HYDROLOGIC MODELS
OF SURFACE MINED AREAS

by
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ABSTRACT

Problems related to data acquisition and development of hydrologic models of surface mined areas are discussed in the present study. After a brief review of the hydrologic aspects of the surface mining act, some of the recent studies related to measurement of hydrologic properties and characterization of their variability are reviewed. These studies clearly indicate the need for better measurement and representation of spatial and temporal hydrologic properties of surface mined areas.

The diversity of distributed rainfall-runoff models is discussed by using the example of watershed representation in different models. The absence of studies which would help modelers to choose one or a few models for use is emphasized. Finally the need for coordination between data acquisition and modeling efforts is brought out.
INTRODUCTION

The Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87) is intended to improve the lands from which coal has been extracted by surface mining. This law addresses the problem of nonpoint-source pollution and its enforcement requires computer modeling of mined areas to identify the sources of pollution, to quantify pollution, and to evaluate impacts of surface mining. The basic aspects of this law are briefly reviewed below as it provides the basis for the research discussed herein.

The nonpoint source pollution aspects of the law that regulates mining activities, PL 95-87, have the objectives of minimizing the impacts of mining and reclamation on the hydrologic balance of the mine site and adjacent areas. Hydrologic balance is defined as "the relationship between the quality and quantity of water inflow to, water outflow from, and water storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, lake, or reservoir. It encompasses the dynamic relationships among precipitation, runoff, evaporation, and changes in ground and surface water storage (Joyce (1980))."

The components of hydrologic balance of an area which must be identified and the problems which must be addressed include water quality standards and effluent limitations, overland, shallow ground water and ephemeral stream flows, stream channel diversions, sediment control measures, design and maintenance of sedimentation ponds, discharge structures, spoil producing acid
and toxic substances, permanent and temporary impoundments, ground water protection, protection of ground-water recharge capacity, surface and ground-water monitoring, transfer of wells, water rights and replacement, discharge of water into an underground mine, postmining rehabilitation of sediment ponds, diversions, impoundments, treatment facilities, and stream buffer zones (U.S. Congress (1977)).

The act requires that environmental resources to be impacted by mining activities must be completely and accurately described. Information on general environmental resources, geology, ground and surface waters, alternative water supplies, climate, vegetation, fish and wildlife resources, soil resources, and land-use are specifically required to be supplied (U.S. Congress (1977)). The regulations permit the use of models to investigate the problems and to propose solutions.

A determination of the probable hydrologic effects of mining and reclamation operations, both on and off mine sites, is required by the act. Consequently, hydrologic regime, quantity and quality of water in surface and ground water systems including dissolved and suspended solids under seasonal flow conditions must be investigated. Sufficient data from the mine site and surrounding areas must be collected so that cumulative impacts of all anticipated mining in the area on the hydrology of the area and particularly upon water availability can be assessed by the regulatory authority as required by the act (U.S. Congress (1977)). The most important consequence of this requirement on
present research is that the effects of mining and reclamation on the existing flow regime, including peak flows, low flows, water yield, chemical water quality, sediment yield, and the aquatic biology must be predicted and reported. For predicting the probable consequences of mining and reclamation on the site which is being mined and on surrounding and downstream areas, a spatially distributed information system for providing hydrologic and sediment yield inputs is preferable. Such a system is also necessary for providing the outputs such as downstream water quality effects required by the law.

Further restrictions posed by the act are that (1) an X-year, Y-hour precipitation event must be used as a design storm format for various hydraulic and sediment control structures, (2) the best technology available be used in order to minimize the impacts of mining. The personnel of regulatory agencies, the mine operator, the Soil Conservation Service, engineering consulting firms are affected by the act and are identified as potential users of the models.

The controversial act PL 95-87 has undergone several changes since its enactment. PL 95-87 was enacted in August, 1977. A Permanent Regulatory Program was then published (Federal Register (1979a, b)) in March, 1979. These regulations specified the expectations of the Office of Surface Mining, forming a framework for all future state laws. Some parts of these regulations have been under attack in the courts. Recently, the pointsource effluent limitation guidelines have been exempted and new point
source performance standards have been established, the effluent suspended solids limits have been suspended, and portions of sediment pond design criteria have been suspended and withdrawn.

