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Case Study of the Effects of Longwall Mining Induced Subsidence on Shallow Ground Water Sources in the Northern Appalachian Coalfield

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BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	pct	percent
in	inch	yr	year

CASE STUDY OF THE EFFECTS OF LONGWALL MINING INDUCED SUBSIDENCE ON SHALLOW GROUND WATER SOURCES IN THE NORTHERN APPALACHIAN COALFIELD

By J. S. Walker[1]

ABSTRACT

The Bureau of Mines monitored surface subsidence and water level fluctuations in 10 shallow observation wells above a series of four adjacent longwall panels in southwestern Pennsylvania, for about 4 yr. This study attempted to correlate the changes in the water levels within the observation wells to the measured vertical and horizontal ground movements associated with subsidence. Results of this study indicate that the fluctuation of the water levels appears to be a function of the well location relative to the mine layout and the proximity of mining. Wells are generally unaffected by mining of a preceding panel unless they are located within the angle of draw for that panel. Wells located at the centerline of a longwall panel exhibit the greatest fluctuation and head loss. This relationship may be related to the strain developed by the advancing longwall face. The water levels in the wells monitored fell at the greatest rate when the ground surrounding the well was in tension. The rate of the decline decreased as the dynamic development of the strains was changing from tension to compression. The water levels were found to be near the premining level before the ground was subject to maximum compressive strain. Nine of the ten wells investigated recovered to their premining water level after mining was completed.

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INTRODUCTION

Loss or interruption of water supplies has long been a concern of mine operators and surface land owners alike, yet very little information is available on this subject. The Bureau of Mines, as part of its Environmental Technology research, is investigating the effects of subsidence caused by longwall mining on shallow aquifers. This case study should provide coal operators in the Northern Appalachian Coal Region with detailed information to enable them to plan for the effect of mining on springs, streams, or domestic water wells located within an area of proposed longwall mining.

Prior investigations have addressed changes in well yield and water quality for shallow aquifers, but few have included subsidence monitoring as part of the investigation (*1-4*).[2] This study is directed towards the correlation of fluctuations in levels of shallow water supplies with the vertical and horizontal ground movements. Because such movements can be predicted with good accuracy in the Northern Appalachian Coal Region, it is reasonable to assume that the discovery of firm cause and response mechanisms for ground water variations as related to subsidence would allow the eventual prediction of effects on ground water supplies prior to mining (*5*). However, before technology can progress to such a state, many additional site-specific studies are needed to fully understand the nature the local geological, topographical, and hydrologic interrelationships within ground water systems.

SITE DESCRIPTION

The study site is located in southwestern Pennsylvania, near the city of Waynesburg (fig. 1). The topography of the site is typical of the Northern Appalachian Coal Region, consisting of hilly terrain with steep to moderate slopes. The relief within the study area is approximately 400 ft. Surface waters in the area collectively form a dendritic drainage pattern. Such drainage forms upon strata of uniform resistance and implies a notable lack of structural control (*6*). The land use in the vicinity of the study site is chiefly grazing and forage crop production, with small woodlots and treelines separating small agricultural fields. Several barnyards and rural dwellings are also present in the study area.

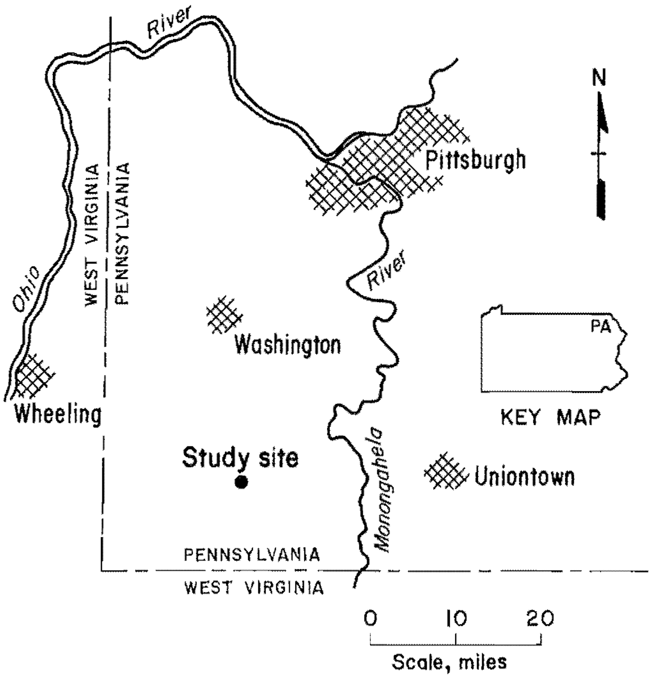

Figure 1.—Location of study area.

