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Response of Hydrology to Underground Coal Mine Subsidence—Literature Assessment and Annotated Bibliography

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RESPONSE OF HYDROLOGY TO UNDERGROUND COAL MINE SUBSIDENCE—LITERATURE ASSESSMENT AND ANNOTATED BIBLIOGRAPHY

By Liane L. M. Kadnuck[1] and A. J. Fejes[2]

ABSTRACT

This U.S. Bureau of Mines publication is intended to provide mining industry representatives and regulatory authorities with a reference package dealing with studies on hydrology and underground mine subsidence. An annotated bibliography and a list of additional sources are given and represent references published prior to June 1993. Ninety-two references were identified and 72 obtained for assessment. Annotating the references included evaluating the study methodology and summarizing the basic results. The references are also compiled based on geographic location to aid the user in identifying articles of particular interest.

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INTRODUCTION

The purpose of this U.S. Bureau of Mines (USBM) report is to present a listing of available information pertaining to hydrologic response to underground mine subsidence. The basic intent is to assist mine operators, mining consultants, and regulatory agencies in identifying sources of information that will aid in quantifying the impacts of coal mine subsidence on hydrology. By using this reference list and annotated bibliography, mining industry personnel will be better able to evaluate potential hydrologic consequences of underground mining, deal with permit requirements, and develop their own subsidence and hydrology information sources.

As part of a continuing subsidence research program, the USBM expanded conventional subsidence studies to include the investigation of underground mining effects on overburden stratigraphy and associated effects on the hydrologic regime. As part of this effort, an intensive literature search was performed to locate available information. Ninety-two articles are identified, and 72 are annotated for this publication. The annotated articles listed in this report are on file at the USBM's Denver Research Center.

This report outlines available information and state-of-the-art research programs targeted at quantifying the impacts underground mine subsidence has on hydrology, including both surface and ground water resources. Articles identified represent hydrologic studies undertaken in the Illinois, Appalachian, Alabama, and Western coal regions, as well as some in Europe, Australia, and China. The literature provides information regarding hydrologic and geomechanical instrumentation plans, hydrologic modeling, research plans, and combined hydrologic and subsidence monitoring procedures.

Table 1 is a summary of the annotated articles categorized geographically by coal region. Appendix A is the annotated bibliography giving authors, publishing information, and a brief synopsis for each article. Appendix B provides a listing of additional sources identified dealing with subsidence and hydrology. All references listed provide as much information on dates and locations of each publication as was available at the time this report was prepared.

Table 1.—Geographic summary of annotated articles

Geographic area	*References pertaining to geographic location*[1]
Australia	30, 72
Europe	2, 3, 23, 24, 42, 46, 70, 71
United States:	
Alabama	50
Appalachia:	
General	22, 25, 47, 48, 49
Kentucky	59
Maryland	21
Northern	31, 32, 33, 34, 53, 65
Ohio	17, 36, 41
Pennsylvania	5, 7, 8, 26, 28, 35, 37, 38, 39, 40, 44, 52, 55, 56, 60, 61, 63, 67, 68
Virginia	54
West Virginia	1, 13, 14, 16, 18, 19, 20, 27, 29, 57, 64, 69
Illinois	4, 6, 9, 10, 11, 12, 15, 43, 51, 58, 66
Western	45, 62

[1]Numbers refer to annotated references in appendix A.

With the general public's increasing awareness and concern over the impacts of mining on water resources, regulators and mine operators must become more aware of some of the possible hydrologic effects of underground mining that can be expected. Because of limited amounts of available data and studies analyzing hydrologic impacts caused by mining, the USBM identified available information and created this document to provide a common source of information that would be a useful tool for mine operators, consultants, and regulators.

HYDROLOGIC MONITORING INFORMATION REQUIRED BY MINE OPERATORS

The Code of Federal Regulations (CFR), Title 30, Part 784, states that underground coal mine operators must include a determination of probable hydrologic consequences (PHC) with permit applications.[3] Included in the PHC is the determination of the consequences the proposed mining operation could have on the quality and quantity of surface and ground water. Additionally, mine operators are required under Part 817.41 to "...minimize disturbance to the hydrologic balance within the permit and adjacent areas, (and) to prevent material damage to the hydrologic balance outside the permit area." In order to provide the information needed for a PHC, and to prevent material damage, mine planners and operators need information on hydrologic response under various hydrologic, geologic, and mining conditions. Few studies have been undertaken in this area, but those currently available provide invaluable knowledge to other concerned

[3]U.S. Code of Federal Regulations. Title 30, Mineral Resources; Chapter VII, Office of Surface Mining Reclamation and Enforcement; Part 700 to end, Mineral Resources; July 1, 1993.

parties. Information contained in this report provides an accounting of specific studies conducted under varying conditions throughout the United States and abroad. Use of these information sources will aid mine operators and planners in complying with current Federal regulations.

AVAILABILITY OF INFORMATION

Few studies have been published that deal specifically with subsidence impacts on hydrology. Work published to date has been performed at various locations and by various institutions. Good sources of subsidence and hydrology information are universities with mining engineering departments, State and Federal agencies, and professional societies. The USBM, the U.S. Geological Survey, and the Office of Surface Mining are the Federal agencies most likely to deal with hydrologic impacts from subsidence. Additionally, many mining companies and consulting firms undertake their own studies and publish them in professional journals.

With the growing concern over availability and quality of water resources, research on the impact of mining to hydrologic resources is expected to increase in the future.

APPENDIX A.—ANNOTATED BIBLIOGRAPHY

1. Ahnell, G., and H. W. Rauch. The Effect of Underground Coal Mining on Water Wells in Monogalia County, West Virginia. Ground Water, v. 16, No. 5, 1978, p. 358.

Outlines results of a study in Monongalia County, WV, of water wells located in proximity to underground mines. Results indicated that wells went dry when less than 82 vertical m (250 ft) of overburden was present between the mine and the well bottom. (Abstract)

2. Aston, T. R. C., and R. N. Singh. A Reappraisal of Investigations Into Strata Permeability Changes Associated With Longwall Mining. Int. J. Mine Water, v. 2, No. 1, 1983, pp. 1-14.

Evaluates permeability changes ahead of the longwall face, at the face end, and in the ribside pillar. Several studies were reevaluated using a unified cumulative difference analysis to monitor in situ permeability changes within British Coal Measures strata. Data from this study suggest that the onset of permeability changes occurs well in advance of observed surface subsidence.

3. Aston, T. R. C., R. N. Singh, and B. N. Whittaker. The Effect of Test Cavity Geology on the In Situ Permeability of Coal Measures Strata Associated With Longwall Mining. Int. J. Mine Water, v. 2, No. 4, 1983, pp. 19-34.

Reviews the two methods most commonly used to measure in situ permeability changes, namely "pumping in" and "pumping out," along with the advantages and disadvantages of their use in British Coal Measures strata. Five investigation sites in Great Britain were evaluated for the effects of test cavity geology on in situ permeability. Permeability comparisons between several sites and several different types of geology are included. The majority of fluctuations in permeability values occurred in the ribside coal pillar.

