HYDROLOGIC CONDITIONS IN THE COAL MINING DISTRICT OF INDIANA AND IMPLICATIONS FOR RECLAMATION OF ABANDONED MINE LANDS[1]

by

Greg A. Olyphant[2] and Denver Harper[3]

Abstract. Bedrock strata of the mining district of Indiana (Indiana Coal Mining District, ICMD) include numerous coalbeds of economic importance, together with underclays, roof shales, limestones, and sandstones of Pennsylvanian age. These are typically poor aquifers with low hydraulic conductivities and specific yields. Surficial materials include loess, till, alluvium, and other deposits of Pleistocene age. The loess and till also have low hydraulic conductivities, so that very few shallow aquifers exist in the vicinities of abandoned mine land (AML) sites, except where they are close to the alluvial fill of large bedrock valleys. The hydrologic cascade at AML sites in Indiana is strongly conditioned by the existence of elevated deposits of coarse-grained coal-preparation refuse and flooded underground mine workings. Flooded mines are the principal conduits of groundwater flow in the area, but their boundaries, flowpaths, and mechanisms of recharge and discharge are very different from those of natural aquifers and are poorly understood. Acidic mine drainage often emerges as seepages and springs on the edges of the elevated refuse deposits, but the low permeability of the natural surficial materials and bedrock inhibits the development of off-site groundwater contaminant plumes. The water balance across the surface of the refuse deposits is critical to reclamation planning and success. Enhancing runoff through reduction of infiltration capacity has the beneficial effect of reducing recharge through the acid-generating refuse, but the excess runoff may be accompanied by soil erosion that can lead to reclamation failure. Furthermore, during cool seasons and stormy periods, a well vegetated surface promotes recharge through increased infiltration, resulting in greater rates of acidic baseflow seepage. Passive Anoxic Limestone Drains (PALDs) have been successfully coupled with wetland treatment systems to improve surface waters that discharge from AML sites. Storm runoff from reclaimed refuse deposits is often alkaline, and techniques could be devised to utilize this alkalinity in the on-site treatment of both groundwater and surface water. In some instances, the flooded underground mines also contain alkalinity that could be used to treat acidic baseflow, but to date, no efforts have been made in Indiana to explore the possibility of beneficially incorporating underground mines in reclamation planning.

Introduction

In the state of Indiana, hundreds of Abandoned Mine Land (AML) sites have been reclaimed by the Division of Reclamation (DOR) during the past 30 years or so, yet dozens of AMLs remain and some of the reclamation sites will need to be revisited due to incomplete reclamation and/or partial failures. Since about 1985, we have had the opportunity to work with DOR personnel on hydrological conditions at AML, sites and in the process we have gained some insights about the character of hydrogeological conditions in the mining district of Indiana. The purpose of this paper is to share some generalizations that we have derived from our studies and to speculate on their importance to AML reclamation. Most of the data presented here comes from the five project areas depicted in Figure 1. These sites encompass most of the hydrogeologic settings within the mining district and are referred to as the Blackhawk (BHS), Cannelberg (CBS), Friar Tuck (FTS), Midwestern (MWS), and Wheatland sites (WLS).

---

[1]Paper presented at the 1998 National Meeting of the American Society for Surface Mining and Reclamation, St. Louis, Missouri, May 16-21, 1998.

[2]Greg A. Olyphant, Associated Professor, Department of Geological Sciences and Center for Geospatial Data Analysis, Indiana University, Bloomington, IN 47405.

[3]Denver Harper, Senior Environmental Geologist and Senior GIS Specialist, Indiana Geological Survey and Center for Geospatial Analysis, Bloomington, IN 47405.

