STUDY OF THE IMPACTS OF A LONGWALL COAL MINING OPERATION ON SURFACE AND GROUND WATER RESOURCES AT THE WINDSOR MINE, WEST VIRGINIA, USA

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ABSTRACT

Windsor Coal Company, a subsidiary of Ohio Power Company operates an underground coal mine in the northern part of the State of West Virginia. Recently the underground operation introduced longwall mining after many years of using the room and pillar mining method. Because of the strict mining regulations and to address the public concern about the potential impacts of the proposed longwall operation on the local surface and ground water resources, the mining company conducted extensive hydrologic studies prior, during, and after mining of the first three panels.

The mine plan includes nine panels in the first coal block each 183 meters (600 feet) wide and 1,830 meters (6,000 feet) long. The mined Pittsburgh No. 8 coal seam is on the average 1.45 meters (4.75 feet) thick and is covered with an overburden 85.3 to 167.6 meters (280 to 550 feet) thick. The ground surface around the mine is characterized by hilly terrain, and the land is used primarily for livestock grazing and crop production. Several perennial streams drain the mine area and numerous springs and water wells have been developed for the water supply above the longwall panels.

The prediction of subsidence due to mining and potential impacts on surface and ground water resources were based on an extensive study of mining methods, overburden composition, and terrain configuration. Surface streams, ponds, springs, seeps, and water wells within an area of potential impacts were inventoried and monitored for 24 months prior to mining, during undermining and after completion of mining. Permeability tests were repeated in several monitoring wells, installed in the overburden, prior to and after completion of mining.

The study confirmed the predicted impacts on surface and ground water resources located within a zone of 51.8 meters (170 feet) above the mined coal. Surface streams, springs, and wells located above the zone of increased fracturing experienced either no impacts or only temporary and limited impacts to water levels or flow.

The study concluded that the impacts of longwall mining on the water resources are predictable and mostly temporary. No impacts on water quality were noticed during repeated water quality testing prior, during, and after the undermining.

INTRODUCTION

Windsor Coal Company, a subsidiary of Ohio Power Company operates an underground coal mine in the northern part of the State of West Virginia. Recently the underground operation introduced longwall mining after many years of using the room and pillar mining method (since 1980). Because of the strict mining regulations and to address the public concern about the potential impacts of the proposed longwall operation on the local surface and ground water resources, the mining company conducted extensive hydrologic studies prior, during, and after mining of the first three panels.

Windsor Coal Company (Windsor) retained Hydro-Geo Consultants, Inc. (Hydro-Geo) to study the hydrologic consequences of the Windsor coal mine operations located in Ohio County, West Virginia. The study analyzed the effects of longwall mining on domestic water wells, monitoring wells, springs, and streams located within the area of the first three panels.

Numerous studies of the effects of longwall mining on surface and ground water resources have been conducted in the northern Appalachian Coal Region. The most pertinent reports include Shultz (1988)[8], Walker (1988)[12], Trevits, King and Johnson (1986)[11], Jeran and Barton (1985)[4], Moebs and Barton (1985)[5], and Coe and Stowe (1984)[1]. These studies concluded that the effects of longwall mining on water resources are generally temporary and minor in nature. Water levels and flow rate fluctuations in affected wells, springs, and streams caused by undermining usually return to or near pre-mining levels and flows within several months following mining operations. However, site-specific geologic, hydrologic, mining, and topographic interrelationships affect the nature of the hydrologic impact on surface and ground water resources.

Study Area

The study area is located in Ohio County in northeastern West Virginia near the town of West Liberty (Figure 1). The area is characterized by hilly terrain with maximum relief of 122 meters (400 feet). The land near the site is used primarily for livestock grazing and crop production. The study area is rural and sparsely populated.

The Windsor Mine site is located east of the town of West Liberty. The project site covers an area of approximately 910 hectares (2,250 acres). The mine site is drained on the east by Castleman Run and the central portion of the site is drained by Longs Run, a tributary of Castleman Run (both are perennial streams). The northern part of the area is drained by Logan Run, and the western portion is drained by the North Fork of Shorts Creek, and its tributary Weidman Run. The current mining operations are taking place underneath an unnamed tributary of Longs Run.

Mine Development

Since 1989 Windsor has been employing the longwall mining method at the mine. During the first phase, the mine plan included nine panels (in block "A") each approximately 183 meters (600 feet) wide and approximately 1,830 meters (6,000 feet) long (Figure 1). The panels were being mined consecutively in an east to west direction. Panels 1A, 2A, and 3A were mined-out by 1992. The average mining advance in a panel is 122 to 183 meters (400 to 600 feet) per month. The mining sequence is illustrated on Figure 2.