4. Bauer, R., E. Gefell, and D. Barkley. Characterization of Coal Mine Subsidence and Impacts on Bedrock and Near Surface Hydrology Over a Shallow High-Extraction Retreat Mining Operation in Illinois. Paper in Proceedings of 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Univ. KY, Lexington, KY, Dec. 1987). Off. Eng. Serv., College Eng., Univ. KY, 1987, pp. 197-202.

Details the results of hydrologic and geotechnical response to high-extraction mining using bedrock and drift piezometers, time domain reflectometry (TDR), and multiple position borehole extensometer (MPBX) instruments in the subsurface. The instrumentation was installed in two clusters on opposite ends of the longwall panel. Sudden and complete dewatering of the bedrock wells and gradual decline of the drift wells were observed.

5. Booth, C. J. The Effect of Longwall Related Deformation on Ground-Water Flow Above an Abandoned Coal Mine. Geol. Soc. Am., Abstr. with Programs, v. 15, No. 6, 1983, p. 530.

Briefly discusses data gathered for use in building a numerical model based on the mining engineering concept of stress patterns, and further uses the theory to dictate head distribution above coal seams.

6. Booth, C. J. Hydrogeologic Impacts of Underground (Longwall) Mining in the Illinois Basin. Paper in Proceedings of the 3rd Subsidence Workshop Due to Underground Mining (WV Univ., Morgantown, WV, June 1992). WV Univ., 1992, pp. 222-227.

Presents results of a monitoring program that examined the hydrogeological impacts of active longwall mining at two sites in Illinois using piezometers installed at various depths in screened wells. Results showed that subsidence causes fracturing and dilation of joints and bedding planes, which increase the fracture permeabilities and storage coefficients. Local variations in geological conditions will dictate whether these effects will enhance an aquifer or not. In general, recovery and enhancement would perhaps be less likely in open-ended aquifers than in closed-ended aquifers.

7. Booth, C. J. The Hydrogeological Impact of Deep Longwall Mining, Appalachian Plateau, Pennsylvania. Paper in Proceedings of the National Water Well Association Conference on the Impact of Mining on Ground Water (Denver, CO, Aug. 1984). Natl. Water Well Assoc., 1984, pp. 360-379.

Discusses a hydrological investigation of a deep longwall mine in Cambria County, PA, conducted to provide a conceptual model and calibration data for the development of a numerical model of ground water flow associated with underground coal mining. An extremely detailed discussion of geology, precipitation, and mine drainage is included. Water levels in approximately 15 wells above and near the mine were monitored. The mine drainage data indicated a hydraulic connection between the mine and the shallower ground water system. At this site the response of ground water levels to undermining by longwall panels is considerable.

8. Booth, C. J. Strata Movements Concepts and the Hydrological Impact of Underground Coal Mining. Ground Water, v. 24, No. 4, July-Aug. 1986, pp. 507-515.

Presents an overview of the expected response of ground water to undermining based on monitoring results of shallow wells over a longwall panel. The results showed that there was little response in the wells and that strata permeability changes occurring in the tensile zone were of higher magnitude than those in the compressional zone. The results also indicated that based on the pressure arch theory of subsidence, dewatering of the seam and roof should be expected, but not higher in the stratigraphic column.

9. Booth, C. J., and J. A. Saric. The Effects of Abandoned Underground Mines on Ground Water, Saline County, Illinois. Paper in Proceedings of the 1987 National Symposium on Mining, Hydrology, Sedimentology and Reclamation (Univ. KY, Lexington, KY, Dec. 1987). Off. Eng. Serv., College Eng., Univ. KY, 1987, pp. 243-248.

Presents results of a study that focused on ground water response over an abandoned room-and-pillar mine in Illinois. Wells were installed in shallow drift and bedrock aquifers. The study showed that no effects were observed in the shallow drift wells, though the bedrock wells showed a decline in head over the mined area. It was also found that some leakage from the shallow to deep aquifers was possible through fracturing and subsidence mechanisms.

10. Booth, C. J., and E. D. Spande. Potentiometric and Aquifer Property Changes Above Subsiding Longwall Mine Panels, Illinois Basin Coalfield. Ground Water, v. 30, No. 3, May-June 1992, pp. 362-368.

Evaluates alterations in the hydrogeologic regime at a longwall coal mine in Illinois. Two aquifers, a shallow drift aquifer and a deeper bedrock aquifer, were monitored during undermining. Packer, pump, and slug tests were performed on wells in each aquifer and water-level fluctuations were continually measured. Results showed that water levels in the drift aquifer experienced little change due to mining, although wells in the bedrock showed gradual declines as mining progressed, then declined sharply as the face passed beneath. The sharp declines corresponded to a period of maximum tension in the ground. Aquifer testing indicated that hydraulic conductivity increased an order of magnitude in the bedrock aquifer after mining.

11. Booth, C. J., and E. D. Spande. Response of Groundwater Hydrology to Subsidence Above a Longwall Mine in Illinois. IL State Geol. Surv., IMSRP-1991-2, 1991, 7 pp. Also in Proceedings of the National Symposium on Mine Subsidence, Prediction and Control (Assoc. Eng. Geol. 33rd Annu. Meet., Pittsburgh, PA, Oct. 1990). Assoc. Eng. Geol., 1990, pp. 113-118.

Details an evaluation of wells in drift and bedrock aquifers above an Illinois coal mine for response to undermining. Drift wells did not show effects from mining, although the bedrock wells showed sharp declines as the face passed, with recovery observed later. Bedrock permeability increased in sand and shale units, and the hydraulic gradient changed in sandstone.

12. Booth, C. J., E. D. Spande, D. F. Brutcher, and B. B. Mehnert. Hydrogeological Response to Longwall Coal Mining in Illinois. Geol. Soc. Am., Abstr. with Programs, v. 21, No. 6, 1989, p. A230.

Gives a brief description of ground water monitoring over a longwall mine in Illinois. Preliminary results indicated that wells in a shallow drift aquifer show little response, but bedrock wells show greater water-level fluctuation and subsequent recovery. (Abstract)

13. Bruhn, R. W. Influence of Deep Mining on the Ground Water Regime at a Mine in North Appalachia. Paper in Proceedings of the 2nd Workshop on Surface Subsidence Due to Underground Mining (WV Univ., Morgantown, WV, June 1986). WV Univ., 1986, pp. 234-248.

Describes results of strata and ground water monitoring over a pillar retreat operation. In-mine and borehole instrumentation was used to monitor stratigraphic movements. Hydraulic testing was performed in the wells and showed a general increase in hydraulic conductivity after mining. Water chemistry showed an increase in total dissolved solids content after the area was undermined.

14. Bruhn, R. W. A Note on Ground Movements and Associated Ground Water Responses at an Underground Appalachian Mine. Soc. Min. Eng. AIME preprint 85-63, 1985, 9 pp.

Presents results of monitoring ground water over a pillar retreat mine in West Virginia during mining. Seven wells were installed in two clusters at the ends of a panel. Instrumentation included mine roof extensometers, roof bolts, stress meters, surface inclinometers, time domain reflectometers (TDR's), and ground survey monuments. Total extraction mining caused significant declines in water levels in deep-lying strata, but had little effect on water levels at shallower depths.

