application due to the lack of sufficient hydrologic and mine drainage data for corresponding time periods. The test site selected by the authors, located near Elkins, West Virginia, had relatively complete data sets for the pair of models as a result of studies 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 surface mines within the Roaring Creek and Grassy Run watersheds. Thus, partial records of minewater quality and quantity 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 of the input data necessary for modeling were collected either completely or consistently, enough information was compiled, by synthesis of missing data, to apply the models. The Hydrologic Model was applied to the entire Roaring Creek watershed while the Surface Mine-Refuse Pile Model was applied to the North Branch of Flatbush Fork watershed, a sub-watershed of the Roaring Creek watershed. The following describes the experiences of this application.

Location

The North Branch of Flatbush Fork watershed is located in east central West Virginia, within the Eastern coal fields of the United States. This oblong watershed encompasses an area of 0.95 square miles and is drained by the North Branch of Flatbush Fork to Roaring Creek, a tributary of the Tygart Valley River. Figure 4 shows the location of the study area in West Virginia and the continental United States, and also depicts the location of the North Branch of Flatbush Fork watershed within the Roaring Creek watershed.

Climate

The climate of the study watershed is typical of continental mountain climates. The area is subject to cold winters and mild summers and has an average normal temperature of 50.7°F. Average yearly precipitation is 45.92 inches with the majority of this precipitation being the result of intense thunderstorms during the summer months or large scale, low intensity, cyclonic storms that occur in the early spring. Snowfall in the area averages 47 inches and usually occurs 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 rock. The western two-thirds of the watershed, which includes the