Proceedings America Society of Mining and Reclamation, 1998 pp 283-288
DOI: 10.21000/JASMR98010283

https://doi.org/10.21000/JASMR98010283

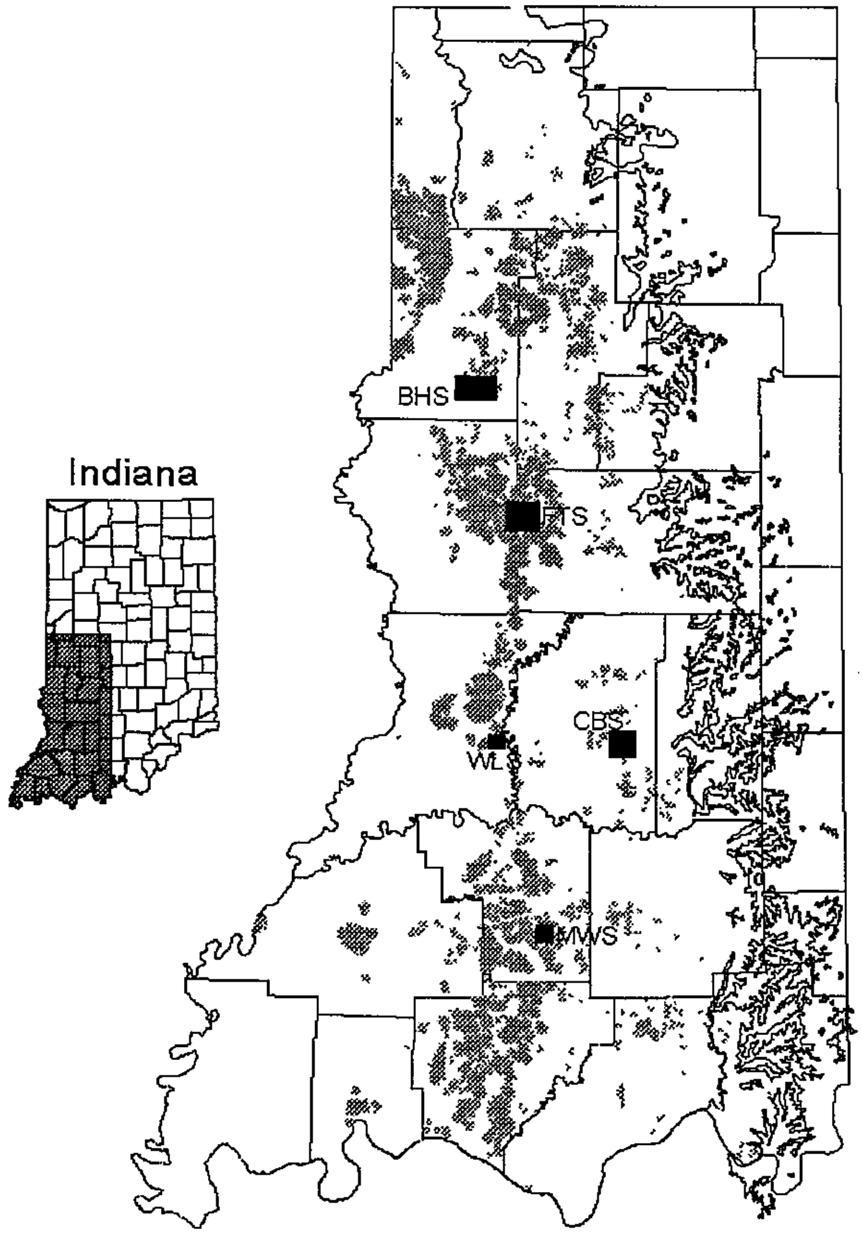

Figure 1. Map of Indiana Coal Mining District showing: a) boundary of Pennsylvanian bedrock system, b) distribution of surface and underground mines, and c) locations of study sites referred to in text.