The mine is developed in the Pittsburgh No. 8 coal seam with an average thickness of 1.45 meters (4.75 feet). The longwall operation removes a total of 1.88 meters (6.17 feet) of coal and adjacent strata. The thickness of overburden above the mined coal ranges from 85 to 168 meters (280 to 550 feet). It was predicted that a zone, approximately 56 to 76 meters (185 to 250 feet) thick, of increased permeability will develop above the advancing mining face. This zone was expected to return to pre-mining conditions several months after the mining face has passed. The overburden at the Windsor Mine is composed of approximately 73 percent weak rock (shale, siltstone, claystone) and 27 percent strong rock (limestone, dolomite, and sandstone). The weak rock will not be effected by the mining induced increases in permeability as much as the stronger rock.

SITE HYDROLOGY

The surface water characteristics at the Windsor Mine site have been monitored since 1986. Locations of the surface water monitoring stations are shown on Figure 2. The mine site is drained on the east by Castleman Run and its tributaries Rices, Curtis, Crupe, and Garrison runs. The central portion of the site is drained by Longs Run, a tributary of Castleman Run. The current mining operations, including the mined-out panels 1A, 2A, and 3A are taking place mostly underneath an unnamed tributary of Longs Run. The unnamed drainage is situated west of Longs Run.

The study area is underlain by unconsolidated Quaternary alluvium or colluvium and the bedrock units of the Pennsylvanian Dunkard, Monongahela, and the Permian Conemaugh groups strata. The alluvium, found in stream valleys, consists of unconsolidated gravel, sand, silt, and clay. This unit serves as a low yield water bearing strata to shallow dug wells in the area. The colluvium is found on the hillsides and at the base of the slopes. It is composed of unconsolidated materials of various size. The colluvium is a water bearing unit with a variable, typically low, well yield.

The bedrock water bearing units are composed of sandstone, siltstone, shale, limestone, and coal. The Dunkard Group is approximately 46 meters (150 feet) thick. The ground water in the Dunkard Group bedrock occurs in locally perched zones, where low permeable strata impede the ground water infiltration resulting in saturated zones in overlying permeable strata. The Monongahela Group underlies the Dunkard Group and is approximately 76 meters (250 feet) thick. The water bearing units in this group are mostly limestone strata. The limestone and sandstone units of the Conemaugh Group produce water to local wells. The aquifers in the Dunkard, Monongahela, and Conemaugh groups are unconfined near the outcrops and are confined in the deeper sections. A typical geologic composition of the coal bearing strata is presented on Figure 3.

The bedrock strata have a combination of primary (intergranular) and secondary (fracture) permeability. The secondary permeability is prevalent and ground water flow occurs through joint systems and bedding planes. Secondary permeability tends to decrease with depth and most of the ground water flow is within 46 meters (150 feet) of the land surface (Walker, 1988[12]).

The recharge into the water bearing units occurs at the outcrops from precipitation and from the local streams where the permeable zones are exposed in the drainages. Discharge from the aquifers occurs at the lower reaches of the drainages as springs and seeps. The quantity and quality of the ground water are dependent on seasonal climatological variations. It has been estimated that as much as 20 to 25 percent of the average annual precipitation infiltrates into the water bearing strata in this region (Stoner, 1983[10]).

MONITORING SYSTEM

The U.S. Department of Commerce, National Oceanic and Atmospheric Administration, maintained a climatologic data station at Wellsburg, WV, which is about 9.6 kilometers (6 miles) northwest of the study area until 1989. The Windsor Coal Company has been operating a continuous recording rain gage at the West Liberty Portal site since September 1987. The climate in the study area is humid and temperate. The mean annual temperature is 11° C (51.8° F), with a mean daily maximum of 17.7° C (63.8° F) and mean daily minimum of 4.3° C (39.7° F). The average annual precipitation is approximately 965 mm (38 inches), with the greatest amount generally falling in the spring and early summer. Average annual snowfall is 584 mm (23 inches).

Forty-five (45) surface water stations were monitored to determine water quality and quantity in the mining area. The monitoring program included Castleman Run from Rices Run to Longs Run, the Longs Run watershed, Logan Run, Weidman Run, and the North Fork of Short Creek. Most surface water monitoring stations were sampled monthly from September 1986 through May 1987 and sampled bimonthly until September 1987, with stream flow measurements taken monthly through September 1990. Since initiation of the program several additional stations have been added and stream flow staff gages have been installed at several stations.