The type, extent and frequency of data collection needs before, during, and after mining must be examined to determine whether these data are adequate to evaluate impacts. Presently, as specific guidelines and methods to evaluate the impact of mining are lacking, there is considerable confusion about the type and extent of data collection efforts which are needed. Consequently an investigation of the type of data which is being collected and which will be legally required to be collected in the future would provide guidance about optimal data collection programs. As data collection is the most expensive and labor intensive activity in impact assessment, it is important that this aspect be analyzed carefully.

Although the data and impact assessment requirements are strongly specified in the act, no guidelines are available about the extent and the quality of data which must be collected nor about the method or models which must be used in assessing the cumulative impacts. Some of these guidelines are not properly specified even now. However, well tested methods which may be used to assess the cumulative impacts of mining do not yet exist. Considerable research and development effort is needed in this area. OWRT has considered this a priority research area under the category "Water for Energy".
The PL 95-87 requires extensive collection of surface, sub-surface and water quality and quantity data which are needed as inputs to models. A recent publication (Office of Surface Mining (1979)) of the Office of Surface Mining (OSM) has encouraged the use of computer models, particularly those of the regional parameter type, for predicting the effects of mining on surface water flows and for determining the consequences of mining. The first objective of the research discussed herein is related to the problems of data collection.

In order to undertake investigations such as those mandated in PL 95-87, basin representation schemes which allow proposed land-management changes to be easily evaluated must be developed. It is desirable that land-management changes be put in as changed variables and parameters which affect the hydrologic and water quality processes in the watershed. The second objective of research reported herein deals with problems related to appropriate basin representation so that the models may realistically reflect the surface mining conditions.

RESEARCH RESULTS

Objective No. 1

The instrumentation needed to measure water quality and quantity variables in flows from surface mined areas are readily available. Methods of measurement are also being standardized. Consequently there is no necessity to investigate these aspects.
The questions related to the spatial distribution of samples and sampling frequencies, on the other hand, deserve considerable attention and these aspects are investigated and are discussed below.

An important aspect of measurement of water quality and quantity variables from surface mined areas is the variability in watershed processes and parameters in surface mined areas. This aspect has been almost completely neglected in discussions of data acquisition requirements in surface mined areas. Some of the recent research in hydrology strongly suggests the importance of this aspect and are briefly reviewed below.

Pilgrim and Huff (1978) and Pilgrim et al. (1978) used radioactive tracers to investigate flow characteristics on a visually uniform sloping grassed plot and found runoff and infiltration to vary irregularly over the plot. The plot used by Pilgrim and Huff for their experiments was not disturbed and was in a well settled condition. Sharma et al. (1980) had a network of twenty-six double ring infiltrometers on a 9.6 hectare watershed. Infiltration rates were measured in these and Phillip’s infiltration model was fitted to the data thus acquired. Sharma et al. (1980) found no obvious spatial pattern in the two parameters of Phillip’s infiltration model. However they found that the two parameters in the infiltration equation and the infiltration rates were similarly distributed as log-normal distributions. Ullah and Dickinson (1979 a, b) measured the depth, volume and area on three plots on a microscale. The plots had comparable
physiographic characteristics and had experienced the same mold board plow tillage treatment. They found large variations in depression storage volumes. The spatial distribution of depressions depended partly on the direction of tillage but also had a random component. The Weibull distribution was found to best fit the data. Baker (1978) found that the hydraulic conductivities varied log-normally among nine soils. He classified these soils on the basis of similar hydrologic behavior.

One of the few studies of variation of soil properties in a surface mined area is that by Rogowski (1980) who studied the infiltration rates on a mine spoil by using double ring infiltrometers. Rogowski's experiment was similar to that by Sharma et al. (1980), but Rogowski analyzed the behavior of the two parameters of Phillip's infiltration equation by using Kriging method. The two infiltration parameters were found to vary uniformly within a neighborhood of twenty meters. Beyond twenty meters, the parameters were random or increased linearly, although the rate of growth was small.

Recently the concept of variable source area has been advanced in hydrology by Engman and Rogowski (1974), Corbett et al. (1975), and Bonell and Gilmour (1978) and others. The basic idea behind the variable source area concept is that the runoff source area varies from one runoff event to another and that this source area extends upslope from the stream channel.