15. Cartwright, K., and C. S. Hunt. Hydrogeology of Underground Coal Mines in Illinois. Paper in Proceedings of International Symposium on Water in Mining and

Underground Works (SIAMOS) (Granada, Spain, Sept. 1978). Natl. Assoc. Min. Eng. in Spain, 1978, pp. 61-82.

Profiles hydrologic problems that may be encountered in underground coal mines in Illinois. It was found that shallow ground water was generally unaffected by mining, although deeper water sources could create mine stability problems. The hydrogeology of the mined area was stated to be of primary importance in mine planning, for example, location of channel sands.

16. Cifelli, R. C., and H. W. Rauch. Dewatering Effects From Selected Underground Coal Mines in North-Central West Virginia. Paper in Proceedings of the 2nd Workshop on Surface Subsidence Due to Underground Mining (WV Univ., Morgantown, WV, June 1986). WV Univ., 1986, pp. 249-254.

Describes the rapid dewatering of wells and piezometers as the longwall face passed underneath and until it was 6.6 m (20 ft) beyond the monitoring point. An upper water-bearing unit responded more slowly to undermining than a lower unit. An angle of influence for dewatering was calculated and found to range from 24° to 32° off the end of the panel. Streamflow decreased as the percentage of the watershed undermined increased. Streamflow was more responsive to undermining during baseflow conditions than during high flow.

17. Coe, C. J., and S. M. Stowe. Evaluating the Impact of Longwall Coal Mining on the Hydrologic Balance. Paper in Proceedings of the 1984 Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation (Univ. KY, Lexington, KY, Dec. 1984). Off. Eng. Serv., College Eng., Univ. KY, 1984, pp. 395-403. Also in Proceedings of the National Water Well Association Conference on the Impact of Mining on Ground Water (Denver, CO, Aug. 1984). Natl. Water Well Assoc., 1984, pp. 348-359.

Quantifies changes in the hydrologic balance resulting from longwall subsidence using a method of overlaying hydrographs over precipitation and time of mining. Results of the study show that subsidence effects on hydrology are related to the fracture pattern that develops above the longwall panel. Two case studies were presented and showed that effects were less where ground water was more localized, and impacts were reduced when shales and mudstones were present in the overburden.

18. Dixon, D. Y. The Impact of Three Longwall Coal Mines on Streamflow in the Northern Appalachian Coal Field. Geol. Soc. Am., Abstr. with Programs, v. 21, No. 6, 1989, p. A231.

Outlines results of undermining a stream, and states that streamflow showed fewer effects with increased overburden thickness. Streams located over mines with more overburden recovered more quickly. (Abstract)

19. Dixon, D. Y., and H. W. Rauch. The Impact of Three Longwall Panels on Streamflow in the Northern Appalachian Coal Field. Paper in Proceedings of the 9th International Conference on Ground Control in Mining (WV Univ., Morgantown, WV, June 1990). WV Univ., 1990, pp. 169-182.

Focuses on the effects of subsidence on streams over three longwall mines. Results showed that the streams went dry over the panel under baseflow conditions. A dewatering angle of influence was calculated to be 22° to 27° off the nearest panel edge. The degree of dewatering was less at mines with thicker overburden, and streamflow recovered within 1 year after undermining.

20. Dixon, D. Y., and H. W. Rauch. Study of Quantitative Impacts to Ground Water Associated With Longwall Coal Mining at Three Mines in the North West Virginia Area. Paper in Proceedings of the 7th International Conference on Ground Control in Mining (WV Univ., Morgantown, WV, Aug. 1988). WV Univ., 1988, pp. 321-335.

Reports on a study of ground water fluctuations due to underground mining at three mines in West Virginia. Results indicated that dewatering of wells was more severe at mines with shallow overburden. Well dewatering due to crack propagation started before the face passed at one site with shallow overburden. Dewatering occurred after subsidence had commenced at sites with thicker overburden. An angle of dewatering influence was calculated to be 24°. Wells located close to streams exhibited less impact and recovered more quickly.

21. Duigon, M. T., and M. J. Smigaj. First Report on the Hydrologic Effects of Underground Coal Mining in Southern Garrett County, Maryland. MD Geol. Surv. Rep. Invest. 41, 1985, 62 pp.

Discusses the monitoring of hydrologic resources in proximity to a new underground mine in Maryland. Ground water wells and streams near the mine were gauged for flow and quality both prior to and during mining. Results showed that the streams began losing water to subsidence-induced fractures. Local ground water gradients were expected to shift once subsidence occurred.

22. Emrich, G. H., and G. L. Merritt. Effects of Mine Drainage on Ground Water. Ground Water, v. 7, No. 3, 1969, pp. 27-32.

Gives a brief overview regarding the formation and effects of acid mine drainage on ground water. At this site, the general effect of underground mining on ground

water is a lowering of the local water table. Acid mine drainage seeps into the local ground water through cracks and fractures resulting from subsidence.

23. Fawcett, R. J., S. Hibberd, and R. N. Singh. Analytic Calculations of Hydraulic Conductivities Above Longwall Coal Faces. Int. J. Mine Water, v. 5, No. 3, 1986, pp. 45-60.

Discusses an investigation into using an analytical method to predict hydraulic conductivities above longwall faces using calculated stresses and field data. Boreholes were instrumented to measure hydraulic conductivity changes from subsidence-induced fracturing and caving. Results indicated that rock failure leading to increases in hydraulic conductivity is due to high compressive stresses in advance of the face followed by fracture dilation from tensile stresses behind the face.

24. Garrity, P. Water Percolation Into Fully Caved Longwall Faces. Paper in Proceedings of Symposium on Strata Mechanics, Developments in Geotechnical Engineering (Univ. Newcastle-Upon-Tyne, Newcastle, England). Univ. Newcastle-Upon-Tyne, v. 32, 1982, pp. 25-29.

Investigates the mechanisms of mine water inflow in mines located off the northeast coast of England. Areas identified to be the primary causes for inflows included areas of strata discontinuity, where overburden was less than 100 m (305 ft) thick, where tensile strains exceeded 0.6%, and where sandstone formed less than 35% of the overburden.

25. Girrens, S. P., C. A. Anderson, J. G. Bennett, and M. Kramer. Numerical Prediction of Subsidence With Coupled Geomechanical-Hydrological Modeling. Paper in Proceedings of the Workshop on Surface Subsidence Due to Underground Mining (WV Univ., Morgantown, WV, Mar. 1982). WV Univ., 1982, pp. 63-72.

Discusses use of a subsidence model coupled with a three-dimensional finite-element code for ground water flow to study the relationship between changes in rock strain and permeability of the formation. The ADINAT code was used for the simulations. It was concluded that much more information on hydraulic properties is needed to adequately perform this type of research.

26. Green, J. B., M. A. Trevits, and J. S. Walker. A Case Study of the Effects of Subsidence on a Local Groundwater System. Paper in the Proceedings of the 1986 National Symposium on Mining, Sedimentology and Reclamation (Univ. KY, Lexington, KY, Dec. 1986). Off. Eng. Serv., College Eng., Univ. KY, 1986, pp. 223-231.