TABLE 1. - Longwall panel information

Panel	Width, ft	Length, ft	Date	
			Started	Completed
A	635	4,700	Sept. 1982	Sept. 1983
B	635	5,670	Oct. 1983	Sept. 1984
C	630	5,740	Sept. 1984	May 1985
D	635	5,170	June 1985	Jan. 1986

The study area overlies four adjacent longwall panels (fig. 2). The panels are spaced on 900-ft centers and are approximately 630 ft wide and 5,300 ft long, with the exception of panel A, which is approximately 4,700 ft long, (table 1). The panels were mined consecutively using the retreat longwall mining method in a west to east direction. The mining occurs in the Pittsburgh Coalbed, which was typically 65 to 75 in thick in the study area with an overburden thickness ranging from 700 to 1,000 ft.

The regional geology near the study site is characterized by gently dipping folds trending northeast-southwest. The study site is located on the southern flank of the Waynesburg syncline, dipping less than 4° in a northwest direction. A generalized stratigraphic column is shown in figure 3. The column is composed of interbedded fine-grained sedimentary rocks with occasional predominant layers of sandstone, limestone, and coal. Bedrock is overlain with 7 to 10 ft of residual soil containing weathered shale fragments. There is evidence of weathering to a depth of approximately 50 ft.

The ground water system in Greene County has been investigated by the U.S. Geological Survey. As part of that study, Stoner (*7*) has published a case study that defines the hydrology of the area as it is related to underground mining. This study describes the groundwater flow system as complex, and strongly

[2]Italic numbers in parentheses refer to items in the list of references preceding the appendixes.