All these studies—and the work reviewed above is not
exhaustive-point out that the hydrologic conditions in watersheds, as indicated by infiltration equation parameters and variable source area studies, vary considerably over watersheds, which are either undisturbed or only slightly disturbed by agricultural practices. The variability in soil properties in surface mined areas would be considerably higher. Furthermore, these properties would be changing with time as the mine spoils settle down and as mines are reclaimed. Almost no information is available about the spatial variability of hydrologic characteristics in surface mined areas or even about how these characteristics change with time.

The variability in these properties may not be of great concern in large watersheds, as their effect may not be very significant in affecting runoff. In modeling flows from relatively small areas such as surface mines, variability in these parameters may be quite significant. Consequently measurement of important hydrologic variables both in space and in time over selected mines which are in various stages of mining is quite important and deserves attention.

Another aspect of surface mine hydrology which deserves attention is the representation of these hydrologic properties in surface mined areas. Both probability distributions and spatial characterizations have been used to express the variability in hydrologic properties. Because these hydrologic properties are used as inputs to runoff and water quality models, the characterization of these properties must be appropriate for such use.
The model by Freeze (1980) for example, provides a good starting point to think about appropriate characterizations of these data. The rainfall in Freeze's model is routed through and over the soil. The rainfall input and parameters describing the surface and subsurface inputs are stochastic. The model parameters each have a deterministic and a stochastic component. If a model similar to Freeze's model is used to estimate flows from surface mined areas, then the probability distribution and spatial variability of each of the parameters are needed.

The following conclusions are arrived at as a result of the investigation of the first objective.

1. There is almost no information about the spatial and temporal variation in hydrologic parameters in surface mined areas. It is recommended that such information be acquired in mines which are in different stages of mining and over a period of time.

2. The representation of these parameters so that they are of maximum use in developing runoff models of surface mined areas also needs attention. The structure of spatially distributed models and input parameters of these models must be analyzed and considered in summarizing the parameter variation data from surface mined lands.
Objective No. 2

Research in the hydrology of surface mined areas has started only recently. The main emphasis in the research reported so far is towards adapting methods developed in other branches of hydrology to surface mined areas. Also, as the surface mining act does not specify the techniques or models which must be used in assessing impacts, models covering a wide range, from crude to refined models with varying data requirements are being used. For example, Has-further and Akerbergs (1979) have used the NOAA-NWSRFS Program to model the precipitation-runoff relationships in the Powder river basin in Wyoming and Northern Great Plains. The basic premise of this study is that the calibrated model may be used to determine the pre-mining response of watersheds in the Powder river basin. The basic tool used in the TVA Strip Mine model (Bales (1979)) is a double triangle unit hydrograph. The lag time of watersheds are related to the five parameters of the double triangle unit hydrograph. Standard statistical techniques such as regression analysis and methods of analysis of data from paired watersheds have been used by Bryan and Hewlett (1979) to analyze the differences in responses from mined and undisturbed watersheds.

Investigation of effects of surface mining on groundwater quantity has also started only recently. Moran et al. (1979) have investigated problems related to drawdowns in
wells immediately outside mining areas and to development of post-mining water supply in North Dakota. Problems related to monitoring ground water to fulfill the OSM regulations have been discussed by Nawrocki (1979). The complex ground water model proposed by Wilson et al. (1979) to design and evaluate ground water systems in surface mined areas needs further testing. The preliminary results, (Wilson and Hamilton (1978)) however, appear promising.

The infiltration into reclaimed land has been studied by Lehrsch (1979) who has used a nonlinear regression equation as his basic model. Pearson (1979) has proposed a model for estimating the flow through mine spoil bank hydraulics, which however has not been tested by using field data.

As seen above, a variety of models such as those based on unit hydrographs, index flood method, geomorphology of streams, and of the Stanford watershed model type are being proposed or used to assess the impact of mining on surface water hydrology of mined areas. Obviously these models give results of varying accuracy and very little is known about their performance. Although these models may be tested to find the most promising of these models by using data collected before, during, and after mining to arrive at conclusions about their performance, models based on the physics of the phenomenon appear to be most promising, mainly because of their portability. Even these models are under
development and some problems remain about their use. Data requirements and simplicity would be important considerations in evaluating these models. If the performance of these models indicate that better models need to be developed then efforts should be expended to develop them.

One of the aspects of these models, which is treated here as an example, is the spatial representation of basins. A variety of representations are possible and some of these are discussed below. A detailed review of these representations brought about questions such as "is there any one or a few of these representations which is superior to others?" and "how valid are the assumptions made about parameters being constant in these models?" Some of these aspects are discussed after a review of the different spatial representations used in distributed rainfall-runoff models.