Studies the effects of mining on water-level fluctuations and head loss in 10 wells over three longwall panels at mines in Pennsylvania. Results indicated that the greatest changes occurred over the panel centerline, and decreased at the rib and over chain pillars, similar to the subsidence trough. Thus, the water-level fluctuations appear to be a function of panel geometry and position of the face, as the largest changes occurred as the face passed underneath and continued until the face was past the well a distance corresponding to the overburden thickness. In general, wells did not exhibit effects during extraction of an adjacent panel unless the well was located within the angle of draw for the panel.

27. Hasenfus, G. J., K. L. Johnson, and D. W. H. Su. A Hydrogeomechanical Study of Overburden Aquifer Response to Longwall Mining. Paper in Proceedings of the 7th International Conference on Ground Control in Mining (WV Univ., Morgantown, WV, Aug. 1988). WV Univ., 1988, pp. 149-162.

Discusses use of a system of monitor wells, time domain reflectometry (TDR) instrumentation, coreholes, and seismic surveys to correlate aquifer response with strata response to undermining. Results showed that the wells went dry as the face passed underneath or when slightly outby, and most showed subsequent recovery. Changes in water levels coincided with identified zones of bed separation. A four-zone conceptual model was derived to delineate areas of gob, fracture, composite beam, and surface.

28. Hill, J. G., and D. R. Price. The Impact of Deep Mining on an Overlying Aquifer in Western Pennsylvania. Ground Water Monit. Rev., v. 3, No. 1, Winter 1983, pp. 134-143.

Details a study in which eight monitoring wells completed in shallow and deep water-bearing zones were used over a single panel. Observations showed that water levels declined in the deep wells as the face passed underneath and progressed up to 65.6 m (200 ft) beyond. The response to undermining was greater in the deeper wells and the impacts appeared to be localized. Correlation with subsidence measurements indicated that the most significant hydrologic response occurs during maximum subsidence.

29. Hobba, W. A. Effects of Underground Mining and Mine Collapse on the Hydrology of Selected Basins in West Virginia. WV Geol. and Econ. Surv. Rep. Invest. 33, 1981, 77 pp.

Presents an overview of mine subsidence effects on the surface and ground waters in three basins in West Virginia. Surface water budget and quality were examined along with ground water gradient change and aquifer dewatering. Also includes some discussion on remediation techniques.

30. Holla, L., and M. Buizen. The Ground Movement, Strata Fracturing and Changes in Permeability Due to Deep Longwall Mining. Int. J. Rock Mech., Min. Sci. and Geomech. Abstr., v. 28, No. 2/3, 1991, pp. 207-217.

Gives overview of multiwire borehole extensometer measurements in overburden strata. Specific observations on bulk permeability changes were inconclusive, and many reasons were cited for lack of data confidence.

31. Johnson, K. L. Effects of Longwall Coal Mining on the Hydrology of Two Appalachian Stream Valleys. Paper in Proceedings of the National Water Well Association Fifth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Monitoring (Las Vegas, NV, May 1991). Natl. Water Well Assoc., 1991, pp. 1111-1125.

Presents studies of water quality, aquifer transmissivity, and water levels at two longwall mining sites in the Northern Appalachian coalfields where the depth of mining is 164 to 197 m (500 to 600 ft). Four monitoring wells were drilled prior to mining at each site. A premining and postmining comparison of significant factors was made. Localized surface flow was also evaluated by examining the streamflow above each site. This study showed that longwall mining beneath the two stream valleys did not lessen the quantity or quality of shallow ground water in the valleys, nor did it affect streamflow. At this specific site, shallow aquifers yielded more water to wells after mining.

32. Johnson, K. L. Influence of Topography on the Effects of Longwall Mining on Shallow Aquifers in the Appalachian Coal Field. Paper in Proceedings of the 3rd Subsidence Workshop Due to Underground Mining (WV Univ., Morgantown, WV, June 1992). WV Univ., 1992, pp. 197-203.

Discusses the response of hilltop and stream valley aquifers in Appalachia as longwall mining occurred beneath them. Wells in the hilltop aquifers showed decreases in water levels as mining progressed, and showed partial to complete recovery. Wells in the valley aquifer showed increases in transmissivity and well yield. Wells located outside the mine limits did not sustain any change.

33. Johnson, K. L., and A. S. C. Owili-Eger. Hydrogeologic Environment of Full Extraction Mining. Longwall USA Conference Papers (Pittsburgh, PA, June 1987). Ind. Presentations West, Inc., 1987, pp. 147-158.

Examines the results of four studies of the effects of longwall mining on overburden permeability at two mines in England and two in northern Appalachia. Results indicated that shallow wells on hilltops or hillsides may experience depressed water levels but usually recover in 2 to 3 months, and yields may increase because of increased permeability. At this site, the fully developed caving zone was believed to be less than 35 times the extracted seam height.

34. Leavitt, B. R., and J. F. Gibbens. Effects of Longwall Coal Mining on Rural Water Supplies and Stress Relief Fracture Flow Systems. Paper in Proceedings of the 3rd Subsidence Workshop Due to Underground Mining (WV Univ., Morgantown, WV, June 1992). WV Univ., 1992, pp. 228-236.

Assesses the response of 174 domestic water supplies to longwall mining in the Pittsburgh Coal Seam. The response of each well was categorized by the need for intervention to reestablish a suitable water supply. The response of the wells was strongly correlated with the topographic setting, with valley wells showing the least effect and hilltop wells showing the greatest effect. Results also indicate that water supplies remained unaffected or were reestablished at 149 of 150 sites.

35. Matetic, R. J., and M. A. Trevits. A Case Study of Longwall Mining Effects on Water Wells. Soc. Min. Eng. AIME preprint 90-141, 1990, 7 pp.

Describes the monitoring of eight ground water monitor wells installed over a longwall panel. The water levels were monitored as the panel was moved. Results showed that changes in the water levels start when the face is less than one overburden thickness from the well. Water was lost from the wells, but recovery had started before subsidence was complete. Wells located outside the panel perimeter were not affected.

36. Matetic, R. J., and M. A. Trevits. Does Longwall Mining Have a Detrimental Effect on Shallow Ground Water Sources? Paper in Proceedings of the National Water Well Association Fifth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods (Las Vegas, NV, May 1991). Natl. Water Well Assoc., 1991, pp. 1087-1100.

Describes the results of monitoring hydrologic response in seven wells located above two contiguous longwall panels in Vinton County, OH. Water-level fluctuations, surface subsidence, and hydrologic properties were measured as mining progressed through the study area. Overburden depth varied from 65.6 to 115 m (200 to 350 ft), and the seam had a thickness of 1.5 m (4.5 ft). The seven wells were located on a transverse profile of the longwall panels. The data suggested that longwall mining in this area did not have a detrimental effect on the shallow ground water system. There was an overall increase in specific capacity, and the transmissivity of the wells was generally unchanged.

37. Matetic, R. J., and M. A. Trevits. Hydrologic Variations Due to Longwall Mining. Paper in Proceedings of the 3rd Subsidence Workshop Due to Underground Mining (WV Univ., Morgantown, WV, June 1992). WV Univ., 1992, pp. 204-213.