Climate and Geology of the Indiana Mining District

The mining district of Indiana is concentrated in the southwestern part of the state. The climate of the area is transitional from the cool-temperate continental conditions of the upper midwest to the warm-humid subtropical conditions of the southeastern United States. The average annual precipitation is slightly more that 100 cm. Precipitation occurs during all months of the year (Figure 2). October is the driest month, but it receives almost 6 cm of precipitation, on average. June is the wettest month, receiving an average of more than 12 cm of precipitation. Snowfalls are common in winter, but much of the winter precipitation occurs as rain or sleet. The large amounts of precipitation that fall on the mine lands of Indiana pose both a benefit and a threat to reclamation. The rain and snow promotes vegetation growth on the one hand, but excess precipitation also promotes groundwater recharge (that can lead to generation of acidic mine drainage) and storm runoff (that can lead to soil erosion and loss of vegetation).

The mining district of Indiana lies on the eastern flank of the Illinois Basin, a vast structural trough that was actively subsiding during the Pennsylvanian Period. The principle lithologies of the district are claystones, shales, sandstones, and carbonates that are interbedded in places with coal seams (Shaver, et al., 1986). The eastern edge of the Illinois Basin was deeply dissected by streams during the Tertiary Period and then subjected to glaciation during the Pleistocene Epoch. The upland portions of the dissected basin are veneered by glacial till and loess, but the drainageways are partially filled by outwash sands and gravels (main channels), or lacustrine silts and muds (minor tributaries)(Fleming et al., 1995).

Hydrogeologic Conditions

Coal beds and sandstones comprise the primary aquifers of the ICMD, but these units are commonly discontinuous in extent and are closely interbeded with shales, limestones and underclays. Also, the rocks are well cemented, so that their hydraulic conductivities and well yields are low (Table 1). A large portion of the ICMD has been subjected to underground mining. These underground mines, when flooded, constitute the primary aquifers of the area. [For purposes of our hydrologic studies we refer to the flooded mine voids and associated fractured bedrock (pillars, roof rocks, and surrounding unmined coal) in close hydraulic connection with the voids as the *mine aquifer* system.] Detailed monitoring of mine aquifers at four of the five sites identified in

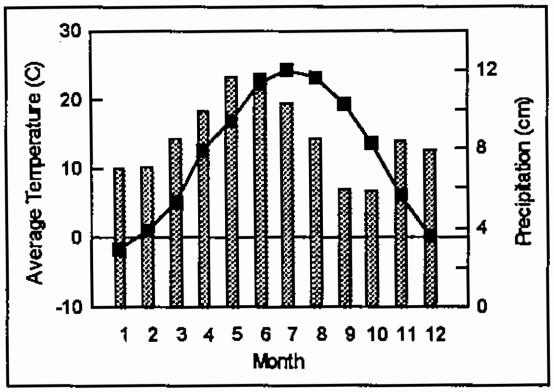

Figure 2. Representative climograph for the Indiana coal-mining district (Source: National Climatic Center, Asheville, NC).

Figure 1 indicates the following about the role of flooded underground mines in the ICMD:

1. Water levels in many mine aquifers are highly responsive to seasonal and short term (storm period) variations in precipitation (Harper and Olyphant, 1992, 1993, 1996) indicating that these systems are generally in good connection with the surface. The one exception, in our experience, is the BHS where water levels have remained fairly steady after an initial (delayed) excursion that was probably associated with infilling of a refuse pit following reclamation (Harper et al., 1990).

2. Recharge of mine aquifers probably occurs mostly as vertical percolation through fractured roof strata, but poorly plugged air shafts and slope entries may also be locally important recharge pathways. At the MWS we have identified a lake situated between ridges of overburden spoil as the probable (primary) source of recharge to the mine aquifer (Harper et al., 1996). The recharge occurs as lateral flow through a highwall of apparent high permeability

3. Many mine aquifers in the ICMD are under artesian head conditions because their recharge sources are on elevated upland areas (Harper and Olyphant, 1990, 1992). When the mine aquifers are located near eroded stream valleys, they may discharge into valley fill sediments as subsurface seepages or onto those sediments as perennial springs (Brooks et al., 1991) .