The Grid Approach

In the grid approach parameters and variables characterizing watersheds are distributed by assuming that they are uniform over the grids, but independent of other grids constituting the watershed. Both square and rectangular grids have been used in the literature. The degree of lumping is adjusted by increasing or decreasing the size of the grid network. The most frequently used grid shape is the square. The grid size used in various models varies widely depending on the size of the watershed being studied.
Gupta and Solomon (1977a, b) and Solomon and Gupta (1977) constructed a model using fixed square grids. Continuity equation is applied to each element and the resulting outflows and sediment are routed. Each grid element is assumed to be homogeneous in soil properties, land use, and subsurface characteristics. The model allows spatial and temporal variation in surficial and climatological parameters and variables. A slope, azimuth, and flow direction are assigned to each element based on digitized topographic maps. The subsurface and overland flows are routed from one element to the next and flows reaching channels are routed by channel routing methods. A computational sequence is sequentially established for all elements. Sediment yield from the area which is being modeled can also be simulated in these models. The model is designed for land use evaluation.

The grid size used can vary, depending on available computational time and required accuracy. Gupta and Solomon (1977b) suggest the use of variable sized grids, using smaller elements to more accurately model those areas where spatial variability is greater and larger elements where it is smaller. However, the version of model described by them does not have this capability of handling variable sized grids. The grid area used in their example is one km².

Beasley et al. (1980) have developed the ANSWERS model, in which the grid approach is used to distribute process
parameters. ANSWERS is an event-based planning model which has the capacity to spatially simulate the hydrologic and sediment yield processes. Originally developed for small agricultural watersheds, Huggins et al. (1977) suggest an upper limit of watershed area of 200 km$^2$ up to which the ANSWERS model can be used, but do not indicate a lower limit.

In both the ANSWERS model and the models by Gupta and Solomon the basin is represented as shown in Figure 1. In both of these models, channels are lumped into single grid elements.

Knapp et al. (1975) and Green and Pogge (1973) describe a large basin-scale continuous simulation model. Watersheds are characterized by using several layers as shown in Fig. 2. The model structure allows for homogeneous square grids of size 1 mi$^2$ for saturated zone modeling, and homogeneous rectangular shaped areas for surface and unsaturated zones. A stream network is superimposed on all basin zones. Continuity equation is applied to each zone and flows are routed through the channel network.

Rectangular Planar Surfaces

In another basin representation scheme watersheds are assumed to be represented by uniformly-sloping rectangular planes of homogeneous hydrologic characteristics. A cascade
FIG. 1. Grid Representation in ANSWERS Model.

FIG. 2. Square and Rectangular Grid Representation in Knapp’s Model.
of planes, where water flows from one homogeneous plane onto another, or multiple cascading sets of planes are used in this type of models.

Rovey et al. (1977) describe the KINGEN model, which is based on the kinematic wave method of flood routing. In the KINGEN model, infiltrating, uniformly sloping, homogeneous rectangular planes, and straight, trapezoidal or circular channels are used. Figures 3 and 4 show the general model schematization and an example of an actual basin representation used in the KINGEN model.

Li et al. (1977) have developed a simple watershed model (Fig. 5) called ANAWAT composed of two planes. The model is designed to simulate hydrographs due to a time varying, but spatially uniform, rainfall falling on two infiltrating plane surfaces. The planar schematization is promising in developing viable models of surface mined areas provided the watersheds can be described in detail economically.

Equivalent Rectangular Planar Surfaces

Overton and Meadows (1976) describe a scheme for watershed representation by the use of "equivalent uniform planes". Let us consider a surface mined area, shown in Fig. 6, having slopes $S_1$ and $S_2$, lengths $L_1$ and $L_2$, and different roughness and slope features. The planes $L_1$ and $L_2$
FIG. 3. Watershed Representation Used in KINCN Model.

FIG. 4. Basin Representation Used in KINCN Model.
FIG. 5. Basin Representation in ANAWAT Model.

FIG. 6. Equivalent Basin Representation for Two Planes in Overton and Meadows Model.
may be combined by using equivalent length variable $L'_1$, for plane 1 such that the lag time for plane $L'_1$ is the same as that for plane 1. The concept can be expanded to include a watershed of several planes with different slopes as shown in Fig. 7. The equivalent plane for any watershed would have the slope and roughness feature of the last plane in the cascade, and an equivalent length $L'$. The lag time is the variable preserved for each plane and is expressed as a length variable. A limiting feature of this representation scheme is that it assumes a rainfall of uniform intensity, although rainfall volumes are allowed to vary over elemental planes.