Discusses a study of water-level fluctuations and changes in hydraulic conductivity and water chemistry at a mine site in Pennsylvania. Two longwall panels were instrumented with three piezometers and two pumping wells. The piezometers were arranged subparallel to the panel centerline. Subsidence monuments were installed to monitor ground movement. The study showed that water levels began to decline when mining started and dramatically decreased when the face passed beneath them. Recovery began when the face was located at a distance corresponding to 40% of the overburden thickness past the well. Hydraulic conductivity was observed to increase fourfold in some wells. Minor changes in water chemistry were observed, but they did not reduce the water quality.

38. Matetic, R. J., and M. A. Trevits. The Impact of High-Extraction Mining on Near-Surface Water. Paper in Proceedings of the National Water Well Association 4th National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods (Las Vegas, NV, May 1990). Natl. Water Well Assoc., 1990, pp. 1205-1217.

Describes monitoring results of eight wells installed over two adjacent longwall panels in shallow saturated zones. Water-level monitoring and hydraulic testing both before and after mining were performed. The wells showed a sharp decrease in fluid level as the face approached, but began to recover before subsidence was complete. Wells located over the active panel showed the most effects from the mining, and wells located outside the panel boundaries showed little or no response.

39. Matetic, R. J., and M. A. Trevits. Longwall Mining and Its Effect on Ground Water Quantity and Quality at a Mine Site in the Northern Appalachian Coal Field. Paper in the Proceedings of the FOCUS Conference on Eastern Regional Ground Water Issues (Newton, MA, Oct. 1992). Natl. Water Well Assoc., 1992, pp. 573-587.

Describes the results of monitoring hydrologic response at a site in Cambria County, PA, through the use of nested piezometer and producing wells. In addition, samples from two wells were periodically collected and analyzed to determine the effects of mining on the local ground water chemistry. Changes in ground water chemistry that occurred did not affect the potability of the water. A decrease in water levels after the longwall face passed beneath the wells was noted, and water-level recovery began when the longwall face had progressed approximately 40% of the overburden thickness beyond a well.

40. Matetic, R. J., and M. A. Trevits. Longwall Mining Impact on Near-Surface Water. Paper in Proceedings of the National Symposium on Mine Subsidence Prediction and Control (Assoc. Eng. Geol. 33rd Annu. Meet., Pittsburgh, PA, Oct. 1990). Assoc. Eng. Geol., 1990, pp. 131-139.

Describes monitoring results from eight wells installed over two longwall panels. Conclusions indicated that changes in water levels occurred when the face was less than one overburden thickness from the well and that loss of water occurred before the subsidence process was complete.

41. Matetic, R. J., M. A. Trevits, and T. Swinehart. A Case Study of Longwall Mining and Near-Surface Hydrological Response. Paper in Proceedings of 1991 American Mining Congress Coal Convention (Pittsburgh, PA, June 1991). Am. Min. Congr., 1991, pp. 1-12.

Discusses a study of the response of seven shallow ground water wells to undermining. Results showed that the timing of fluid level fluctuations coincided with passage of the mine face. There was a general increase in the wells' specific capacities and no change in transmissivities.

42. Mather, J. D., D. A. Gray, and D. G. Jenkins. The Use of Tracers To Investigate the Relationship Between Mining Subsidence and Groundwater Occurrence at Aberfan, South Wales. J. Hydrol., v. 9, 1969, pp. 136-154.

Discusses a study in which sodium chloride and sodium fluorescein tracers were used to map ground water movement in the subsurface under a mine. The tracers were used to test the theory that areas of tensional strain create conduits for preferential flow, and areas of compressional strain reduce conductivity and thus create ground water mounds. The tracers were used to follow the ground water flow path and showed that a fissure corridor was present in the area of tensional strain and that the strain regions represented hydraulic discontinuities.

43. Mehnert, B. B., D. J. Van Roosendaal, R. A. Bauer, and D. F. Brutcher. Effects of Longwall Coal Mine Subsidence on Overburden Fracturing and Hydrology in Illinois. Paper in Proceedings of the National Symposium on Mine Subsidence, Prediction and Control (Assoc. Eng. Geol. 33rd Annu. Meet., Pittsburgh, PA, Oct. 1990). Assoc. Eng. Geol., 1990, pp. 105-112.

Describes an investigation in which wells, piezometers, time domain reflectometry (TDR), and geophysical surveys were used to map changes in subsurface hydrology due to underground mining. Wells were installed in the drift, overburden sandstone, and shale. The drift wells showed little effect from the undermining. The bedrock wells showed head loss as the face approached, piezometric lows at tensile events, and then partially recovered during

compression. A cone of depression formed and followed the location of the dynamic tensile event. Hydraulic conductivity in the bedrock increased two to three orders of magnitude. Rock quality designation (RQD) and shear wave velocity decreased after mining.

44. Moebs, N. N., and T. M. Barton. Short-Term Effects of Longwall Mining on Shallow Water Sources. Paper in Mine Subsidence Control. BuMines IC 9042, 1986, pp. 13-24.

Discusses monitoring results of five ground water wells located over a longwall panel. Results showed that wells within the boundary of the longwall showed the greatest effects, with the largest impact at the center of the panel. Wells outside the angle of draw were unaffected. Springs and streams in the area were not affected by the mining.

45. Moore, R. C., and M. A. Nawrocki. Effects of Subsidence From Thick Seam Coal Mining on Hydrology (contract J0295012, Hittman Assoc., Inc.). BuMines OFR 93-80, 1980, 245 pp.; NTIS PB 80-219280.

Presents results of a literature search to identify mines in the western United States mining thick seam coal. Site reconnaissance of 10 mines in different coalfields was conducted, and subsidence calculations and estimations of hydrologic alterations were made. Synopses for each mine site studied are included in the text. The authors acknowledge the lack of hard data available and recommend future studies of subsidence and hydrology be undertaken.

46. Neate, C. J., and B. N. Whittaker. Influence of Proximity of Longwall Mining on Strata Permeability and Ground Water. Paper in Proceedings of the 20th U.S. Symposium on Rock Mechanics (Austin, TX, June 1979). Univ. TX, Austin, TX, 1979, pp. 217-220.

Details results of monitoring changes in strata permeability in two boreholes located at the end of a longwall panel in a mine located under the seabed. It was observed that the peak change in permeability occurred in front of the center part of the face, and the largest changes were related to the ground strain configuration.

47. Ouyang, Z., and D. Elsworth. Evaluation of Groundwater Flow Into Mined Panels. Int. J. Rock Mech., Min. Sci. and Geomech. Abstr., v. 30, No. 2, 1993, pp. 71-79.

Discusses results of a study in which a finite-element model was used to simulate strata deformation over a longwall panel and the associated effects on the hydrogeologic regime. Rock mass properties including hydraulic conductivity, fracture spacing, and stiffness were used to simulate ground water inflow to a longwall panel after the subsidence process began.

48. Owili-Eger, A. S. C. Geohydrologic and Hydrogeomechanical Impacts of Longwall Coal Mining on Local Aquifers. Soc. Min. Eng. AIME preprint 83-376, 1983, 16 pp.

Describes a study in which four wells were installed over a longwall panel, including one over a barrier pillar. It was observed that aquifers 100 m (305 ft) above the mining horizon suffered water losses, but generally recovered. The overall piezometric levels were lowered, although aquifer yields were not affected. The well located over the barrier pillar did not sustain any change.

