Groundwater as an environmental constraint of longwall coal mining

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Abstract: Groundwater impacts are a common cause of opposition to longwall mining. Most are due to subsidence-related fracturing. Case studies in Appalachia and Illinois show that upper zones are protected from drainage to the mine by a confining zone; groundwater levels decline due to fracture dilation, but drawdown expands outward a few hundred meters. Recovery of water levels is common.

Key words: longwall mining, subsidence, well losses.

Introduction

Longwall underground coal mining causes rapid subsidence of the overlying strata and ground surface. Most of the environmental groundwater impacts from longwall are caused indirectly by subsidence-related fracturing. Mining companies are required to compensate landowners for loss of water and to provide alternative water supplies, but the loss of water supply is still a serious concern to the people affected. These impacts are a common reason for opposition to longwall mining from residents and environmental groups; for the companies, they can become a significant obstacle in obtaining mining permits. This presentation summarizes findings and current concepts about the complex groundwater impact of longwall mining, for the benefit of hydrogeologists and engineers who may need to be involved as consultants. Case studies are selected from the Appalachian and Illinois coalfields, USA.

Nontechnical information about longwall environmental controversies is readily available on the internet. Most internet-media reports concern opposition to longwall permit applications from environmental groups and residents on the basis of anticipated or anecdotal impacts: structural damage or drainage problems, loss of stream flow due to fractures in stream beds, loss of springs, and drying of wells and lowering of water levels. Among examples are a controversy concerning proposed longwall mining adjacent to old-growth woods in Ohio, disputes over well-water losses due to longwall in West Virginia, and the expansion of longwall mining in southwest Pennsylvania. Pennsylvania mining law was revised in 1994 to give companies the right to longwall mine and subside beneath homes and structures, but required them to provide remedial action, compensation, and alternative water supplies if wells were lost. The new law was strongly opposed by environmental organizations. A 1999 study of longwall and room-and-pillar operations by the state's Department of Environmental Protection[1] noted water loss or damage in about 28 % of the properties and that mine operators were replacing water supplies and fixing subsidence damage. However, opponents criticized the data, and controversy continues[2]. There is no doubt that longwall

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mining impacts well water levels, but state laws consider this an acceptable consequence of mining provided that the mining companies remediate and compensate for damage. Groundwater will be an issue in court each time there is opposition to a longwall permit or disputes over remediation and compensation.

THE HYDROGEOLOGICAL IMPACT OF LONGWALL MINING

Two regions of the USA in which longwall mining and groundwater case studies have been conducted are the Appalachian and Illinois coalfields. The first is an unglaciated, dissected plateau region of moderate to high relief, with typical Pennsylvanian-age coal measures including minor sandstone aquifers. Illinois has low relief, a glacial drift cover, and generally less permeable strata. A conceptual model of the hydrogeological effects of longwall coal mining has gradually been developed from case studies[3]. All underground mines are potential groundwater drains, but subsidence and strata movement due to longwall mining affect the groundwater system separately from mine drainage. Fracturing and bedding separation cause changes in fracture porosity and permeability and thus in hydraulic gradients and groundwater levels. Above a mined panel, the overburden strata form major zones of deformation and hydrologic response[4, 5]: a lower, severely fractured zone which dewaters into the mine, and in which wells would lose their water; an intermediate low-permeability zone; and an upper extensional zone of increased permeability in which wells commonly have significant but temporary water-level declines. The intermediate low-permeability zone typically prevents drainage from shallow aquifers to the mine.

Increases of one to two orders of magnitude of permeability due to fracturing are commonly reported for Appalachia and also in our studies in Illinois. The typical potentiometric response to longwall mining is a drop in groundwater level in bedrock aquifers, due to:

(1) Direct drainage to the mine, if the well bottom is within the lower fractured zone.
(2) Increases in fracture porosity in strata overlying the panel, which cause large head drops in confined bedrock aquifers because of their low storativity and low fracture porosity[3]; this response is not significant in unconfined and unconsolidated aquifers.
(3) Increases in fracture permeability, causing decreases in hydraulic gradient. Up-gradient heads and spring flows decline, while down-gradient from the site, groundwater levels in valley wells may rise and groundwater discharges to springs and streams may increase [5].
(4) Draining of upper-level aquifers through fractured aquitards down to lower levels [6, 7].
(5) A transmitted drawdown expands outwards from the primary potentiometric low.

