

THE RELATION OF WATER TO STRIP-MINE OPERATION

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Water is a major factor in all problems relating to strip-mine reclamation. Dominant among these problems is the formation of acid drainage from old mines and mine spoils. This paper will consider the part played by water in the total strip-mining situation, and especially in the attendant problem of acid mine drainage.

Water has a direct controlling influence on acid mine drainage mainly because it is a reactant in the formation of sulfuric acid from the natural iron sulfide minerals with which it comes in contact. As Dr. S. A. Braley stated in his *Summary Report of the Commonwealth of Pennsylvania* (1954), "Acid drainage is never discharged from a dry mine nor will acid be found in the drainage if the water that enters the mine does not come in contact with oxidized areas and leach them." Thus water is aptly considered one of the principal chemical agents involved in sulfuric-acid production.

The ability to quantitatively predict and evaluate the occurrence of water in relation to mining is of considerable economic value in planning and carrying out extensive operations. A basis for a rational engineering approach to the design and installation of water-removal systems may thus be provided. Hence, more thorough knowledge of the hydrological conditions becomes an important factor in the selection of the most feasible means of reducing acid-water production from inactive and abandoned workings.

The following discussion attempts to point out the importance of the water problem in strip mining of coal and suggests that hydrologic methods may be applied in water-quantity evaluations. It is fully realized that, in certain characteristics, each operation is unique. Some operations have similar features, however, and it is not unreasonable to assume that, within limits, certain applications would be adaptable to specific categories or groups of workings. It is therefore suggested that proper collection and analysis of hydrologic information and the correlation of this data with the prevailing geologic characteristics will assist in establishing ranges of hydrologic behavior applicable to mining problems. It is not intended that all of the suggested factors be considered in each operation, since economic considerations may well determine the choice between an extensive survey and the minimum study necessary to deal with the problem.

IMPORTANCE OF WATER IN COAL PRODUCTION AND PROCESSING

With respect to the coal production and associated activities, water behaves in a dual capacity:

- A. It complicates the problems encountered in mining.
 - 1) It is solvent, and hence dissolves mineral salts from the soils and rock strata. It also provides a suitable environment for, and in the presence of oxygen (air) reacts with, the metallic sulfides present in the strata to ultimately form sulfuric acid, metallic sulfates, and metallic hydroxides. It acts as a weathering agent, since the dissolution of certain mineral salts exposes more surface area and subjects the material to an increasing degradation.
 - 2) It is a transporting agent for pollutants, and carries dissolved suspended materials from the pollution source into areas where undesirable results accrue from the acid concentrations and the accompanying metallic-hydroxide precipitates.

- 3) It is an obstruction to the mining operations, and often necessitates the installation of heavy and costly equipment to remove the excess.
- B. On the credit side, water may assist in the control of the acid problem.
- 1) It provides dilution for pollutants, and furnishes a means of controlled release to handle low acid concentrations satisfactorily.
 - 2) It may be beneficial in flooding abandoned operations and thus inhibiting or "drowning" further acid production, and reducing degradation by limiting contact with oxygen to the point where the acid-production rate becomes negligible.
 - 3) It may be used as a seal and a diluent where impoundments are constructed to inundate the last cut of strip-mine operations. The impounded water is raised to a level to seal off the exposed coal and associated strata and thus diminishes further oxidation of the exposed mineral sulfides. Continued precipitation and drainage into the basin gradually dilutes the acid and dissolved mineral concentrations.

BEAVER CREEK STUDY

A comprehensive study of the "Influences of Strip Mining on the Hydrologic Environment of Parts of Beaver Creek Basin, Kentucky," published as U. S. Geological Survey Professional Paper No. 427-B, compared results of studies of three originally similar areas in the basin: (1) an area with about 10 per cent strip mining, (2) an area with some prospecting, and (3) an area with no mining activity and virtually unchanged (strip mining in the area began in 1955).

This is the most complete study the author has found of the effects of major changes of land characteristics on hydrologic conditions of an area. It is an excellent example of the use of hydrologic measurements and correlations in the comparative study of land conditions. Results of the study indicated that strip mining was significant in changing the chemical quality of both the surface and ground waters in the area. There was increased sediment in the streams and aquatic life in general was adversely affected.