49. Owili-Eger, A. S. C. Geohydrologic and Hydrogeomechanical Impacts of Longwall Coal Mining on Local Aquifers. Trans. Am. Soc. Min., Met. and Pet. Eng., v. 276, 1984, pp. 1909-1914.

Details a study consisting of four wells located over one longwall panel, with one well placed over a barrier pillar. Monitoring of the piezometric levels and aquifer characteristics prior to and after mining indicated a sixfold increase in transmissivity in one well and that aquifer yields were not adversely affected. It was observed that water levels had responded at the time of mining, but had not recovered to premining levels after 2 years.

50. Park, D. W. Effect of Mine Subsidence on Ground Water Hydrology. Soc. Min. Eng. AIME preprint 87-98, 1987, 8 pp.

Gives a brief overview of the effects of underground mining on ground water in the Warrior Coalfield of Alabama. Four mines are profiled, and the information indicates that mining does not cause permanent damage to ground water and that less severe effects are noticed with thicker overburden.

51. Pauvlik, C. M., and S. P. Esling. The Effects of Longwall Mining Subsidence on the Groundwater Conditions of a Shallow, Unconfined Aquitard in Southern Illinois. Paper in Proceedings of the 1987 National Symposium on Mining, Hydrology, Sedimentology and Reclamation (Univ. KY, Lexington, KY, Dec. 1987). Off. Eng. Serv., College Eng., Univ. KY, 1987, pp. 189-195.

Describes a study performed using three wells completed into an unconfined aquitard 164 m (500 ft) over a coal seam. Two wells were placed over a longwall panel and the third over a chain pillar. Results showed that the ground water table dropped one-third the amount of ground subsidence; flow direction and gradient changed. Flow direction returned to premining conditions, but the gradient increased by a factor of 1.5.

52. Pennington, D., J. G. Hill, G. J. Burgdorf, and D. R. Price. Effects of Coal Mine Subsidence on Ground Water Aquifers in Northern Appalachia. BuMines OFR 142-84, 1984, 129 pp.; NTIS PB 84-236710.

Describes a study in which ground water well, pump tests, downhole geophysics, and surface water monitoring devices were utilized to quantify response to mining of a longwall panel in western Pennsylvania. During the study, ground water in wells was observed to decline sharply as the mine front approached, and levels continued to decrease until maximum subsidence had occurred. Deep wells were affected more dramatically than shallow wells. Aquifer dewatering caused significant decreases in aquifer transmissivity. Wells located over the panel center showed greater impacts than did wells located over the panel edge.

53. Rauch, H. W. A Summary of the Ground Water Impacts of Underground Mine Subsidence in the North-Central Appalachians. Paper in Proceedings of Special Institute on Coal Mine Subsidence (WV Univ. Law Center, Morgantown, WV, Dec. 1989). East. Miner. Law Found., 1989, pp. 2.01-2.31.

Summarizes observed effects of underground coal mining on water resources in Eastern coalfields. The author discusses both surface and ground water response to room-and-pillar and longwall mining.

54. Scales, A. S. A Model for Relating Coal Mining Impacts to Appalachian Plateau Fracture-Flow Ground Water Systems. Prof. Geol., Spec. Rep., Mar. 1992, p. 15.

Describes a conceptual hydrologic model built for the Appalachian region and includes a brief profile of potential mining-related impacts.

55. Schmidt, R. D. Factors Affecting Residential Water Well Yield in the Vicinity of Room and Pillar Mines. Paper in Proceedings of the 3rd Subsidence Workshop Due to Underground Mining (WV Univ., Morgantown, WV, June 1992). WV Univ., 1992, pp. 244-252.

Discusses monitoring results of 12 wells above a room-and-pillar mine in Indiana County, PA. Temperature, caliper logs, and nested piezometer data were evaluated for specific wells. Fracture intercepts and geology of the site are discussed briefly. A comparison between seven wells that were monitored in the valley and five wells that were monitored along a hillside above the mine was compiled. The data from this study support a conceptual model of hillside and valley conditions in which underground mining results in extension of vertical fractures, increased hydraulic conductivity, and increased ground water throughput in shallow strata.

56. Schmidt, R. D., and W. F. Ebaugh. Some Considerations Regarding the Steady-State Response of Shallow Aquifers to Underground Mining. Paper in Proceedings of the 1985 Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation (Univ. KY, Lexington, KY, Dec. 1985). Off. Eng. Serv., College Eng., Univ. KY, 1985, pp. 1-7.

Assesses the changes in domestic well supply due to presence of a room-and-pillar mine. Fracture trace analysis was used to plan wells and piezometer nests that served to monitor aquifer response. The study concluded that effects on domestic wells could be reduced by drilling shallower wells with larger diameters.

57. Schultz, R. A. Ground-Water Hydrology of Marshall County, West Virginia, With Emphasis on the Effects of Longwall Coal Mining. U.S. Geol. Surv. WRI 88-4006, 1988, 139 pp.

Details a study of wells and springs near longwall mines at three sites in West Virginia for response to mining. Hydraulic changes induced by longwall mining at these sites included increases in aquifer transmissivity, declines in ground water levels, increases in water-level fluctuations, and decreases in spring flow.

58. Sells, D. E., R. G. Darmody, and F. W. Simmons. The Effects of Coal Mine Subsidence on Soil Macroporosity and Water Flow. IL Mine Subsidence Res. Program preprint 1992-3, 1992, pp. 137-145.

Focuses on characterizing subsidence-induced fracturing in soil from longwall mining in Illinois, giving rise to preferential water flow paths. It was observed that fracturing was greatest at the panel edge and least at the panel center. Preferential flow paths were similarly located at the edge of the panel where fractures remained open, whereas fractures at the panel center closed because of compression.

59. Sloan, P., and R. C. Warner. A Case Study of Groundwater Impact Caused by Underground Mining. Paper in Proceedings of the 1984 Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation (Univ. KY, Lexington, KY, Dec. 1984). Off. Eng. Serv., College Eng., Univ. KY, 1984, pp. 113-120.

Presents a case study of underground mining impacts on ground water in Kentucky. Domestic wells were inventoried and monitored. The authors make a case for the inadequacy of current hydrologic prediction models based on misuse of fracture permeability in hydraulic conductivity calculations. An outline of basic data needs is also given.

60. Stoner, J. D. Probable Hydrologic Effects of Subsurface Mining. Ground Water Monit. Rev., v. 3, No. 1, Winter 1983, pp. 128-137.

Describes a study focused on the Greene County, PA, coal region. An assumption of the study was that the magnitude of water-level decline was inversely proportional to the thickness of overburden between the seam and the bottom of a given well. Rapid declines of water levels over a longwall panel were observed with recovery to near premining levels. A two-dimensional finite-difference program was implemented and used to simulate changes in hydrology. These conclusions were found: Water levels in wells located in undermined valleys will decline; springs and shallow wells will not be affected; streamflow may be reduced because of vertical fracturing, and fracturing could increase mine inflows.

61. Stump, D. E., Jr. Underground Coal Mine Subsidence Impacts on Surface Water. Abstract in Proceedings of the 3rd Subsidence Workshop Due to Underground Mining (WV Univ., Morgantown, WV, June 1992). WV Univ., 1992, p. 253.

