

MODEL SIMULATIONS OF HYDROLOGIC RESPONSES AT COAL MINES AND PROJECTION OF GROUND-WATER DISCHARGE RATES IN COAL-BED METHANE SETTINGS¹

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Abstract. Large scale coal-strip mining has been on-going in southeastern Montana for over three decades. In order to address the potential hydrologic impacts on aquifer systems, extensive long-term monitoring has been conducted since the inception of this mining. As a result, an excellent ground-water database has evolved. This database allows for refinement of key hydraulic parameters in the affected hydrogeologic strata in the vicinity of these mines. In turn, this facilitates prediction of the impacts of future hydraulic/hydrologic stresses imposed on coal bed aquifer systems via any of the following: 1) Mine expansion; 2) Mine development; and 3) Development of coal-bed methane (CBM). One method of refining the understanding of aquifer systems is to use ground-water modeling. To this end, Nicklin Earth & Water, Inc. (NE&W) has developed four separate ground-water models representing coal mines for predicting the impacts of surface mining on aquifer systems in and near the vicinity of coal mines in the northern Powder River Basin. The mine modeling simulations demonstrate that the applicable range of hydraulic conductivity at a mine scale is from 0.1 to 0.3 m/d. The mine simulations also demonstrate that vertical hydraulic conductivity for overlying and underlying strata bounding coal beds is very low. Vertical hydraulic conductivity values in the range of 10^{-5} to 10^{-6} m/d produced simulation results reasonably consistent with field observations at clustered vertical well sequences. The issue of vertical hydraulic conductivity (or very low vertical leakance) in confining units is a significant issue in estimating CBM production. The very low leakance rates lead to very little contribution of water from the confining units bounding the coals in the Northern Powder River Basin. In general, methods, such as Lohman (1972) and MODFLOW are best employed before the full on-set of methane gas flow begins. Once the on-set of gas flow becomes significant, it has been our experience that both these methods tend to significantly over-estimate actual water production rates during CBM production.

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Introduction

Large scale coal-strip mining has been on-going in southeastern Montana for over three decades. In order to address the potential hydrologic impacts on aquifer systems, extensive long-term monitoring has been conducted since the inception of this mining. As a result, an excellent ground-water database has evolved. Geologic log information, water level data and hydraulic parameter data for ground-water monitoring wells in the vicinity of these mines are available from the Montana Bureau of Mines and Geology (MBMG) in its GWIC database (<http://mbmggwic.mtech.edu>). Mine-specific ground-water water data are also available at Montana Department of Environmental Quality in Helena, MT. These data allow for refinement of key hydraulic parameters in the affected hydrogeologic strata in the vicinity of these mines. NE&W has conducted four coal mine model simulation efforts in the Northern Powder River Basin. The results of these model simulation efforts are very helpful in predicting the magnitude of discharges from coal bed methane (CBM) production in the Northern Powder River Basin.

Coal Mine Simulation Summary

NE&W had completed four mine model simulation efforts including two at the Rosebud Mine (Area C and Area D); and one each at the Absaloka Mine and Spring Creek Mine in the Northern Powder River Basin. Generally, all mine modeling calibration efforts started with use of data obtained by MBMG [e.g., data described in Wheaton and Donato, 2004] and field studies completed by the mining companies. Generally, the use of field-based parameters proved to be a good starting point in the numerical simulation process.

Hydraulic Conductivity

The MBMG has reported a wide range of hydraulic conductivities for coal bed aquifers. The geometric mean for hydraulic conductivity in coal centers near 0.3 m/day (1 ft/d). The coal mine simulation efforts indicate that defining this parameter from about 0.1 to 0.3 m/d (0.3 to 1 ft/d) tended to provide for reasonable calibration results when considering potentiometric head and discharge data available at the mines.

Vertical Hydraulic Conductivity (Overburden/Underburden)

The mine modeling simulations also demonstrate that vertical hydraulic conductivity for overlying and underlying strata bounding coal beds is very low. Vertical hydraulic conductivity values in the range of 10^{-5} to 10^{-6} m/d produced simulation results reasonably consistent with field observations at clustered vertical well sequences. The issue of vertical hydraulic conductivity in confining units is a significant issue in estimating CBM production as is discussed later.