A total of forty-two (42) ground water stations have been monitored for water quality and quantity in the mine area. Ground water was initially sampled quarterly with monthly water level or flow measurements taken since March 1987. Four piezometers and two monitoring wells were installed to provide additional ground water stations and to provide aquifer characteristics. Two single piezometers were installed since May 1987. One multiple piezometer was installed in August 1987 and a second multiple piezometer was completed in September 1987. Permeability testing was performed in each of the piezometers. Two additional monitoring wells were installed in 1988.

IMPACTS OF LONGWALL MINING ON HYDROLOGY

A total of nineteen (19) surface water monitoring stations were monitored in the general area of the first two mined panels. Most of the surface water monitoring stations are located on the unnamed drainages, tributaries to Longs Run. Surface stream flow measurements and water quality data have been collected monthly from September 1986 through May 1987. These stations were then monitored for water quality bimonthly until September 1987, with stream flow measurements taken monthly through September 1990.

Several of the surface water monitoring stations are located outside of the mined panels. Station 15 is located on a drainage flowing from Panel 1A. Monitoring stations 12, 21, 22, 28, 29, 30, 31, and 32 are located above or near Panel 2A. Monitoring stations 17 and 18 are located above Panel 3A. Results of monitoring at all surface water monitoring stations were analyzed. Monitoring station 21 was selected to assess the impacts of the mining operations in panels 1A and 2A (Table 1). This station was selected because of its location near the confluence of the unnamed stream with Longs Run. Figure 2 shows locations of the surface water monitoring stations.

A total of twenty three (23) ground water monitoring stations were monitored in the general area of the first two mined panels. Ground water quantity and quality monitoring has continued regularly since 1987. Monitoring locations are shown on Figure 2. The results of monitoring at all of the monitoring stations in the study area were reviewed for potential impacts of mining. Seven wells and four springs located above the mined-out panels were used to analyze the impacts of the mining operation on the ground water quality and quantity. Table 1 lists the selected ground water monitoring points and Figure 2 shows their locations. Permeability tests were conducted on four of the selected stations. One station was selected to assess the impacts of mining on water quality (Table 2).

Impacts on Surface Streams

None of the surface water monitoring stations located above or near the longwall panels 1A and 2A indicated any significant and permanent decrease of flow during and after the undermining. Monitoring station 15, located on the upper reaches of a small drainage flowing from above the Panel 1A area, did not flow during the summer of 1988. However, flow was observed during the summers of 1989 and 1990. The section of the drainage monitored at station 15 was undermined in September 1989. During August and September 1989 a low flow was measured at this station, however, this was due to the low precipitation and not due to the mining activities. The stream flow at this station was normal during October 1989.

Monitoring station 12 was located below a confluence of two small drainages flowing from above panels 1A and 2A. This station, located above Panel 2A was undermined early in March 1989. No reduction of flow has been noticed during or after the undermining of this station and the monitored sections of the drainages.

Monitoring stations 28 and 29 were located on small drainages (south and north forks). This area, located above the middle of Panel 2A, was undermined in mid-March 1990. A slight decrease of flow at both stations 28 and 29 was noticed during the March 1990 measurements. However, the flow at both monitoring stations returned to normal in April 1990.

Monitoring stations 30, 31, and 32 were located on small drainages above Panel 2A. This area was undermined in early January 1990. No unusual reduction of flow in these three monitoring stations was noticed during or after the undermining.

Surface monitoring station 21 was selected to analyze the impacts of the mining operations in panels 1A and 2A in more detail. This station was located above Panel 2A at the mouth of the unnamed tributary of Longs Run that drains the Panel 1A and 2A area (Figure 2). Because this station was located on the lower reaches of the drainage, the flows were more continuous during the dry season. The hydrograph developed for this station clearly shows that precipitation has a greater impact on the flow of the drainage than the base flow from ground water. Throughout the period of record (June 1988 to September 1990) flow measurements ranged from 14.0 to 4,250 l/min (3.7 to 1,122.8 gpm). From June to October 1988 stream flows ranged from 14.0 to 33.0 l/min (3.7 to 8.7 gpm) which was particularly low for this time period. However, the low flow period did not appear to be related to mining activities. This station was undermined in November 1989, and the upstream sections of the monitored stream were mined during December 1989, and January and February 1990. The hydrograph throughout the mining period did not indicate any effects from mining.

Impacts on Ground Water

Ten of the ground water monitoring stations were located above Panel 1A and two above Panel 2A. Out of the twelve ground water monitoring stations (springs and wells) four did not indicate any impacts, four showed temporary impacts attributed to weather conditions and four of the ground water monitoring stations indicated changes related to undermining (Table 1).