Provides a brief overview of probable impacts subsidence may have on surface water. Anticipated impacts include loss of water to the ground water system, creation of flooded subsidence troughs, relocation of springs, and alteration of surface drainage patterns. (Abstract)

62. Thurman, A. G., V. Straskraba, and R. D. Ellison. Development of a Ground Water Hazard Map for an Underground Coal Mine. Paper in Proceedings of International Symposium on Water in Mining and Underground Works (SIAMOS) (Granada, Spain, Sept. 1978). Natl. Assoc. Min. Eng. in Spain, 1978, pp. 273-291.

Discusses how field and laboratory data were utilized to develop a ground water hazard map over three potentially minable coal seams near Hanna, WY. A detailed investigation into the geology, coal reserves, aquifers in the area, and possible water inflow into the mine is included. All aquifers in the area were of the artesian type. Water inflow was estimated using the ground water hazard map. Hydraulic conductivity of all major aquifers in the area was established by utilizing 25 boreholes that were drilled over the planned mine site.

63. Tieman, G. E., and H. W. Rauch. Study of Dewatering Effects at an Underground Longwall Mine Site in the Pittsburgh Seam of the Northern Appalachian Coal Field. Paper in Proceedings of Eastern Coal Mine Geomechanics. BuMines IC 9137, 1987, pp. 72-89.

Describes a study that was performed at a mine that contained both room-and-pillar and longwall mining methods. An inventory of domestic wells and culinary (domestic use) springs was made. Results showed that dewatering was most extensive at the panel centerline and limited to strata located 215 to 230 m (655 to 700 ft) above the seam. A ratio of panel width to overburden thickness in relation to dewatering was found to be 0.75 to 1.0. The areas of room-and-pillar mining did not affect water resources. Ground water lost from formation did not migrate to the mine but rather emerged as new springs or migrated to base level flow. Most water wells lost water and did not recover, although streams that lost flow recovered to premining state.

64. Tieman, G. E., H. W. Rauch, and L. S. Carver. Study of Dewatering Effects at a Longwall Mine in Northern West Virginia. Paper in Proceedings of the 3rd Subsidence Workshop Due to Underground Mining (WV Univ., Morgantown, WV, June 1992). WV Univ., 1992, pp. 214-221.

Highlights the results of a study concerning past hydrologic impacts of longwall coal mining at a mine located in northern West Virginia. These impacts include ground water and streamflow effects. The mined coal seam is 230 to 427 m (700 to 1,300 ft) deep with a surface topographic relief of 98 to 164 m (300 to 500 ft). About 70 well and spring water supplies were studied during this project. Five springs and one dug well were reportedly dewatered by mining. Three of these six supplies showed partial recovery within 1 year. Most apparent hydrologic dewatering impacts appear to be temporary, and the most vulnerable areas for these impacts are hillsides.

65. Trevits, M. A., and R. J. Matetic. A Study of the Relationship Between Saturated Zone Response and Longwall Mining-Induced Ground Strain. Paper in Proceedings of the National Water Well Association Fifth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods (Las Vegas, NV, May 1991). Natl. Water Well Assoc., 1991, pp. 1101-1109.

Describes monitoring of surface subsidence and water-level fluctuations at three coal mines in Northern Appalachia. Water-level variations and ground strain were compared to one another and showed that water levels in wells began to decline at the same time the ground went into tension. Dramatic decreases in water levels were observed when the longwall face was directly beneath the wells, at the point of maximum tension. Water levels were then observed to recover at the time of maximum compressive strain.

66. Van Roosendaal, D. J., P. J. Carpenter, B. B. Mehnert, M. A. Johnston, and J. T. Kelleher. Longwall Mine Subsidence of Farmland in Southern Illinois: Near-Surface Fracturing and Associated Hydrogeological Effects. IL Mine Subsidence Res. Program preprint 1992-4, 1992, pp. 147-158.

Describes results of monitoring a saturated zone delineated 4.9 m (15 ft) below the surface at an active longwall mine in southern Illinois using seismic refraction, electrical resistivity, and vertical and horizontal displacement measurement techniques. Displacement measurements suggested a linear strain profile with depth of surface fracture penetration of 8.9 to 10.2 m (27 to 31 ft).

There were no widespread subsidence-induced changes to the level or character of this zone.

67. Walker, J. S. Case Study of the Effects of Longwall Mining Induced Subsidence on Shallow Ground Water Sources in the Northern Appalachian Coalfield. BuMines RI 9198, 1988, 17 pp.

Details a study that involved monitoring water-level fluctuations in 10 wells located over four longwall panels and simultaneous monitoring of strain caused by subsidence. Results indicated that water-level fluctuations started when the face was 131 to 197 m (400 to 600 ft) from the well and continued until the face was a similar distance past. A sharp decline in fluid levels was observed when the face was one-third the overburden thickness from the well. The greatest fluctuations were observed in wells over the panel centerline, and fluctuations decreased in wells toward the chain pillars. The largest water-level changes occurred when the strata surrounding the wells were in tension, and only wells located within the angle of draw of a panel were affected.

68. Walker, J. S., J. B. Green, and M. A. Trevits. A Case Study of Water Level Fluctuations Over a Series of Longwall Panels in the Northern Appalachian Coal Region. Paper in Proceedings of the 2nd Workshop on Surface Subsidence Due to Underground Mining (WV Univ., Morgantown, WV, June 1986). WV Univ., 1986, pp. 264-269.

Focuses on monitoring water-level fluctuations in five wells located over three longwall panels. There was a general lowering of the piezometric surface due to undermining. The wells located within the draw angle for the panel showed the greatest response. The wells showed response when the face distance was equal to the overburden thickness. Water levels dropped sharply as the face passed and then recovered to premining levels.

69. Werner, E., and J. C. Hempel. Effects of Coal Mine Subsidence on Shallow Ridge-Top Aquifers in Northern West Virginia. Paper in Proceedings of the 3rd Subsidence Workshop Due to Underground Mining (WV Univ., Morgantown, WV, June 1992). WV Univ., 1992, pp. 237-243.

Discusses how the effects on aquifers by coal-mine-induced subsidence vary significantly depending on the position of the aquifer with respect to hydrologic base level. Water well response to subsidence is categorized into four general scenarios and each scenario is described by a hydrograph. Results of various studies indicate that effects on aquifers above base level, generally called perched aquifers, are substantially different from the effects on the base level aquifers, and different principles apply.

70. Whittaker, B. N., R. N. Singh, and C. J. Neate. Effect of Longwall Mining on Ground Permeability and Subsurface Drainage. Paper in Proceedings of the 1st International Mine Drainage Symposium (Denver, CO, May 1979). Miller Freeman Publ., 1979, pp. 161-183.

Discusses use of borehole instrumentation to test changes in strata permeability as undermining occurred. Permeability increased as the area was undermined then decreased as fissures and cracks closed. Change in permeability was detected up to 40 m (122 ft) above the mining horizon. Effects were greater at shallower mines.