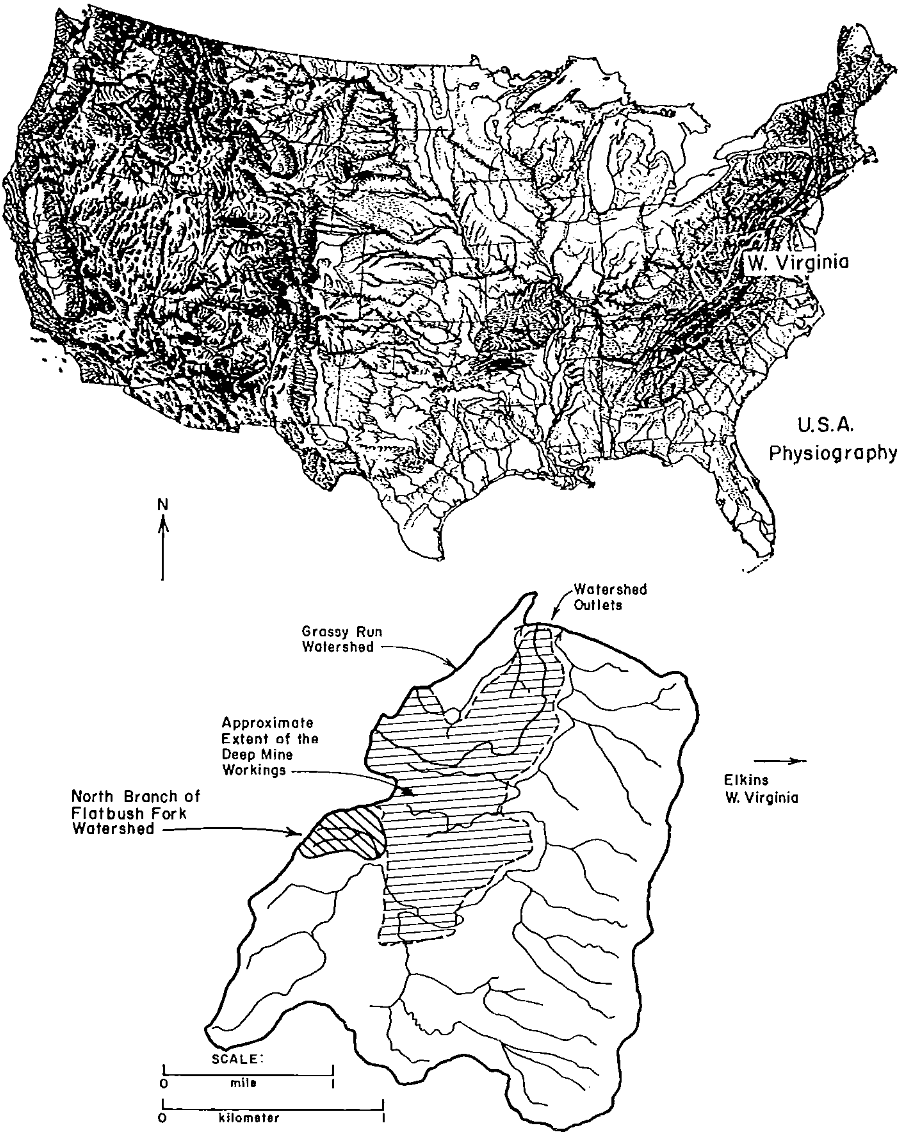

Figure No. 4: Location of the Study Watershed

the North Branch of Flatbush Fork watershed, consists of gently dipping beds of relatively non-resistant 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 physiographic regions and influences the establishment of the main direction of drainage for the watershed.

Coal and Mining Activities

The most economically significant coal seam in the North Branch of Flatbush Fork watershed is the Kittanning seam. Strip mining in the area has disturbed approximately 0.20 square miles or abour 21 percent of the watershed area. The strip mines lie on the high side of the Kittanning coal seam and drainage was generally into underground mines.

HYDROLOGIC MODEL APPLICATION

The Hydrologic Model (SWM) is applied to generate input for the Surface Mine-Refuse Pile Model. After the SWM is calibrated and is deemed to be successfully simulating the hydrologic behavior of the watershed, specific information on the direct runoff, interflow, and baseflow for the watershed is generated and stored on magnetic tapes.

Climatological Data

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

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 I. Determination and/or adjustment of values for most of the parameters followed guidelines and procedures recommended by Ricca (3). 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, all evaporation, precipatation, and recorded streamflow data were transferred into 9-track magnetic tape. These measures reduced the amount of input data on cards to essentially those parameters shown in Table I, 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 general slight undersynthesis of streamflow for the water years modeled, a moderate undersynthesis of winter streamflow, and a moderate oversynthesis of streamflow for the summer months. 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 1967-68 represent the average success achieved during the hydrologic modeling effort. Results were generated in both tabular and graphical form and include the recorded daily streamflow annual and monthly summaries of recorded and simulated streamflow, precipitation and evapotranspiration, end-of-the-month values of certain key parameters, the water balance for the year, the daily correlation coefficient, the daily soil moisture status and recorded and simulated streamflow hydrographs. Plots of the recorded and simulated streamflow hydrographs for Roaring Creek are presented in Figure 5.