Storativity

Much of the coal aquifer testing at coal mines was conducted prior to the on-set, or during early phases, of mining. The coal aquifers were more likely to be confined then. However, as the mining process evolves, these coal aquifers are often transformed from confined aquifers to unconfined aquifers because of mine penetration into the confined strata. The use of pumping test aquifer parameters indicative of confined conditions does not work well during the simulation process in matching the transient response of wells. For instance, pumping tests of confined aquifers in the vicinity of coal mines show storativities from 10^{-5} to 10^{-4} . During transient calibration efforts, the use of storativities of about 0.003 yielded much more reasonable

matches to time series of potentiometric head data. The latter value is more indicative of semiconfined aquifers.

Recharge Rates

Typical simulation recharge rates from precipitation, which produce simulated water balances reasonable for a mine setting, are about 0.64 centimeters (0.25 inches) per year. Some variation of recharge rates may be applicable depending upon the existing site setting. For example, in some instances better calibrations were achieved by either increasing or decreasing recharge rates depending upon localized geologic conditions (e.g., presence of alluvium, areas with extensive clinker, etc.).

Stepping to Coal Bed Methane

NE&W has found that the hydraulic properties of the coals and coal-bounding strata in the Northern Powder River Basin are very similar throughout this basin when they are averaged at the mine scale or at the Plan of Development (POD) level in a CBM development. Hence, ground-water modeling is evaluated as a tool for estimating the long-term ground-water extraction rates for CBM operations in this portion of the Northern Powder Rive Basin.

Hydraulic parameters employed in the mine modeling efforts can be applied directly to the CBM production models. These include hydraulic conductivity, vertical hydraulic conductivity, and recharge. However, the following two primary differences between CBM production settings and coal mines should be understood if modeling is to be employed:

- 1) Confined aquifer conditions are maintained in the targeted coal in CBM production. In other words, the coal is not dewatered during CBM production. Nearer surface coals which are involved in coal mining are more likely to be unconfined. Hence, storativity values representative of confined conditions are more appropriate. NE&W typically uses storativity values of 10^{-4} for CBM model simulations. Using leakances defined in mining settings coupled with this storativity value yields reasonable matches to observed discharge rates in earlier phases of CBM production for PODs.
- 2) CBM production also leads to the evolution of a complex flow system with time. As the desorption process continues, gas saturation within the cleat system accelerates and the flow of methane increases with time while at the same time water production decreases. In effect, a dual-phase flow system consisting of water and methane evolves. Thus, flow predictions developed using hydraulic models, especially after the on-set of gas production, must be treated with caution as they tend to significantly over-estimate the long-term yield of production water for a CBM POD.

During CBM production, the issue of vertical hydraulic conductivity is also very significant for the following two reasons:

- 1) It affects the rate of ground-water production.
- 2) It affects the degree of potentiometric response (e.g., drawdown) in non-CBM strata above and below the targeted coal. For instance, if the vertical hydraulic conductivities of the non-CBM strata are very low, then drawdown in the non-CBM strata will be very low as well.

The vertical hydraulic conductivity is quantified in ground-water hydraulic modeling via a term known as vertical leakance. Vertical leakance is proportional to the vertical hydraulic

conductivity of the strata and inversely proportional to that strata thickness. If the vertical hydraulic conductivity of a thick confining unit is very low, then very low values of leakance result. The impact of very low leakance values is to cause very low rates of leakage to occur into or out of these coals via these confining units. This is one factor that explains why much lower discharges are being observed in the Montana CBM PODs than what has been predicted by some.

The issue of leakance and leakage rates as they affect discharge in CBM production wells is discussed in Onsager and Cox (2000) (see Fig 1). Since vertical leakances of the overburden and interburden strata tend to be very low in the Northern Powder River Basin, flow through these confining units is also very low. For instance, the mine setting models NE&W has completed show that Northern Powder River leakage rates place at or below the lower plot shown on Figure 1 (the 0.003 md curve).