Considerable difference in runoff characteristics was found, the stripped area having much greater flow variability than the undisturbed area. Flows from the stripped area were sharper and more responsive to changing precipitation than those from the undisturbed area. Recession curves for the stripped area indicated that base flow after 20 days amounted to only half that of the undisturbed area for the same time, and one-fourth or less after 50 days. Thus, ground water in the stripped areas appears to contribute less to the base flow than in the undisturbed area. The stripped area appeared to have a much greater flood potential, with the five-year flood nearly twice that of the unchanged area. Flood hydrographs for the stripped area appeared narrower, and peak flows occurred sooner than in the undisturbed area. The more rapid runoff is indicative of the shorter and less retarded overland flow to gullied channels.

There was some variation in ground-water levels, indicating changes in spoil-bank water storage. Little contamination of ground water by seepage of acid water from the spoil bank could be detected.

The rate of chemical degradation in the stripped area was greater than that of the undisturbed area. After one year of mining, the dissolved-solids content of the stream draining the stripped area rose to a median of 310 ppm, 10 to 15 times that of the unchanged area.

Chemical content of the water was related to the kind of material composing the spoil bank in any given place, and to the rate of recharge for portions of the bank. There was considerable local variation in the chemical quality of water in and on the spoil bank. The water, however, generally had a low pH, solids content in excess of 400 ppm, and large amounts of aluminum, iron, manganese, magnesium, and sulfate.

WATER RELATIONS

Mining operations may affect both quantity and quality of runoff water, including pit drainage and seepage from spoil banks, ground water, and water contained in pools and impoundments. During and after completion of each strip-mine operation, surface and ground-water discharge flows into strip pits to form pools. During periods of high runoff, when water in the pools is at a higher level than the water table in the spoil banks, flow may be from the pools into the spoil banks. Flow may be reversed during periods of high evaporation, when pool-water elevation is below that of the surrounding water level. The areal outflow shows considerable increase when excessive storm runoff from slopes and highwalls overflows the pools. Peak flows are considerably higher from barren areas than they are from vegetated areas, where retardation and infiltration cause reduction of flow. The larger peak discharges generally occur in late winter and early spring, and are caused by longer, less intense storms. The amount of runoff is thus related to the impervious frozen surface.

Ground water as used here is defined as that portion of rainfall that percolates through the soil and underlying strata until it reaches the water table. Since the water table bears some relation to the surface topography, it follows that strip mining will markedly influence its location. Ground water exhibits considerable lateral movement through permeable strata; thus, exposure of fresh rock surface by removal of overburden may allow free flow of ground water to the surface. If the intercepted ground water is from a relatively deep source, the resulting increase in outflow will be more uniform than that from perched water bodies, which generally follow a seasonal pattern.

WEATHERING

The major portion of dissolved material in natural water is contributed by soluble products of chemical weathering. Weathering of rocks involves a solvent-solid relationship. The difference in composition of the two phases, and the external forces of temperature, precipitation, and water flow are factors contributing to the weathering process. Water running over land surface or percolating through soil into underlying strata is the solvent and the resulting reaction dissolves rock constituents to furnish solutes. Precipitation and runoff dissolve both inorganic and organic matter. The inorganic solutes consist mainly of calcium, magnesium, aluminum, iron, sodium, potassium, bicarbonates, sulfates, chlorides, and nitrates. A measure of upstream weathering processes can be obtained by gaging solute quantities at particular stream flow-sites and subtracting the amount contributed by precipitation and ground-water movement.

Shales and waste coals are in general the principal sources of pyritic materials in the spoil banks. Sulfuric acid formed through the oxidation of these sulfuric materials when they are exposed to the oxidizing effects of air and water may well be considered a by-product of the weathering process. Strip-mining activities have in general overturned the soil burden and placed unweathered rocks at or near the surface. The availability of these rocks for chemical reaction increases the weathering rate and results in higher chemical concentrations in the runoff from mined areas.

EROSION

Water erosion dislodges particles by rainfall impact, flow velocities, or impact and abrasion by other particles. The transport of dislodged particles and their eventual settling out depend upon bank or stream-bed slopes and water volume and velocity. Strip-mine spoil banks are especially susceptible to erosion. Level areas on spoil-bank tops erode less rapidly than steep slopes; however, definite drainage patterns are formed, and some gullying occurs. The newer

banks have no vegetative protection to reduce erosion of the loosely compacted material; thus, the weathering and erosion are greatly accelerated. Sediment load varies seasonally. Summer thunderstorms, with high-intensity precipitation and rapid surface runoff, result in greater erosion than less intense winter storms.

WATER QUALITY EVALUATIONS

Quantitative evaluations of water that may be encountered are desirable, and within limits, practicable if based upon sound hydrological procedures, including selection of applicable parameters, collection of pertinent data, and its proper correlation and analysis. Data on seasonal variations are usually required to establish maximum, minimum, and mean values.