The equivalent plane concept is also used in the CREAMS model developed by the USDA (1980). An equivalent plane is constructed by assuming the equilibrium surface detention storage to be equal to that of the set of elemental planes. The final representation used in CREAMS is shown in Fig. 8. Here the final slope is not identical to that of the lowest plane since the criteria for plane descriptions is different.

The equivalent plane concept has the advantage of giving simpler models with reduced computer costs over the multiple plane models. However, in the equivalent plane methods the parameters are lumped, and this aspect reduces the utility of the models.
FIG. 7. Equivalent Basin Representation for a Number of Planes in Overton and Meadows Model.

FIG. 8. Equivalent Basin Representation in CREAMS Model.
Converging Planar Surface

An attempt to remove the shape constraint of rectangular planar surfaces has been reported by Singh and Woolhiser (1976). They incorporate into a kinematic wave model a watershed geometry that is a section of a cone. The surface converges as on larger watersheds thus concentrating the flow, but it is assumed to have a uniform slope which is an assumption that may not always be valid. The surfaces are assumed to have four geometric parameters including length, radius, internal angle, and slope. The dimensions of each variable are dependent on the watershed area which must be preserved. Singh and Woolhiser (1976) state that their representation scheme distorts the basin representation so severely that parameters such as Manning's roughness and slope do not have the same meaning as on natural watersheds. This is an important point to consider in comparing representation schemes, computational methods, and data availability for impact evaluations on alternative land management plans.

Irregularly Shaped Polygonal Planar Surfaces

A promising hydrologic model for use in surface mines is the distributed watershed model based on the finite element method. The basic concept used in these models is to divide the watershed into hydrologically homogeneous zones.
Ross et al. (1979, 1980) describe a hydrologic and sediment yield simulation model in which a basin is partitioned into hydrologic response units (HRU). The HRU’s are delineated by land use and soils maps. Next a finite element structure is developed by representing the basin topography and flow paths by cascading trapezoids whose edges form flow boundaries. These elements can be further subdivided into planar strips so that planning decision features such as a mining site may be spatially distributed. Each of these drainage units is assigned aerially averaged soil and land use properties which are derived from HRU maps. Impoundment simulation is an important feature of this model. The hydrology of each unit is modeled by using the kinematic wave approximation on the overland flow elements.

Jayawardena and White (1977, 1979) have also developed a model similar to that of Ross et al. (1980). Their approach is different from that of Ross et al. (1979) in the sense that spatially varied HRU’s are not considered. Jayawardena and White discretize watersheds by initially constructing stream tubes as described by Onstad and Brakensiek (1968). The kinematic wave method is then used to model flows from a curvilinear surface represented by cascading planes. Each elemental area is used to represent unique hydrologic features, but homogeneity within an area is assumed. A method of assigning parameters to each element, such as the averaging of HRU’s, is not presented by
Jayawardena and White.

Watershed Zones

There are at least two models in which hydrologic features are distributed by the use of zones. The first is the USDAHL-74 model (Holtan et al., 1974). In this model hydrologic response zones which are delineated by soils grouped by land capability classes is (Fig. 9) is employed. These zones follow uplands (Zone I), hillsides (Zone II), and lowlands (Zone III) of a watershed. The model is constructed such that X percent of the Zone I runoff flows onto Zone II and (100-X) percent flows directly into the stream channel.

Triangles

Grayman et al. (1975) developed a data filing system called ADAPT, which utilizes triangles to spatially describe land features, rivers, political boundaries, sewers, and other items (Fig. 10). Any type of triangle and any level of spatial detail is possible in this system. The triangles can be aggregated and isolated to extract features of interest. Each triangle is considered to be homogeneous. The authors report that their scheme has been used in conjunction with hydrology and water quality models. The system is very flexible and has potential for application to detailed impact evaluation models.
FIG. 9. Watershed Zone Classifications Used in the USDAHL Model.
FIG. 10. Example of Triangular Grid Basin Representation Used in the Model by Grayman et al.
Hypsometric Relations

Brackensiek (1967) suggested reducing the features of a watershed to one dimension by the use of hypsometric and contour length relations. By using these curves, a profile of the watershed is constructed of elevation versus distance between slope points, with each segment having a calculated slope. Knowing the slope, the contour length, and the distance between contours at a given elevation, the kinematic wave routing method is used. The hydrograph is optimized by adjusting Manning’s n to obtain a best-fit hydrograph. The n value is varied along the slope, higher at the top and smaller in the lower elevations. The distribution of soil, vegetation, land use, geology, and rainfall can be varied along the synthesized watershed profile in order to meet the modeling objectives.

