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GROUND WATER RECOVERY PROBLEMS ASSOCIATED WITH OPEN PIT RECLAMATION IN THE WESTERN U.S.A.

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INTRODUCTION

Coal consumption and production increased in the United States in 1985. While the coal production in traditional coal-producing states in the Appalachian region (Pennsylvania, Ohio and West Virginia) is decreasing, the coal production in the western region increased in 1985 by 3.4%. The largest open pit mine coal production in the western U.S. are concentrated in Wyoming, Montana, North Dakota, Colorado and New Mexico. Wyoming produced 125 Mt of coal in 1985.

The rank of coal mined by open pits in the western U.S. ranges from lignite to high volatile A. bituminous. The heat value ranges from 7,500 to 12,000 BTU per pound, and the ash and sulfur contents are typically low. Most of the coal is mined by dragline and truck and shovel methods. Production rates reached up to 11 Mt per year in some of the Wyoming mines.

Coal mining in the western U.S. is controlled by strict environmental laws. The Surface Mining Control and Reclamation Act of 1977 established procedures for obtaining a "permit to mine" and for developing plans for reclamation after completion of mining. A federal agency, "Office of Surface Mining" was established to regulate the open pit mining in the U.S. In addition, each state has its own department responsible for regulating mining within the particular state. Federal and State regulations require an analysis of the environmental impacts of mining. Of particular concern in the semi-arid region of the western U.S. is the impact of open pit mining of surface and ground water resources. A detailed evaluation of the pre-mining hydrologic characteristics and the potential effects of mining on the hydrologic balance in the area affected by mining are important components of the studies for each proposed mine site.

HYDROGEOLOGY OF THE COAL MINING DISTRICTS

Most of the coal bearing strata in the western U.S. were deposited during either the Cretaceous Period or the Tertiary Period. Cretaceous and Tertiary coal-bearing formations contain numerous coal seams separted from one another by strata of claystone, siltstone, shale or sandstone. The sandstone and coal strata are typically water-bearing. In many areas of the western U.S. the coal seams are significant aquifers supplying water for domestic and stock purposes. The coal strata are situated predominantly in synclinal basins and, therefore, aquifers are unconfined near the outcrops and confined in the deeper areas of the basins. Permeabilities of both sandstone and coal aquifers are relatively low. Both materials have average hydraulic conductivities of approximately 2×10^{-4} cm/sec and storage values on the order of 5×10^{-6}. These values were obtained by detailed studies of 12 mining districts in Montana, Wyoming and North Dakota (Rehm, et. al, 1980). The sandstone and coal strata are typically recharged at outcrops by the direct infiltration of precipitation and snowmelt and by the infiltration of water from surface streams and reservoirs. Flow patterns are controlled by geologic gradients and structures. Waters from sandstone and coal aquifers in the western U.S. contain a wide range of concentrations of most constituents. The concentration of total dissolved solids typically ranges from 500 to 5,000 mg/l. In most waters sodium is the principal cation and bicarbonate is the principal anion. However, large amounts of calcium, magnesium and sulfate are found in most aquifers.

In the western U.S. where the coal sulfur content is typically low (<0.7%) the acid mine drainage problem is not as pronounced as in the Appalachian region where about 6,000 tons of sulfuric acid are being produced daily through oxidation of pyrite (Ahmad, 1974).

MINING IMPACTS AND REGULATIONS

Open pit mining of coal disturbs the pre-mining physical characteristics of the land on which it occurs. Materials removed from overburden and interburden of mined coal seams are replaced after the mining operation. The original aquifers in sandstone and coal strata are disturbed and replaced by mine spoils. Physical and chemical characteristics of the mine spoils are different from the pre-mining aquifer properties. Hydraulic parameters of mine spoils, permeability and porosity, in particular, are different from the original aquifers. Chemical equilibrium in the pre-mining hydrologic system is disturbed by disposing new chemical constituents available for dissolution in the mine spoils.

Prediction of post-mining surface and ground water conditions is a part of planning for any surface mining operation in the U.S. The determination of the probable hydrologic consequences of proposed open pit mining and reclamation operations is required by law and is part of the application for a permit to mine. The components of the mine impact studies include:

- o description of baseline (pre-mining) hydrologic conditions;
- o prediction of the effects on these baseline conditions in the area of the mine plan and adjacent areas by the proposed open pit mining and reclamation operations.

The purpose of these studies is to insure that the mining and reclamation plans are developed to minimize hydrologic impacts. The studies of mining impacts must also address the probable cummulative impacts in areas where several mining operations are proposed.

The hydrology baseline studies for a mine site typically consist of an analysis of regional and site specific geologic, and surface and ground water hydrologic data. Gaging stations on surface water streams are installed and streams are monitored to determine seasonal streamflow characteristics and water quality. Ground water bearing strata are tested for permeability, storativity and water quality and a network of monitoring wells is established. Samples of overburden are collected during drilling programs and analyzed for physical and chemical properties. Most of the states in the western U.S. require at least one year of monitoring data prior to the commencement of mining.

Prediction of mining impacts on the local hydrologic balance are based on hydrologic baseline studies and the proposed mining and reclamation methods. Several computer models for simulation of the probable hydrologic consequences of open pit mining were developed by federal agencies, universities and consulting firms (Day, et. al, 1984; Schwartz and Crowe, 1984; Lall and Sorenson, 1984).

MINE RECLAMATION EXPERIENCE

Open pit coal mining in the western U.S. have been developed extensively in the last 10 - 13 years and, therefore, monitoring records of the ground water recovery in the reclaimed pits are relatively short in comparison with the eastern U.S. and Europe. However, due to the rapid development of mining, strict environmental laws, and the historical shortage of surface and ground water resources in the mostly semi-arid climate of the western U.S., extensive hydrologic studies of the reclaimed open pit coal mines have been performed in the past decade.