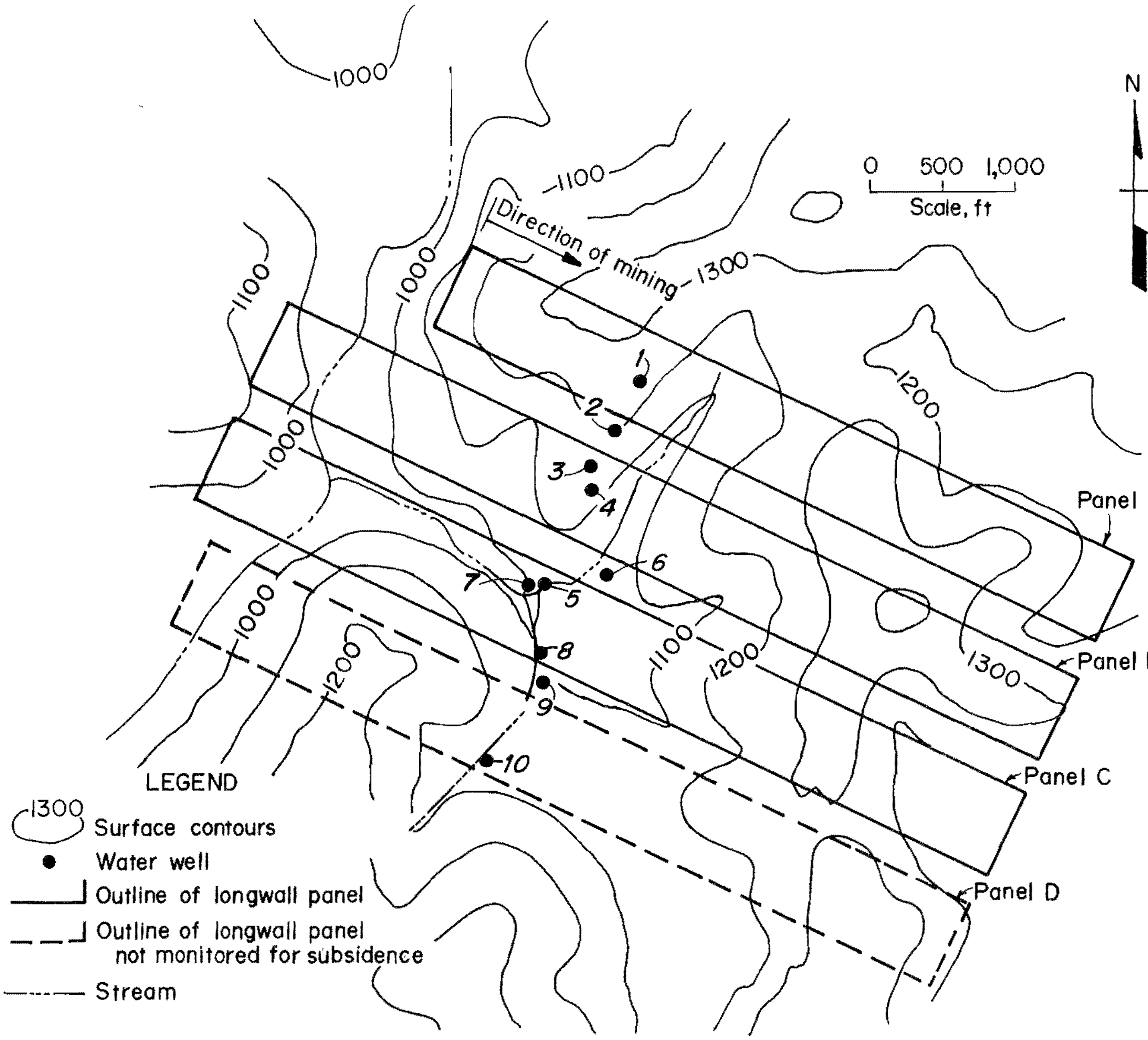

Figure 2.–Layout of study area.

controlled by secondary permeability in the form of fracture zones and bedding plane fractures. Annual precipitation for Greene County ranges from 38 to 41 in. Stream flow hydrograph separations (into base flow and direct runoff components) performed by Stoner estimate that on the average 22 to 25 pct of the mean annual precipitation circulates through the aquifer systems. Drill logs for the 10 observation wells do not indicate the presence of any clearly defined aquifers. Instead, ground water flow occurs as a result of secondary permeability through the joint systems and bedding planes. Fracture openings tend to diminish in width and number as overburden depth increases; thus bedrock permeability decreases with depth and constrains most water circulation to within 150 ft of the land surface. In terms of topographic setting, aquifers beneath valleys exhibit larger average hydraulic conductivity than aquifers beneath hilltops. The flow quantity and quality in shallow systems are generally dependent on seasonal climatological changes.

Ten wells were completed for this study in an area to be undermined by four contiguous longwall panels (fig. 2). The wells were completed in two sets as shown in table 2.

Wells 1 through 5 were positioned in a line perpendicular to the trend of the long axis of panels A, B, and C. Well 7 was added to the array approximately 20 months later. Wells 6, 8, and 9 were drilled as another line and positioned approximately 400 ft beyond the line

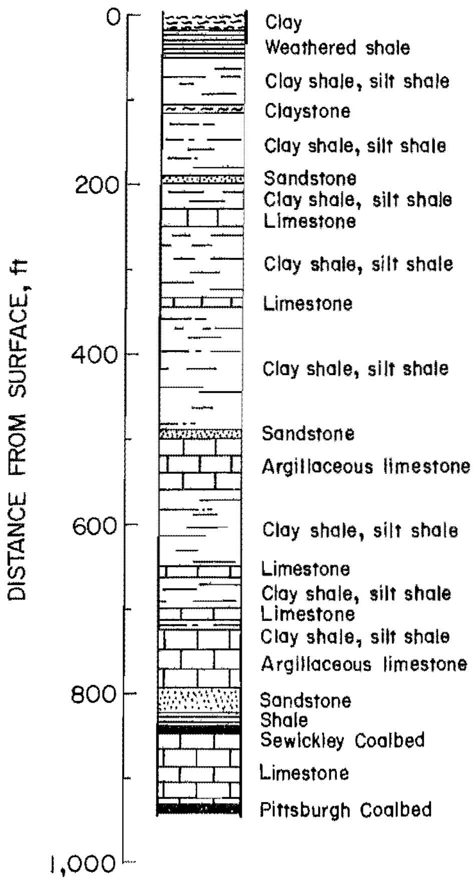

Figure 3.–Generalized columnar section.