71. Whitworth, K. R. Induced Changes in Permeability of Coal Measure Strata as an Indicator of the Mechanics of Rock Deformation Above a Longwall Coal Face. Paper in Proceedings of Symposium on Strata Mechanics, Developments in Geotechnical Engineering (Univ. Newcastle-Upon-Tyne, Newcastle, England, 1982). Univ. Newcastle-Upon-Tyne, v. 32, 1982, pp. 18-24.

Focuses on response of strata overlying the seam and at the margin of a longwall. The main finding was that tensile zones that form at the longwall margin give rise to areas of bed separation where water collects, thus increasing permeability. The degree of bed separation is lithology dependent, as each layer of strata behaves like a beam.

72. Williamson, W. H. Hydrogeological Aspects of Coal Mining Under Stored Waters Near Sydney, Australia. Paper in Proceedings of International Symposium on Water in Mining and Underground Works (SIAMOS) (Granada, Spain, Sept. 1978). Natl. Assoc. Min. Eng. in Spain, 1978, pp. 309-328.

Provides a detailed description of the geology and the hydrological conditions that were analyzed during a public inquiry. The possibility of mining underneath five water storage dams that are used to supply water to Wollongong and part of Sydney, Australia, was evaluated. Permeability was evaluated over current workings in the area with two programs of borehole drilling and testing. Natural ground water and entry of water into existing mines are discussed. It was deemed possible to mine under the stored waters without creating adverse effects to the storage areas.

APPENDIX B.—ADDITIONAL SOURCES

Aston, T. R. C. Hydrogeological Aspects of Rock Mechanics and Mining Subsidence Around Longwall Extractions. Ph.D. Thesis, Univ. Nottingham, Nottingham, England, 1982.

Barla, G. B., and S. Boshov. Investigations of Differential Strata Movements and Water Table Fluctuations During Longwall Operations at the Somerset Mine No. 60. 1978, 49 pp.; NTIS FE-9041-1.

Booth, C. J. Changes in Hydraulic Properties of Strata Over Active Longwall Mining, Illinois, USA. Paper in Proceedings of 4th International Mine Water Congress (Portschach, Austria/Lubljana, Slovenia, Sept. 1991). Int. Mine Water Congr., 1991, pp. 163-174.

Booth, C. J. A Numerical Model of Groundwater Flow Associated With an Underground Coal Mine in the Appalachian Plateau. Unpublished Ph.D. Dissertation, Dep. Geosciences, PA State Univ., University Park, PA, 1984, 458 pp.

Booth, C. J., E. D. Spande, D. F. Brutcher, and B. B. Mehnert. Effects of Longwall-Induced Subsidence on Groundwater Hydrology in Southern Illinois. Pres. at An Industry Under Siege: Some Facts About Subsidence, Conference of the American Mining Congress and the Illinois Coal Association (Mt. Vernon, IL, Feb. 1990). IL Coal Assoc., 1990.

Bowers, J. L. The Effects of Coal Mining on the Surface and Ground Waters of the Scotts Run Drainage Basin. Unpublished M.S. Thesis, Dep. Geol. and Geogr., WV Univ., Morgantown, WV, 1979, 90 pp.

Cifelli, R. C. Dewatering Effects of Underground Coal Mining in Barbour and Upshur Counties of North-Central West Virginia. Unpublished M.S. Thesis, Dep. Geol. and Geogr., WV Univ., Morgantown, WV, 1986, 239 pp.

Darmody, R. G., F. W. Simmons, T. J. Bicki, and S. D. Harding. Soil Hydrologic Impacts of Coal Mine Induced Subsidence: Studies in Jefferson County. Semi-Annu. Rep. to IL Mine Subsidence Res. Program, 1988.

Dixon, D. Y. A Study of Dewatering Effects at Three Longwall Mines in the Northern Appalachian Coal Field. Unpublished M.S. Thesis, Dep. Geol. and Geogr., WV Univ., Morgantown, WV, 1988, 120 pp.

Elsworth, D. Groundwater Effects of Short-Longwall (Impact of Mining on Groundwater Movement). Q. Rep. to PA Energy Dev. Auth., 1990.

Ground Water Associates, Inc. Effects of Land Subsidence on the Hydrologic Balance in the Vicinity of the Meigs No. 2 Mine, Meigs and Vinton Counties, Ohio. Rep. to OH Dep. of Nat. Resour., Div. Reclam., Columbus, OH, 1984, 65 pp.

Kelleher, J. T., D. J. Van Roosendaal, B. B. Mehnert, D. F. Brutcher, and R. A. Bauer. Overburden Deformation and Hydrologic Changes Due to Longwall Coal Mine Subsidence in the Illinois Basin. Paper in IAHS Publication 200: Land Subsidence (Proc. 4th Int. Symp. on Land Subsidence, Houston, TX, 1991). IAHS, 1991, pp. 195-204.

Klenowski, G., and R. N. Phillips. Determination of Groundwater Inflow Rates for Longwall Mining, German Creek, Bowen Basin, Queensland. Paper in Proceedings of 3rd International Mine Water Congress (Melbourne, Australia, 1988). Int. Mine Water Congr., 1988, pp. 21-30.

Neate, C. J. Effects of Mining Subsidence on the Permeability of Coal Measure Rocks. Ph.D. Thesis, Univ. Nottingham, Nottingham, England, 1980.

Pauvlik, C. M. The Effects of Longwall Mining Subsidence on the Ground Water Conditions of a Shallow Unconfined Aquitard. M.S. Thesis, South. IL Univ., Carbondale, IL, 1987.

Rauch, H. W. A Summary of the Effects of Underground Coal Mines on Quantity of Ground Water and Streamflow in the North-Central Appalachians. Paper in Proceedings of Special Institute on Coal Mine Subsidence (WV Univ. Law Cent., Morgantown, WV, Dec. 1985). East. Miner. Law Found., 1985, pp. 2.01-2.23.

Rauch, H. W., W. N. O'Steen, G. Ahnell, and G. F. Giannatos. Predictions for Aquifer Dewatering Over Underground Mines in the Pittsburgh, Sewickley, and Upper Freeport Coals in Northern West Virginia. Paper in Proceedings of Fifth Annual West Virginia Surface Mine Drainage Task Force Symposium, West Virginia Surface Mining and Reclamation Association (Charleston, WV, 1984). WV Surf. Min. and Reclam. Assoc., 1984, 11 pp.

Sgambat, J. P., E. A. LaBella, and S. Roebuck. Effects of Underground Coal Mining on Ground Water in the Eastern United States. EPA Rep. 60017-80-120, Cincinnati, OH, 1980, 183 pp.

Van Roosendaal, D. J., D. F. Brutcher, B. B. Mehnert, J. T. Kelleher, and R. A. Bauer. Overburden Deformation and Hydrologic Changes Due to Longwall Mine Subsidence in Illinois. Paper in Proceedings of the 3rd Conference on Ground Control Problems in the Illinois Coal Basin, ed. by Y. P. Chugh (Carbondale, IL, Aug. 1990). South. IL Univ., 1990, pp. 73-82.

Wohlrab, B. Effects of Land Subsidences Caused by Mining to the Groundwater and Remedial Measures. Paper in Proceedings of the Tokyo Land Subsidence Symposium (Tokyo, Japan, 1969). 1969, pp. 502-511.