The impact on water level in monitoring well MP-6 was anticipated because the bottom of this well was only 52 meters (170 feet) above the mined coal. This well went dry after undermining and the water level did not return to pre-mining depths within 14 months after the undermining. The impact of undermining on water levels in stations Nos. 13 and MP-5 (both wells) was only temporary and water levels recovered to near pre-mining conditions within approximately 3 months after undermining. Impact on station No. 14 was the most puzzling. This spring flowing at 5.8 l/min (1.5 gpm) lost all of its flow after undermining, although the spring is located 117 meters (385 feet) above the mined coal. Later inspection indicated that the spring was flowing at approximately the same rate as in pre-mining conditions at about 5 meters (15 feet) lower elevation. It seems that the thin shale bed acting as an aquiclude, on which the spring was discharging, breached and the spring appeared on the next lower permeable strata. There could have been a possibility of some geologic anomaly in the area of stations 13 and 14 which could contribute to the impacts on these two ground water sources.

Windsor Coal Company replaced two water wells (Stations 2 and 13) after undermining. Pumping tests in these new wells indicated higher values of hydraulic conductivity, transmissivity, specific capacity, and yield than the average area well unaffected by mining. This could indicate that longwall mining, in some cases, improves well yield.

Monitoring well MP-5 was selected to assess the changes in ground water quality due to the mining. This well was chosen because of its location above the first longwall mined Panel 1A, and the availability of pre and post-mining water quality data. Monitoring well MP-5 was undermined on July 25, 1989. Pre-mining water quality was typical of the wells in this area with low acidity, alkalinity, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), and trace constituents. The pre-mining pH value in this well was a little elevated with a March 1988 reading of 9.3 units. The high pH may be the result of grout contamination which may have occurred during installation. Post-mining water quality was similar to pre-mining quality except that the pH had stabilized at a more normal level of approximately 7.5 units, and total alkalinity increased from approximately 80 mg/l $CaCO_3$ to over 250 mg/l $CaCO_3$. The elevated total alkalinity concentration is similar to the levels observed in the other local monitoring wells.

The repeated water quality sample collection and analyses indicated that the ground water quality constituents are fluctuating with time, and no significant changes and/or deterioration of water quality due to the mining has been detected.

CONCLUSIONS

The completed study of the impacts of the Windsor Coal Mine longwall mining operation in panels 1A, 2A, and 3A on surface and ground water sources confirmed that subsidence effects are predictable and in most cases only temporary impacts on water resources occur within a short distance above the mined coal. The study also confirmed the existence of several zones above the mined coal with deceasing impacts of subsidence on the pre-mining permeability of the overburden.

Longwall mining (and, to a lesser extent, partial extraction) of coal seams causes collapse, fracturing, bed separation, and bedding plane slip in the roof strata above the seam. All of these impacts on the overlying strata can result in changes to surface and ground water sources, if a major water resource is within contact of the disturbance. The height of the disturbed area depends on the thickness of the mined coal, the mining method, the rate of the mining face advancement, and on the geological characteristics of the overburden. According to Singh (1986)[9], the area of disturbance is generally divided into five zones, based upon the extent of fracturing, as follows:

Zone 1 Zone of primary caving where the caved rock is completely disintegrated;
Zone 2 Zone of bed separation where separation occurs primarily along pre-existing bedding planes;
Zone 3 Zone of vertical relaxation where a slight increase of permeability is experienced; and,
Zone 4 and 5 Zone of tensile strain at the surface where shallow fractures develop.

Based on international experience, the total thickness of the first and second zones, where the changes of permeability are substantial, typically reaches 3 to 3.5 times (Ropski and Lama, 1973[7]), and rarely more than 10 times the height of the extracted seam (Wardell, 1976[13]). The height of the third zone, or the total height where changes in permeability due to subsidence usually occur, is described by various authors as approximately 30 t (where t is the fully extracted seam thickness), 58 t (Gviroman, 1977[2]), 33.7 t (Williamson, 1978[14]) and 30 t (Wardell, 1976)[13]. Similar results were obtained in several studies in the Appalachian Bituminous Coal Region. These results were reported by Hill and Price (1983)[3], Owili-Eger (1982)[6], Walker (1988)[12], Shultz (1988)[8], and others.

Our study concluded that subsidence above the mined panel can substantially impact water resources located within 52 to 61 meters (170 to 200 feet) above the mined coal. These impacts could indicate the extent of the first and second zones of increased permeability as 2 to 10 x t and the third zone (vertical relaxation) as 27 to 32 x t, as shown on Figure 4. The zones of horizontal extension and compression were expressed on the ground surface in the form of shallow surface cracks. However, the extension of these zones was difficult to establish due to the hilly ground surface. It is believed that the angle of draw in the Appalachian Coal Region ranges from 17 to 25 degrees.