Studies of mine reclamation concentrated on the prediction and post-mining testing and monitoring of physical and chemical properties of spoils and ground water. Prediction of post-mining water quality in spoils are based on pre-mining water quality and chemistry of the overburden materials. The water contamination potential of spoils is based on the availability of both water and contaminants within the reclaimed pits. Based on the assumption that the minimum contaminant potential of the spoils is indicated by the quantities of water soluble cations and anions present, the saturated paste method was developed to chemically characterize the spoils (Herget, 1971). This test consists of saturating crushed spoil samples with distilled water for 16 hours. The water is then removed from the saturated paste by vacuum extraction and analyzed for various cations and anions. Although this method does not express the influence of such factors as weathering, microbe activities, cation exchange capacities and nonequilibrium chemical reactions, the results of water quality estimates based on the saturated paste method correlate well at several mining sites with quality of the ground water in mine spoils (McWhorter, et. al, 1974, and 1979). In some cases leaching tests are performed on the spoils meterials. This type of test consists of passing distilled water through columns of spoil, collecting the leachate in time increments and measuring the specific conductance, or other chemical component, of each increment.

Results of saturated paste and leaching tests on spoils in the Edna mine in western Colorado indicated that 2.4 kg of soluble salts would be removed from each cubic meter of spoils before the concentration of the percolate is reduced to a negligible level (McWhorter, 1974). The major chemical contaminants were found to be calcium, magnesium and sulfate. More detailed descriptions of overburden testing and evaluation can be found in Caruccio and Geidel (1981), Van Voast, et. al (1978), and McWhorter, et. al (1974, 1979).

The hydraulic properties of spoils, hydraulic conductivity, storage and porosity, are very important factors in aquifer restoration during an open pit reclamation . Numerous studies of the hydraulic characteristics of spoils have been performed in reclaimed open pits in Colorado, Wyoming, Montana and North Dakota. Rehm, et. al (1980) summarized available data pertinent to undisturbed and reclaimed pits from five mining areas in the Northern Great Plains. His study concluded that the hydraulic properties of the spoils vary over both the area of reclaimed land and with time. This study indicated that the hydraulic conductivity of mine spoils has a six order of magnitude range with a mean of 8.0×10^{-5} cm/sec. Variability of spoils permeability is due to spatial variation of overburden lithology, the method of mining and spoils handling, and the time of year during which the spoil is handled. Several studies indicated that permeability of spoils handled by a dragline is higher than that of spoils replaced by a truck and shovel operation.

Van Voast, et. al (1978 and 1985) conducted an extensive evaluation of the pre- and post-mining ground water regime in several open pit mines in the Powder River Basin of Montana.

He found that ground water re-enters spoils shortly after mining and that the hydraulic conductivity of spoils is statistically similar to that of coal beds. Van Voast's studies indicated that a confined type of aquifer developed at the mine floor where more coarse spoils accumulated during backfilling of the open pits near the Decker and Colstrip areas of Montana. A confining or semi-confining bed is developed by finer-grained spoils. This has been confirmed by the values of storage coefficient ($1 - 3 \times 10^{-5}$) resulting from pumping tests in spoils. Post-mining water levels were found to be similar to pre-mining levels.

Comparison of water quality in pre-mining sandstone and coal aquifers with water quality in spoils of reclaimed pits are available from many mines in Colorado, Wyoming, Montana and North Dakota. Most of the monitoring data indicates that the chemistry of spoils waters is highly variable, reflecting the lithologic and geochemical variability of overburden materials. Research completed in the coal and spoils of the Decker, Montana mine (Van Voast, et. al, 1978) indicated that spoils contained much more calcium, magnesium and sulfate when compared to the coal water quality. The total dissolved solids content in the spoils water was 2 to 3 times higher than in the pre-mining aquifers. This conclusion was confirmed in other mines in the western U.S., for example in the Big Horn mine in Wyoming, and the Edna and Colowyo mines in Colorado.

In a study of the environmental effects of western Colorado coal surface mining (Skogerboe, et. al, 1979) it was concluded that higher concentrations of arsenic, iron, manganese, selenium and zinc are found in waters draining mine spoils and that the concentration of these elements varies with spoil age. Manganese and zinc concentrations are higher in older spoils and arsenic, iron and selenium are higher in newer spoils. However, these conclusions were not confirmed on other mine sites.

Most reseachers agree that the chemical equilibrium in monitored spoils has not yet been attained. The monitoring history is too short and in many cases the salts available for solution in spoils have not yet been leached. It is assumed that the elevated levels of total dissolved solids in the spoils could decline as leaching reaches equilibrium.

CONCLUSIONS

A considerable number of studies of the hydrologic regimes in reclaimed open pit coal mines in the western U.S. have been performed. Most of the studies concluded that the hydraulic properties (hydraulic conductivity, porosity and storage) of the waters found in the replaced spoil will be similar, however, less homogeneous, when compared to pre-mining properties of sandstone and coal aquifers. Although the original coal and sandstone aquifers have secondary permeability characteristics and the spoils have predominantly primary permeability characteristics, the original flow system is not substantially changed.

Studies of water quality in spoils are not quite conclusive because of a relatively short period of monitoring available on the impacts of open pit mining in the western U.S. A general observation of ground water quality in spoils is that the content of total dissolved solids, calcium, magnesium and sulfate, when compared to the pre-mining conditions, is two to three fold higher at present. However, these elevated levels should decline as leaching of spoils reaches an equilibrium. Even at a three fold increase in the concentration of total dissolved solids the water in the spoils will, in most cases, be suitable for its predominant pre-mining use, stock watering.

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