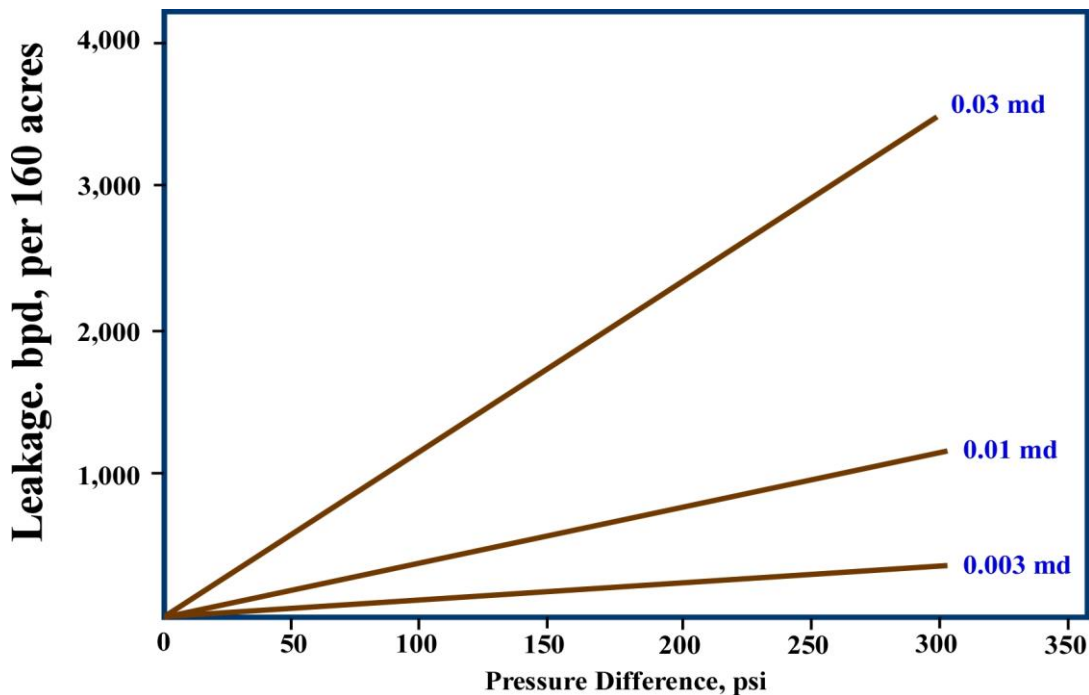


Figure 1. Aquifer leakage as a function of reservoir pressure drawdown and confining layer permeability (Onsager and Cox, 2000). The coal mine simulations indicate that leakage rates associated with a permeability of 0.003 millidarcies (md) or below are appropriate for the Northern Powder River basin (1 md equals 8.34×10^{-4} meter/day). Note that one barrel per day (bpd) is 42 gallons per day is 0.159 cubic meter per day.

In general, methods such as Lohman (1972) and MODFLOW are best employed before the full on-set of methane gas flow begins. Once the on-set of gas flow becomes significant, our experience has been that both these methods tend to significantly over-estimate actual water production rates. As a general rule of thumb, it is not unreasonable to project that water production rates quantified at the POD level using MODFLOW will be about twice the actual CBM production flow rates. This assumes, of course, that the MODFLOW simulations employ reasonably representative hydraulic parameters for both the coal and confining units bounding that coal.

Summary

There are several significant factors and hydraulic parameters that must be understood before reliable simulations can be performed in coals subjected to mining and CBM production. Long-term data collected from mining operations are invaluable in better quantifying the response of aquifer systems to either expanded mining in the future or to CBM production. In particular, the following factors must be accounted for when projecting flow rates and drawdown in strata associated in the vicinity of CBM production:

- 1) Formation hydraulic conductivity;
- 2) Formation vertical leakance;
- 3) Storativity; and
- 4) Dual-phase flow conditions evolving during the on-set of significant methane gas flow.

The first three factors can be quantified using the existing databases, especially using the information that has been developed over the past several decades at coal mines in Montana and more recently in areas projected to see CBM production. The impact of dual-phase flow does affect projected flow rates. Use of traditional methods employed by hydrogeologists must be conducted with caution when projecting long-term ground-water extraction rates associated with CBM development since these hydraulic based methods do not address dual-phase flow.

Literature Cited

- Lohman, S. W. 1972. Ground-water Hydraulics. U.S. Geological Survey Professional Paper 708. U.S. Department of the Interior.
- Onsager, P. R. and D. O. Cox. 2000. Aquifer controls on coalbed methane development in the Powder River Basin, Wyoming. Society of Petroleum Engineers. SPE Annual Technical Conference, Dallas, October 2000. <http://dx.doi.org/10.2118/63090-MS>.
- Wheaton, J. R, and T. A. Donato. 2004. Ground-water Monitoring Program in Prospective Coalbed-Methane Areas of Southeastern Montana: Year One. Montana Bureau of Mines and Geology Open-File MBMG 508.