Results of the impacts of the longwall mining analysis in the first three panels mined by the Windsor Coal Company were confirmed in the consequent mining of additional panels. In June 1994 mining in nine panels has been completed without any substantial unpredictable impacts. Extensive monitoring of surface and ground water resources is continuing during the current mining operation.

ACKNOWLEDGEMENTS

Authors of this paper wish to thank the Ohio Power Company and Windsor Coal Company management for the permission to publish the results of this study. Special mention should be given to Mr. Dan Carney of Windsor Coal Company and Ms. Jody Belviso of American Electric Power Corporation for their cooperation.

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REFERENCES

1. Coe, G.J, and S.M. Stowe, 1984. Evaluating the Impact of Longwall Coal Mining on the Hydrologic Balance. Proceedings of the 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation, Lexington, Kentucky, Dec. 2-7, 1984.

2. Gviroman, B.Y. et al., 1977. Undermining Water Reservoirs Without Risk (in Russian), Nedra, Moscow, p. 174.

3. Hill, G.J., and D.R. Price, 1983. The Impacts of Deep Mining on an Overlying Aquifer in Western Pennsylvania. Ground Water Monitoring Review, V.3, N.1, pp 138-143.

4. Jeran, P.W., and T.M. Barton, 1985. Comparison of Subsidence Over Two Different Longwall Panels. Paper in Mine Subsidence Control. Proceedings of the Bureau of Mines Technology Transfer Seminar. U.S. Bureau of Mines, I.C. No. 9042.

5. Moebs, N.N., and T.M. Barton, 1985. Short-Term Effects of Longwall Mining on Shallow Water Sources. Proceedings of Technologic Transfer Seminar, Pittsburgh, PA., Sept. 19, 1985. U.S. Bureau of Mines, I.C. No 9042, pp. 13-24, 1985.

6. Owili-Eger, A.S.C., 1987. Predicting the Impacts of a Longwall Mining Unit System on the Water Resources of an Area. Proceedings of the Symposium Water Resources Related to Mining and Energy - Preparing for the Future. AWRA, Utah, pp. 259-269.

7. Ropski, S., and R.D. Lama, 1973. Subsidence in the Near-Vicinity of a Longwall Face. International Journal of Rock Mechanics Mining Science and Geomech. Abstracts, pp. 105-118.

8. Shultz, R.A., 1988. Ground-Water of Marshall County, West Virginia, with Emphasis on the Effects of Longwall Coal Mining. U.S. Geological Survey, Water-Resources Investigations Report 88-4006, Charleston, W.V.

9. Singh, R.N, 1986. Mine Inundations, International Journal of Mine Water, Vol. 5, No. 2 pp. 1-28.

10. Stoner, J.D., 1983. Probable Hydrologic Effects of Subsidence Data from the Northern Appalachian Basin for Subsidence Prediction. U.S. Bureau of Mines. R.I. 8630.

11. Trevits, M.A., R.L King, and V.B. Johnson, 1986. The Bureau of Mines Subsidence Research Program. U.S. Bureau of Mines Information Circular 9137.

12. Walker, J.S., 1988. Case Study of the Effects of Longwall Mining Induced Subsidence on Shallow Ground Water Sources in the Northern Appalachian Coalfield. U.S. Bureau of Mines Report of Investigations, RI 9198.

13. Wardell, K., et al., 1976. Guidelines for Mining Near Surface Waters, Phase II and III. U.S. Bureau of Mines Contract No. HO252021, p. 37, February, 1976.

14. Williamson, W.H., 1978. Hydrogeological Aspects of Coal Mining Under Stored Waters Near Sydney, Australia. SIAMOS - 78, Granada, Spain, pp. 309-328.