Because the bedrock and natural surficial materials are of generally low permeability in the ICMD, contaminant plumes are not common beyond the immediate edges of refuse deposits. In all situations that

Table 1. Hydraulic Conductivities of Selected Bedrock and Surficial Deposits in the Indiana Coal Mining District[a]

Material	Hydraulic Conductivity (m/s)	Well Yield (L/s)
Bedrock Units:		
Sandstone	10^{-6} - 10^{-4}	10^{-1} - 10^{0}
Unmined Coal	10^{-7} - 10^{-5}	10^{-2} - 10^{-1}
Shale	10^{-8} - 10^{-6}	10^{-2}
Surficial Deposits:		
Glacial Till	10^{-8} - 10^{-6}	n.d.
Loess	10^{-7} - 10^{-5}	n.d.
Alluvium	10^{-7} - 10^{-3}	10^{-1} - 10^{2}
Overburden Spoil	10^{-8} - 10^{-5}	n.d.
Coarse Refuse	10^{-7} - 10^{-4}	n.d.
Fine Refuse	10^{-8} - 10^{-4}	n.d.

[a]Source: Banaszak, 1980; Brooks et al., 1991; Cable et al., 1971; Harper et al., 1990, Wangsness et al., 1981.

we have studied, highly concentrated acidic water which originated through weathering in the vadose zones of coarse and fine grained (pyritic) refuse deposits emerges as seepages and springs at the bases of the deposits (where a permeability boundary exists) or as subsurface flow into erosion gullies during rainstorms. At the FTS, two monitoring wells in loess and till just 10 m beyond the edge of a refuse pile contained water with no evidence of acidic contamination. Yet groundwater in the refuse was highly acidic and contained total dissolved solids (mostly iron and sulfate) in excess of 10,000 mg L^{-1} (Olyphant et al., 1991). A geophysical reconnaissance of the undisturbed surficial deposits beyond the two monitoring wells confirmed that the shallow water table was unaffected by acidic mine drainage (AMD) from the refuse (Brooks et al., 1991). However, a small intermittent channel that drained the network of erosion gullies that dissected the refuse deposit always contained AMD, and this channel eventually discharged into the principle stream draining the area (Mud Creek).

Deposits of coarse-grained (pyritic) refuse are the principle sources of AMD in AMLs of the ICMD. Therefore, the water balance of these deposits is of great practical importance. As discussed above, these deposits almost invariably have perennial seepages at their bases or contain deep erosion gullies whose trunk reaches are occupied by perennial or intermittent streams. As a result, much attention has been given to reclamation measures that lead to a reduction of storm infiltration. The down-side of such measures is that reduction of infiltration leads to augmentation of storm runoff which can exacerbate erosion problems. If insufficient attention is given to the tradeoffs between infiltration and runoff reduction, reclamation failures can occur. Two of the sites we studied (WLS and FTS) experienced partial failures prior to, or during, the periods of our monitoring. In both cases erosion gullies began incising the low permeability cap material, which consisted primarily of loess. A complete loss of cap material occurred at the FTS, but remediation measures (rip-rap lining of channels and drainage diversions) eventually halted accelerated erosion at the WLS. The tendency for gullies to develop in loess is enhanced by upward movement of acidic pore water from underlying refuse during dry periods. The acidic water prevents the establishment of the dense vegetation cover that is necessary for successful reclamation.

The refuse deposits at many AML sites in the ICMD contain a weathered-out zone at their surface. Although the surficial soil layer contains acidity in the form of soluble salts, the potential to generate further acidity (from pyrite oxidation) has been exhausted. A series of trial- plot experiments a the FTS demonstrated that a healthy and stable vegetation cover could be established directly on the weathered refuse surface at that site through application of agricultural lime and fertilizer. Additional benefits of direct revegetation are a major reduction of storm runoff (which also became alkaline rather than acidic) and surface erosion, and an increase in the moisture content of the soil (Olyphant and Harper, 1995). However, the enhancement of recharge that must eventually accompany such drastic changes in the water balance of the refuse surface can lead to an increase of acidic groundwater seepage from the refuse deposits.