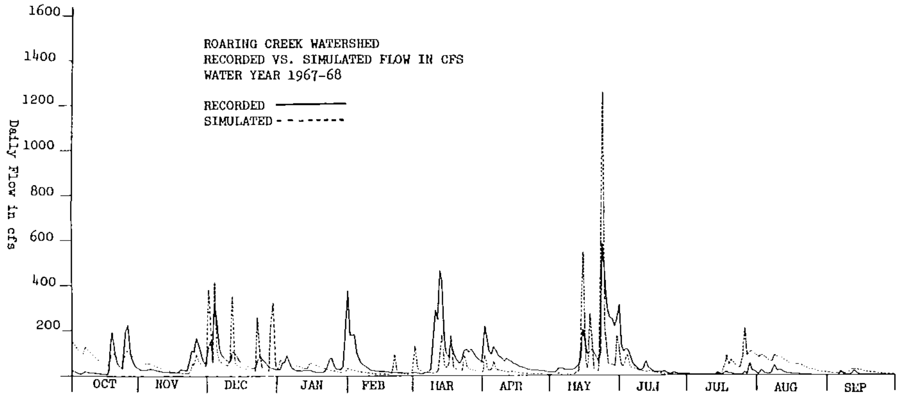

Figure No. 5: Plot of Recorded and Simulated Streamflow

As illustrated by Figure 5, the results of the hydrologic modeling effort provide a reasonable simulation of the overall patterns established by the recorded streamflow hydrograph. However, a less successful simulation of individual streamflow events was noted. Inspection of the monthly results indicated a strong trend toward oversynthesis in the summer months and undersynthesis in the winter months. In addition, some simulated winter peaks appear to be out of phase with the recorded data. The following possible explanations of the summer oversynthesis may be offered: the synthesized precipitation record may not adequately represent the intense local storms which occur in summer months, the actual soil moisture may be less than the modeled volume, or the synthesized evapotranspiration values used for this time period may be too small. During the winter months, snowfall and snowmelt, and their accompanying modeling problems, are the most likely source of simulation difficulties. Although the SWM is capable of handling this problem, the large amounts of specialized data necessary to obtain a satisfactory simulation of snowmelt were not available for the study watershed.

SURFACE MINE-REFUSE PILE MODEL APPLICATION

While the SWM was applied to the entire Roaring Creek watershed, the SMRPM was applied only to the North Branch of Flatbush Fork watershed, a small, sub watershed of the Roaring Creek watershed. This watershed was selected since surface mining was the predominant mining method and since surface mine drainage appeared to be relatively unaffected by deep mine drainage. In addition, minewater quantity and quality data were available for the watershed for the time period to be modeled. Water year 1965-66 was selected for the modeling effort since it exhibited the greatest frequency of minewater data collection.

Minewater Quantity and Quality Data

Minewater discharges were monitoring by a sampling station established by the EPA and located near the mouth of the North Branch of Flatbush Fork. Quality data were originally measured as milligrams/liter, but were converted to pounds of acid per day to be compatible with the SMRPM. Sampling frequency ranged from an average of once every five days for water year 1965-66 to a twice-monthly sampling for water year 1967-68.

Surface Mine-Refuse Pile Model Input Parameters

Table II presents the principal parameter values used for the initial run of the SMRPM in its application to the study area for water year 1965-66. Physical parameters were evaluated from topographic maps, mine maps furnished by the EPA and documented observations of the acid producing layers published in geologic survey reports of the area. Pyrite oxidation parameters were assigned values from a previous modeling effort due to the lack of the specialized data necessary for evaluation of the parameters. Finally, the acid removal parameters were assigned initial values which would be adjusted as the simulation effort progressed. Procedures and methods used to calculate and/or assign initial values to all of the SMRPM input parameters are described in further detail by Schultz (6).

Modeling Experience

Analysis of the results of the initial run of the SMRPM for the North Branch of Flatbush Fork watershed indicated that the total annual acid load had been greatly oversimulated due largely to the oversimulation of minewater flow. Adjustments to several key parameters were made to correct the oversimulation of minewater flow which in turn helped to alleviate the large oversimulation of acid load. In addition, several key pyrite oxidation parameters and acid removal parameters were adjusted until a satisfactory simulation of general trends observed in the recorded data was obtained.

Surface Mine Modeling Results

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 simulated daily direct runoff, interflow, and baseflow, the total simulated daily flow, the simulated daily acid load in direct runoff, interflow, and baseflow, and the total simulated daily acid load.