TABLE 1

**SUMMARY OF MONITORING STATIONS
WINDSOR MINE
WINDSOR COAL CO.**

Monitoring Station	Description	Depth to Mine [1]		Mine Panel	Date Undermined	Average Pre-Mining Water Level & Flow		During Mining Water Level & Flow		Post Mining Water Level & Flow		Mining Effects
		meters	feet			meters / l/min	feet / gpm	meters / l/min	feet / gpm	meters / l/min	feet / gpm	
2	Well	91	300	1A	4/03/89	2.3 / - -	7.5 / - -	4.0 / - -	13.0 / - -	2.7 / -	9.0 / - -	Lower water level (2)
3	Spring	107	350	1A	4/19/89	- - / 6.8	- - / 1.8	- - / 7.6	- - / 2.0	- - / 7.6	- - / 2.0	No effect
8	Well	79	260	1A	3/10/89	24.3 / - -	79.8 / - -	22.3 / - -	73.0 / - -	21.3 / - -	70.0 / - -	Increased water level (2)
11	Spring	145	475	1A	7/29/89	- - / 1.1	- - / 0.3	- - / 1.5	- - / 0.4	- - / 3.8	- - / 1.0	Increased flow (2)
13	Well	113	372	2A	3/16/90	1.2 / - -	4.1 / - -	2.6 / - -	8.4 / - -	3.2 / - -	10.6 / - -	Lower water level (3)
14	Spring	117	385	2A	3/09/89	- - / 5.8	- - / 1.53	dry	dry	dry	dry	Flow stopped (3)
21	Stream	88	290	2A	11/10/89	- - / 85.5	- - / 22.6	- - / 87.4	- - / 230.9	- - / 1,217	- - / 321.6	No effect
25	Spring	117	385	1A	6/15/89	- - / 31.8	- - / 8.4	dry	dry	- - / 17.8	- - / 4.7	Temporary effect (2)
27	Well	119	390	1A	10/27/89	5.7 / - -	18.7 / - -	6.3 / - -	20.6 / - -	5.3 / - -	17.4 / - -	No effect
MP-1-P1	Piezometer	139	455	1A	9/27/89	5.5 / - -	18.0 / - -	6.7 / - -	22.0 / - -	6.4 / - -	20.9 / - -	No effect
MP-1-P2	Piezometer	111	365	1A	9/27/89	36.5 / - -	119.9 / - -	36.5 / - -	119.7 / - -	36.5 / - -	119.7 / - -	No effect
MP-5	Well No. 2	91	300	1A	7/25/89	11.2 / - -	36.6 / - -	34.1 / - -	112.0 / - -	24.1 / - -	79.2 / - -	Lower water level (3)
MP-6	Well No. 1	52	170	1A	7/24/89	42.9 / - -	140.8 / - -	dry	dry	dry	dry	Well went dry (3)

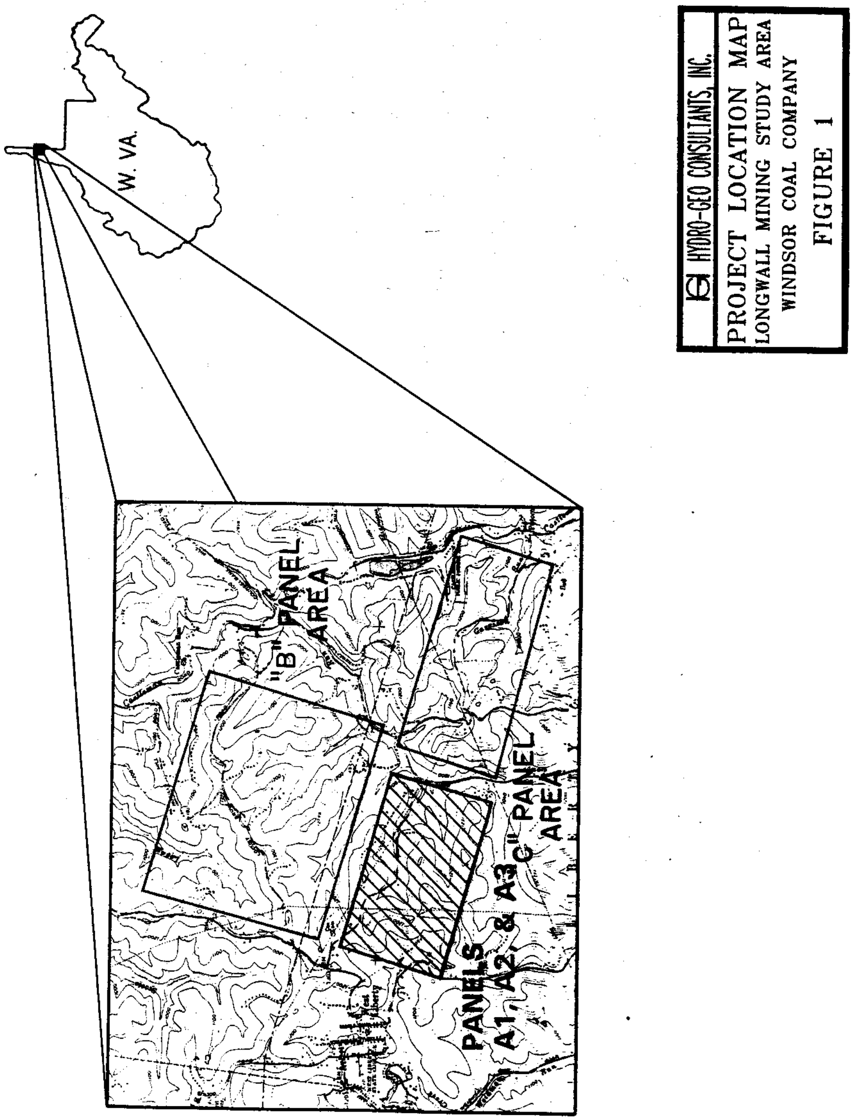
NOTES: (1) Surface elevation for springs. Bottom elevation for wells.
(2) Impacts related to weather conditions.
(3) Impacts related to undermining.