A new reclamation technology that promises to improve the quality of water discharging from AML sites involves the use of fixated scrubber sludge (FSS) as part of the soil-capping process. FSS consists of a mixture of coal-combustion byproducts and quicklime that chemically combine to form an extremely durable material of low permeability. At the MWS, a layer of FSS was placed on top of the coarse refuse that occupies the central lowland. The FSS layer was, in turn, capped by a layer of overburden spoil that serves as the substrate for vegetation. Prior to reclamation, surface runoff and baseflow seepage from the pyritic coarse refuse were the primary sources of AMD leaving the site (Sjogren et al., 1997). The central lowland was densly dissected by erosion gullies and barren of vegetation. Excess rainfall dissolved the acid-generating salts that were abundant on the surface of the refuse, and rainfall that infiltrated flushed the acidic groundwater into the trunk gully. Following reclamation, rainfall-runoff ratios increased so that less infiltrating rain water was available for baseflow generation and acidic groundwater flushing. Also, the rain water that infiltrated did not lead to any increased recharge of the water table because gravity drainage was blocked by the FSS layer. As a result, the acidic outflow from the central refuse area of the site was greatly reduced.

To date, abandoned underground coal mines have been viewed almost exclusively as part of the AMD problem. However, in certain settings, abandoned underground mines may have the potential for being beneficially incorporated into treatment programs. For example, at FTS there is a flooded underground mine that contains net alkalinity, and, because of its great extent, has the potential for partially treating the highly acidic waters that are discharging from the bases of overlying coarse-refuse deposits. In such a setting, treatment might involve either (1) introduction of the contaminated surface waters into the underground workings and retrieval of the partially treated water from the spring that is known to be discharging from the mine, or (2) creation of an artesian outflow from the mine which will discharge into streams that contain base flow from the refuse deposits. Although the partially treated water will still have net acidity, it will have been neutralized to a point where it can be successfully treated by other passive methods (e.g., wetlands or PALD's).

Conclusions

Most of the acidic drainage from AMLs of the ICMD occurs as surface runoff that originates either from Hortonian overland flow during rainstorms or from the emergence of groundwater along the permeability boundaries that occur at the base of elevated refuse deposits. Conventional reclamation practices are directed at stabilizing the surface (through revegetation) and reduction of groundwater recharge, but sometimes these goals cannot be simultaneously achieved. Careful attention should be given to the role of the surface water balance in erosion control, vegetation establishment, and groundwater recharge at each AML site. In many cases it may be impossible to optimize all three factors through reclamation design, but a rational evaluation of the trade offs can benefit the project as a whole.

Currently, Passive Anoxic Limestone Drains (PALDs) and wetland treatment cells form a last line of defense for the surface waters discharging off AML sites. In some cases, the waters are so acidic that they overwhelm the capacity of the existing treatment facilities. In those cases other measures must be made to augment on-site treatment of AMD. As alluded to by Caruccio (1988), concentrated alkaline recharge ponds (CARPs) may provide a viable means of treating contaminated groundwater at its source, but much further research on the movement of groundwater through coal refuse is needed before effective application strategies can be designed. In the meantime, flooded underground workings could provide a vehicle for on site water treatment. By directing acidic and alkaline sources into underground mines prior to discharging them to PALDs and wetland systems, the water quality of even the worst acidic seepages could be improved to the point that they do not overwhelm the passive treatment methods at hand. The hydraulic requirements of such a treatment system are stringent, but the hydrogeologic setting at many AML sites of the ICMD is conducive to such an approach.

Literature Cited

Banaszak, K.J , 1980. Coal as Aquifers in the eastern United States. Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation

(Lexington, Kentucky, December 1-5, 1980), pp 235-241.