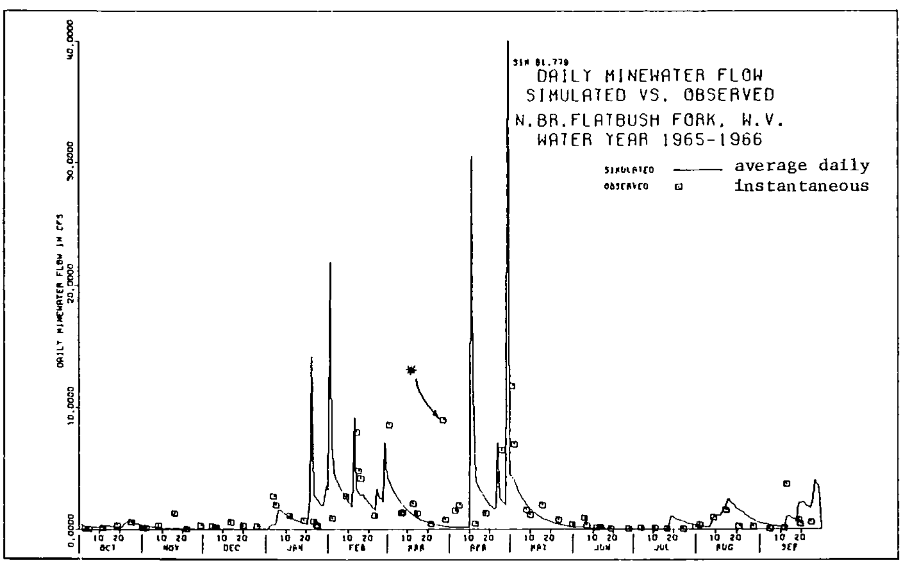

Figure No. 6: Recorded and Simulated Minewater Flow Plots

As illustrated by Figure 6, the results of this modeling effort provide a reasonable simulation of the general trends established by the recorded data. However, the lack of a complete record of minewater flows makes it virtually impossible to assess the accuracy of peak values. There is no reason to believe that spot field observations were timed to obtain peak discharges. Rather, it is likely that recorded flows merely correspond to random observations.

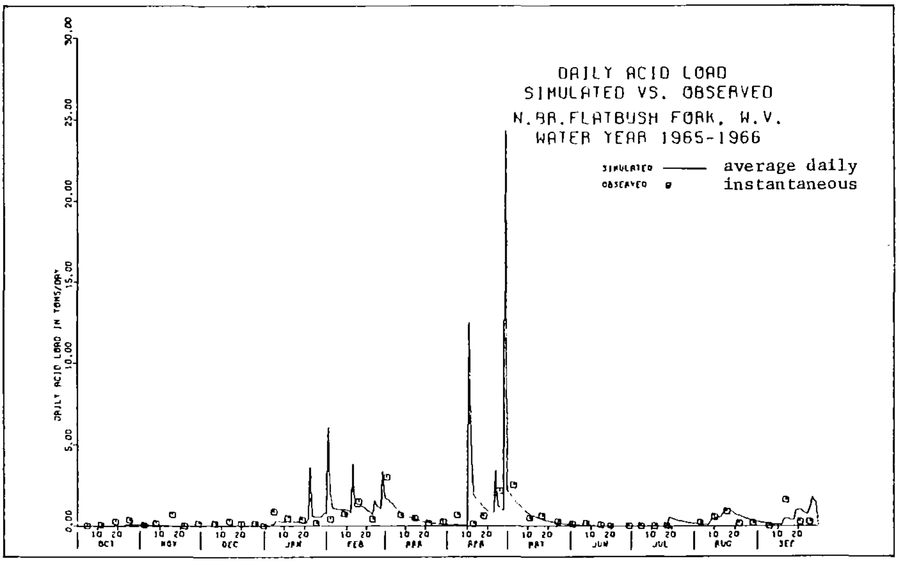

Figure No. 7: Recorded and Simulated Acid Load Plots

As in the case of minewater discharge, the results of the modeling effort provide a reasonable simulation of the general trends established by the recorded acid load data as illustrated by Figure 7. Again, the infrequency of minewater sampling makes evaluation of daily acid load values difficult. The total annual acid load, however, may be evaluated for accuracy. Recorded annual acid flow was reported by the EPA to be 224 tons, while an average of the minewater samples indicated a total load of 175 tons. The simulated acid load for water year 1965-66 of 198 tons agrees to within at least 12 percent of each of the recorded values. Although it is unlikely that the average of the minewater samples provides an accurate annual acid load due to lack of peak values, the trends established by the minewater data remain as the major justification for model adjustment. A more complete minewater sampling would lead to greater agreement between the reported annual acid load and the annual acid load determined by sample averaging and would allow for a more accurate calibration of the SMRPM.

CONCLUSIONS AND RECOMMENDATION

The model application presented herein was only the first field situation attempt to verify 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 surface 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 (7) 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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