ILLINOIS STUDIES

The coal-measures in Illinois are dominated by low permeability shales and overlain by glacial deposits. Groundwater resources are mostly limited to minor sand and gravel within the till and to shallow, poorly transmissive sandstones. We studied the hydrology over two active longwall mines in Illinois from 1988 to 1995; details of the studies have been extensively published[8-11].

Jefferson County Site: Our studies over final panel 4 (183 m wide, 222 m deep into a 3-m seam) focused on the Mt Carmel Sandstone, 23-25 m thick, 174 m above the mine, and 24 m below ground. The aquifer is overlain by shale and glacial drift. Ground subsidence reached 2 m along the centerline, accompanied by considerable strata fracturing. The sandstone permeabilities (initially 10^{-7} m/s) increased by one order of magnitude in the inner subsidence trough and two along the margin. Water levels in the sandstone declined as the mine face approached, reached a minimum (43 m below ground, unconfined) at maximum tension during undermining, partially recovered during the compressional phase, and recovered to about 12 m by four years after mining. Responses of drift water-table wells were minimal. The groundwater chemistry of the sandstone changed from slightly brackish (TDS 900-1200 mg/l; sodium-bicarbonate dominant; sulfate less than 200 mg/l) to brackish (TDS 2600 mg/l, sulfates over 1200 mg/l) during recovery, probably due to leakage from the overlying shale and to the mobilization of sulfate from sulfides in the sandstone.

Saline County Site: The sandstones at this site are thin to discontinuous and poorly permeable (10^{-8} ms/); permeabilities increased only minimally with subsidence. Our studies concentrated on panels 1 (204 m wide, 122 m deep) and 5 (287 m wide, 97 m deep). Centerline subsidences were around 1.4 m. Water levels in the >50-m-deep sandstone at panel 1 fell rapidly at undermining, to an unconfined condition, but did not recover after mining. At panel 5, the sandstone was only 20 m deep and sub-cropped at the bedrock surface, but its water levels behaved similarly except for recovery along the barrier where it was recharged from a sand and gravel unit.

Areas of Influence

The limit of the groundwater influence of mining is often compared to the "angle of draw" which defines the limit of subsidence movement; however, this defines only the edge of the primary hydrologic response to fracture dilation, and the extent of groundwater influence beyond the subsidence zone is controlled by the transmissive properties of the aquifer. For typical coalfield sandstones, the effects reach only a few hundred meters despite the steep head drop over the panel.

Recovery of water levels after mining

Wells which penetrate the lower fractured zone do not usually recover. Water levels in the upper zone in the subsidence area commonly soon recover slightly due to post-subsidence compression, and then recover gradually as water flows back into the temporary potentiometric depression created by the subsidence fracture effects. However, this later recovery depends on connection to sources of recharge and the transmissivity of the aquifer, thus on topography, structure, fracturing, and lithology. Appalachian case studies show that many well water levels and stream flows recover, especially in stream valleys but less so in uplands[5, 6, 7]. Because of permeability changes, some permanent losses will probably occur due to altered gradients and leakage through aquitards.

CONCLUSIONS

Groundwater impacts are an environmental constraint of longwall mining, whether considered as a problem for residents of mined areas or for companies in permit applications. Longwall mining affects overlying aquifers by several mechanisms, of which the most important are fracture dilation over the panel and drawdown effects transmitted outward through the aquifer from the primary potentiometric low. Groundwater levels may be lowered because of drainage to the mine, but normally this is retarded by an intermediate low-permeability zone, and a problem only for deeper wells that penetrate the lower fractured zone.

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