Other Models

Fleming (1975) discusses hydrologic and erosion modeling, and gives a brief description of 19 hydrologic models, some of which have been discussed here. There are many other models which are not discussed in this report. These also have basin representation schemes that are the same or similar to those discussed herein.
Discussion

The above discussion brings out the rather startling fact that a variety of basin representation schemes have been developed to model rainfall-runoff processes. It is easy to consider hydrological aspects of these models to bring out the similar situation which exists in representing hydrologic variables. These models have been developed almost independently of considerations of data collection and spatial and temporal variations in hydrologic properties. In applying these models to surface mines the problems are further increased because of the dynamic nature of surface mined areas. Consequently a detailed examination of different models and their suitability to surface mined areas, in terms of the specific needs and data availability of surface mined areas is urgently needed.

Earlier in the discussion of results of this objective it is mentioned that several other types of models such as unit hydrographs, regression relationships and other techniques have been used in surface mine hydrology. These models are not as portable as the distributed parameter models discussed above. Also the results from these models vary widely. Consequently they have not been considered further in the present study. However, these models have the great advantage of being very simple and easy to use. Consequently they are well suited for preliminary planning studies. At any rate a compilation and examination of
results obtained from these models is again long overdue and deserves attention.

As a result of investigations reported above, the following conclusions are presented.

1. Although several different types of distributed rainfall-runoff models have been developed and some of these have been developed for use in surface mined areas, they vary in sophistication, data needs and in the accuracy of results. A comparative investigation of these models is needed to select the better models from these.

2. Although lumped parameter models have been used in hydrologic studies of surface mines, accuracy of results from these models is not known. Once again a compilation of results from these models and examination of these results would be of considerable use.
SUMMARY

A review of literature of hydrology of surface mined areas has revealed the existence of some problems related both to data collection and to development of models. Some of these problems are common to both general rainfall-runoff models which are used in hydrologic analyses other than that related to surface mines and to hydrologic models of surface mined areas.

The major problems in data collection from surface mined areas arise from a lack of appreciation of hydrology of surface mined areas and of hydrologic models. Although there have been several data collection program underway, the wide spatial variability of hydrologic parameters and conditions in surface mined areas do not appear to have been considered in these programs. Unless the soil moisture and infiltration conditions are properly monitored, runoff data which are being acquired may not be of much use in calibrating and testing runoff models. As discussed above, even in watersheds which are undisturbed, there is considerable variation of parameters. The parameter variability in surface mined watersheds is considerably larger than that in rural or forested watersheds. Measurement of this parameter variability in hydrologic surface mined areas is an important aspect which deserves further attention.

Representation of parameters which are being presently
measured so that they are of maximum utility in models is another problem which deserves further attention. A satisfactory solution to this problem partly depends on the type of model which is best suited to model surface mined areas, and partly on the data measurement schemes.

One of the important problems related to development of hydrologic models of surface mined areas is that of selecting a few models from a large number of models, most of which have been tested only to a limited extent with field data. The diversity of modeling approaches is discussed in this report by using the example of the varieties of spatial representation used in these models. Similar diversity exists in other aspects of these models also. An analysis and selection of better models from those which are available is thus an important present problem. By using an acceptable and accurate model, decisions related to data acquisitions and representation may be better analyzed.

The interaction between field measurements, proper representation of field data, and types of models used in surface mine hydrology, is clear. So far, problems of data acquisition and modeling have been treated separately in surface mine hydrology. The main conclusion of the present study is that, because of the variability in the hydrologic properties in these surface mined areas, and the changes in these over time, the data acquisition and modeling of surface mined areas be considered together for optimal solution of problems related to both.
REFERENCES


41. U.S. Congress (95th), Surface Mining Control and Reclamation Act of 1977, Public Law 95-87, August 3, 1977, 91 Stat. 44.