Knowledge of the over-all area hydrology is necessary for appraisal of the potential water quality and quantity.

- 1) Topographic surveys will delineate the specific limits of the basin, or the area contributing to surface runoff.
- 2) Installation of precipitation gauges, or the extrapolation of precipitation-gauge data from established weather stations will furnish quantitative data for the area.
- 3) Streamlet- or stream-flow measurements provide basin outflow information, and define quantitatively the runoff from the area.
- 4) The relation of precipitation to runoff as established by measurements, or extrapolated data, and adjusted for reasonable evapotranspiration losses, will indicate ground-water variation.
- 5) Geological information obtained from regional charts and maps, and reinforced by local information available from workings, can establish the general position and extent of the water-bearing strata. The location and extent of aquifer outcrops or projected outcrops, and the character of the overburden will assist in predicting the potential replenishment of the ground-water supply.
- 6) Hydrographs of water levels in observation auger holes will indicate seasonal movement of water in and out of the spoil bank.
- 7) Borings or other subsurface samples will reinforce the information relating to types of strata, and examination of the samples will provide porosity data, and thus indicate the potential water capacity of the formation.
- 8) Permeability, or the ability of the strata to transmit water, can most easily be established through simple pumping tests on the aquifer, with simultaneous water-level observations on nearby boreholes. Specific yield and retention of the strata in question can be estimated from the information on permeability and porosity.

Hydrologic data correlated with structural information and the geometry of a mine system is necessary, not only to define the water problem, but also to assist in indicating methods of water control. The rate of flow from the formation will, in general, be a function of the surface exposed, the fluid pressure, the porosity, and the permeability. Porosity and permeability are of prime importance and are identifiable and mappable, particularly when related to the occurrence of sandstone bodies overlaying the coal beds.

The hydrology of the acid mine-drainage problem as related particularly to the strip-mining areas and coincident impoundments should be generalized by proper selection and evaluation of specific parameters. In case of an impoundment, it is desirable to have some means of predicting the rate of reduction of acid concentration in the pool. This concentration is a function of the total acidity by weight and the volume of water in the pool at any one time. The volume of the pool may be related to the rates of rainfall, runoff from the surrounding tributary area, evaporation, and infiltration from the impoundment into the soils. This last factor will fluctuate with respect to the water-table variation.

It is also to be expected that the rate of infiltration will be affected by clogging of pores, due to precipitation of iron and aluminum hydroxides in the impoundment.

WATER-CONTROL MEASURES

Some efforts have been made with varying degrees of success to reduce acid production in strip mining. Dr. Braley reported studies on several strip-mine areas and indicated that significant acid reductions could be obtained through good operation based upon established principles.

The Commonwealth of Pennsylvania, in its bulletin *Control of Acid Mine Drainage*, outlines a basis for preventing or reducing formation of acid by keeping air and water out of contact with sulfur-bearing materials as follows:

1. Keep water out
2. Keep drainage moving
3. Segregate sulfuric materials
4. Neutralize acid pools.

Keeping water out of workings is perhaps the most practical and effective control measure. Surface water can be kept out of a stripping pit by providing one or more drainage ditches along the bank above. Water that does get into the workings should be kept moving out, and not allowed to collect in pools or ditches. Highwall diversion ditches have proved effective in minimizing flows. The Pennsylvania Sanitary Water Board regulations now require that "all strip mines opened or reopened in the future shall have drainage ditches above the entire highwall length constructed and maintained to prevent surface water from flowing into the pit." After completion of open-pit highwall mining (auger mining), the operator must pack the holes with incombustible material for a minimum depth equal to the hole diameter and thereafter restore and plant the area affected as required in the case of strip mines. The regulations also specify that drainage ditches and, if necessary, pumps shall be provided to keep pit floors dry, and the drainage shall, be discharged, through or over the top of the spoil banks.

SUMMARY AND CONCLUSIONS

The preceding discussion emphasizes the importance of the relationship of water to the acid mine-drainage problem, and describes the hydrology, the controlling features, and the effects. The paper discusses the hydrologic properties affecting the acid mine problem, the techniques employed in gathering data, and the rational application of these techniques to engineering procedures. Reference is made to the Beaver Creek study to point out a very practical test application of such knowledge in evaluating hydrological conditions and their effect on water quality.

The author urges continued application of known alleviation methods under controlled conditions, accompanied by monitoring of the controls in order to continue evaluation of the various procedures in the presence of known factors. Only through such evaluations of data can the true value and limitations of hydrological control be established.

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