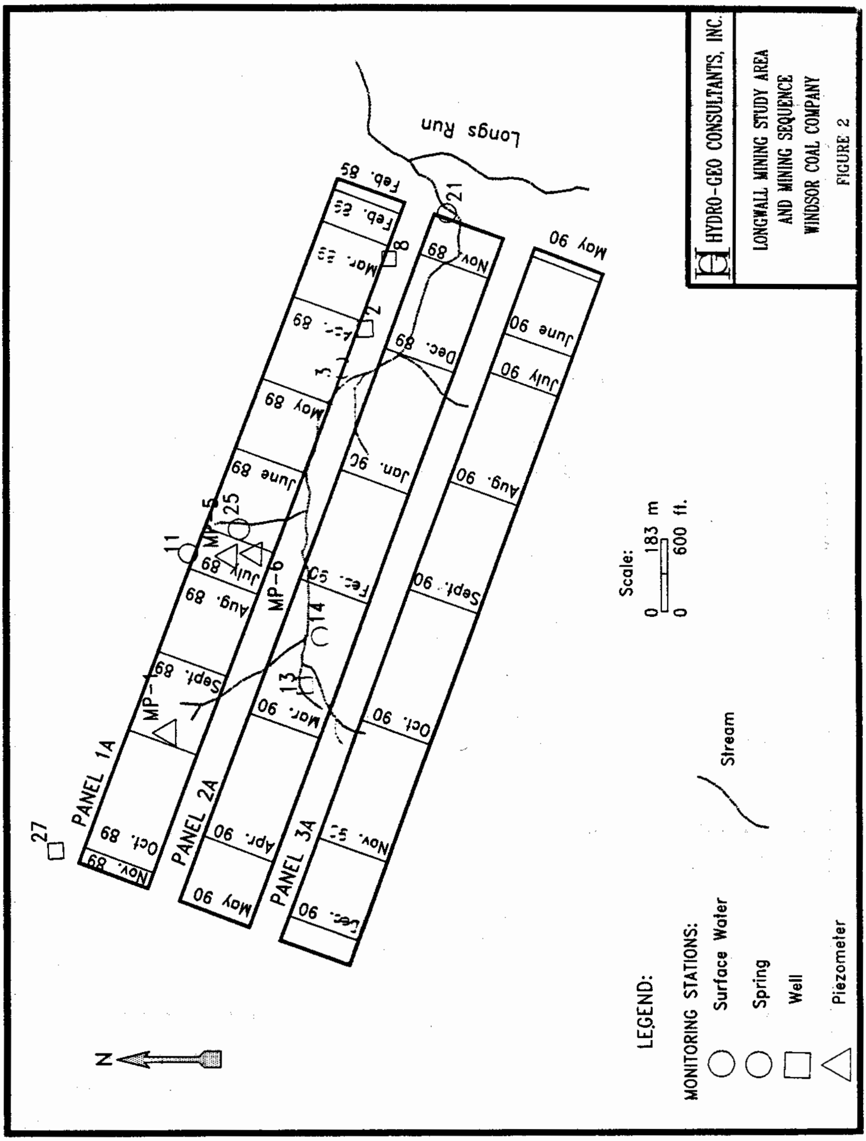
TABLE 2

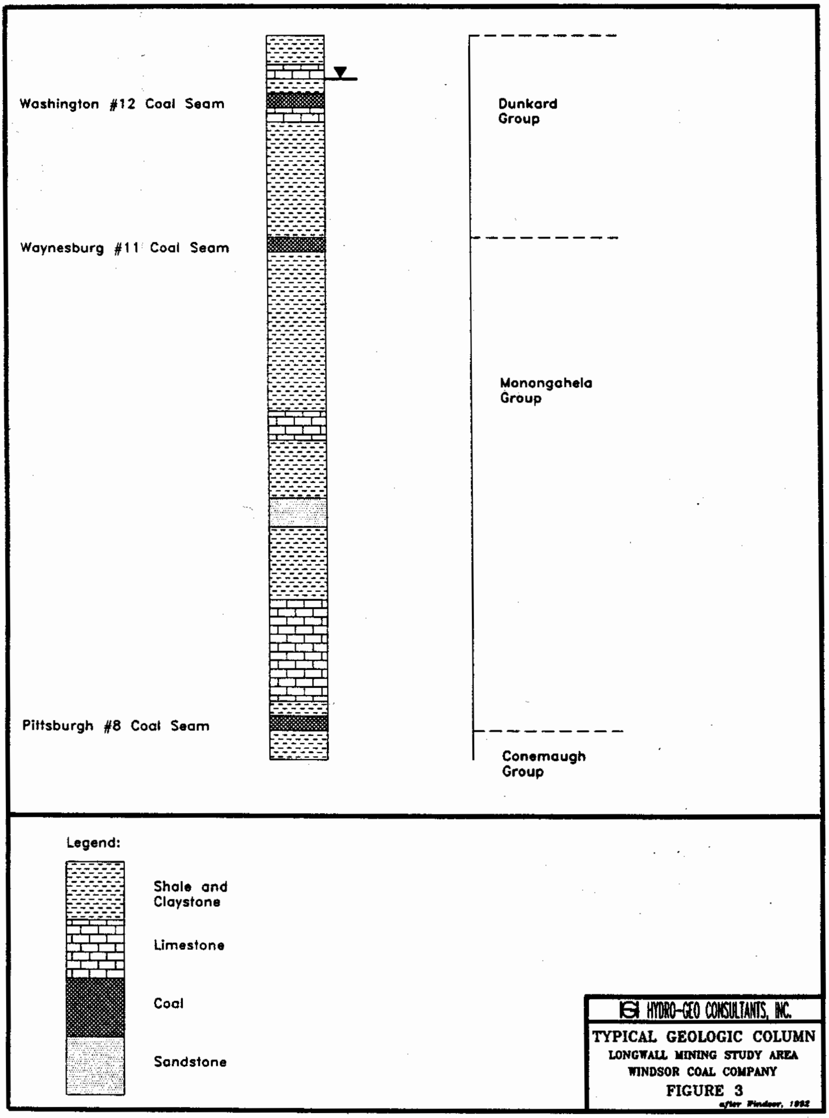
**SUMMARY OF GROUND WATER QUALITY, WELL MP-5
WINDSOR MINE
WINDSOR COAL COMPANY**

Parameters	Pre-Mining	Post-Mining	
	3/14/88	10/16/90	12/13/90
pH (units)	9.3 (1)	7.7	7.3
Total Acidity (mg/l $CaCO_3$)	<1	<1	<1
Total Alkalinity (mg/l CaCO3)	83	338	266
Total Iron (mg/l)	1.12	0.5	0.17
Dissolved Iron (mg/l)	<0.05	<0.05	<0.05
Total Manganese (mg/l)	0.02	0.03	0.01
TSS (mg/l)	2	18	19
TDS (mg/l)	253	439	370
Specific Cond. (umhos)	444	519	608
Sodium (mg/l)	119	51	41
Aluminum (mg/l)	- -	0.53	0.14
Calcium (mg/l)	- -	50.4	104
Magnesium (mg/l)	- -	9.99	22.8

NOTE: (1) Affected by grouting


W. VA.
"B" PANEL AREA
"C" PANEL AREA
PANELS A1, A2, & A3
HYDRO-GEO CONSULTANTS, INC.
PROJECT LOCATION MAP
LONGWALL MINING STUDY AREA
WINDSOR COAL COMPANY
FIGURE 1


HYDRO-GEO CONSULTANTS, INC.
LONGWALL MINING STUDY AREA
AND MINING SEQUENCE
WINDSOR COAL COMPANY
FIGURE 2
Longs Run
PANEL 1A
PANEL 2A
PANEL 3A
MP-5
MP-6
Scale:
0 183 m
0 600 ft.
Stream
LEGEND:
MONITORING STATIONS:
Surface Water
Spring
Well
Piezometer
N


Washington #12 Coal Seam
Waynesburg #11 Coal Seam
Pittsburgh #8 Coal Seam
Dunkard Group
Monongahela Group
Conemaugh Group
Legend:
Shale and Claystone
Limestone
Coal
Sandstone
HYDRO-GEO CONSULTANTS, INC.
TYPICAL GEOLOGIC COLUMN
LONGWALL MINING STUDY AREA
WINDSOR COAL COMPANY
FIGURE 3

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