Brooks, G.A., Olyphant, G.A., and Harper, D., 1991. Application of electromagnetic techniques in survey of contaminated groundwater at an abandoned mine complex in southwestern Indiana, U.S.A. Environmental Geology, 18(1): 39-47.
https://doi.org/10.1007/BF01704576

Cable, L.W., Watkins, F.A. Jr., and Robinson, T.M., 1971. Hydrogeology of Principle Aquifers in Vigo and Clay Counties, Indiana. Bulletin No.34 of the Division of Water, State of Indiana Department of Natural Resources, 34 p.

Caruccio, F.T., 1988. Acid mine drainage: Hydrology's critical role and unifying theme. U.S. Bureau of Mines Information Circular, IC 9183, Volume 1: Mine Water and Mine Waste, pp. 228-231.

Fleming, A.H., Bonneau, P, Brown, S.E., Grove, G., Harper, D., Herring, W., Lewis, E.S., Moeller, A.J., Powell, R., Reehling, P., Rupp, R., and Steen, W.J., 1994. Atlas of Hydrogeologic Terrains and Settings of Indiana. Indiana Geological Survey, Open File Report 94-17, 192 p.

Harper, D., Olyphant, G.A., and Hartke, E.J., 1990. Unexpected hydrologic perturbation in an abandoned underground coal mine: Response to surface reclamation? Environmental Geology, 15(3):179-187.
https://doi.org/10.1007/bf01706409

Harper, D. and Olyphant, G.A., 1992. Requirements of a general operational model for the hydrologic response of flooded room-and-pillar mines to natural and mane made stresses. Proceedings of Fourth Conference on Ground Control for Midwestern U.S. Coal Mines, Mt. Vernon, Illinois, November 2-4, pp. 1-13.

Harper, D. and Olyphant, G.A., 1993. Statistical evaluation of hydrologic conditions in the vicinity of abandoned underground coal mines around Cannelburg, Indiana. Journal of Hydrology, 146: 49-71.
https://doi.org/10.1016/0022-1694(93)90269-F

Harper, D., Olyphant, G.A., and Sjogren, D.R., 1996. Ground- and surface-water interactions involving an abandoned underground coal mine in Pike County, Indiana. Proceedings 13th Annual Meeting American Society for Surface Mining and Reclamation, May 18-23, 1996, Knoxville, Tennessee, pp. 87-95.
https://doi.org/10.21000/JASMR96010087

Olyphant, G.A., Bayless, E.R., and Harper, D., 1991. Seasonal and weather-related controls on solute concentrations and acid drainage from a pyritic coal-refuse deposit in southwestern Indiana, U.S.A. Journal of Contaminant Hydrology, 7:219-236.
https://doi.org/10.1016/0169-7722(91)90029-Z

Olyphant, G.A. and Harper, D., 1995. Effects of revegetation on the hydrology, erosion and sediment yield of an abandoned deposit of coal-mine refuse. Geomorphology, 11: 261-272.
https://doi.org/10.1016/0169-555X(94)00070-8

Shaver, R.H., Ault, C.H., Burger, A.M., Carr, D.D., Droste, J.D., Eggert, D.L., Gray, H.H., Harper, D., Hasenmueller, N.R., Hassenmueller, W.A., Horowitz, A.S., Hutchinson, H.C., Keith, B.D., Keller, S.J., Patton, J.B., Rexroad, CB., and Wier, C.E., 1986. Compendium of Paleozoic Rock-Unit Stratigraphy in Indiana-A Revision. Indiana Department of Natural Resources, Geological Survey Bulletin, 59, 203 p.

Sjogren, D.R., Olyphant, G.A., and Harper, D., 1997. Effects of storm runoff on acid-base accounting of mine drainage. Proceedings 14th Annual National Meeting American Society for Surface Mining and Reclamation, May 10-15, 1997, Austin, Texas, pp. 525-530.
https://doi.org/10.21000/JASMR97010525

Wangsness, D.J., Miller, R.L., Bailey, Z.C., and Crawford, C.G., 1981. Hydrology of Area 32, Eastern Region, Interior Coal Province, Indiana. United States Geological Survey Water Resources Investigations, Open File Report 81-498, 76 p.