TABLE 2. - Well completion data

Well No.	Date completed	Time monitored, days
1	July 28, 1982	1,308
2	July 28, 1982	1,308
3	July 28, 1982	1,308
4	July 28, 1982	1,308
5	July 28, 1982	1,308
6	Mar. 22, 1984	706
7	Apr. 05, 1984	692
8	Mar. 19, 1984	709
9	Apr. 03, 1984	694
10	Mar. 28, 1984	700

of the previous set of wells but over panels B and C. Well 10 was completed over panel D and was located between the two well lines.

The wells were air-rotary drilled to depth of 150 ft, cleaned of debris, and cased with 4-in-diam slotted polyvinyl chloride (PVC) pipe. Surface pipe was installed to isolate the unconsolidated surface material from the well. The 150-ft depth was selected because it typified domestic water wells in the region and did not penetrate any deeper confined aquifers. The wells were not completed in a specific water-bearing zone and, in fact, probably penetrated several zones over the extent of the well array. In order to determine some portion of the variety of possible effects of mining, the wells were strategically positioned near the center of the panels (wells 1 and 4), over the chain pillars (wells 2, 6, and 9), and close to the edge of the longwall panels (wells 3, 5, 7, 8, and 10). Upon completion of drilling, the wells were allowed to stabilize before mining advanced through the area.

MONITORING

Fluid level measurements were obtained using a electrical resistivity water level sensing device manually lowered into the wells or by a continuously recording float setup. The resistivity measurements were made on a weekly basis, as nearly as possible, throughout the life of the study when the continuous recorders were not used. The top of each well casing was used as the reference point, and measurements were made to the nearest 0.1 ft. No aquifer reservoir tests (injection or drawdown) were performed.

Ground movements associated with subsidence were monitored in the vicinity of both profiles defined by the two lines of wells. These movements were measured via an array of permanent monuments installed prior to the advance of mining into the study area. The monuments consisted of steel rebar located on 25-ft centers and driven to refusal, approximately 3 to 4 ft deep. Monument arrays were located along the centerline of each panel and on perpendicular profiles defined by the two lines of wells. The initial positions of the monuments were determined from the survey and subsequent movement from those positions were observed and recorded. Subsidence surveys were conducted on a weekly basis as the mining advanced through the study area. Surveys to determine any additional movement caused by the advance of adjacent panels through the study area were performed on a less frequent schedule. All surveys were conducted using standard ground surveying techniques and equipment.

WELL WATER QUALITY

Water quality samples were obtained from each of the 10 wells at the study site prior to mining of the longwall panels and again about 1 yr after each well was undermined. The water was analyzed for changes in alkalinity, calcium, chloride, chromium, dissolved solids, ferrous iron, manganese, magnesium, nickel, nitrate, potassium, sodium, sulfate, total iron, zinc, and pH. There was no pronounced change in overall water quality (appendix A). In each well the pH increased slightly and the alkalinity and amount of sulfates decreased a small amount. The dissolved solids changed very little. These minor changes could be natural variations or could be attributed to fluctuation in water level, weathering of the wellbore, or altered channels of flow in the overburden as a result of the subsidence process.

DATA ANALYSIS

The results of the ground surveys indicate that subsidence observed over the longwall panels was typical of the Northern Appalachian Coal region. The maximum subsidence observed was 3.82, 3.12, and 3.58 ft for panels A, B, and C, respectively. Surface movements were not monitored over panel D. A 15° angle of draw defined the area of major surface deformation (0.1 in), and the limit of detectable surface movement was determined to extend approximately 24° from the vertical extent of the mined-out longwall panel boundaries (fig. 4).

The water level data collected during the life of the study are shown in figures 5 and 6. Water level histories for individual wells are included in appendix B. A period of low precipitation occurred during the summer and fall of 1984 and can be observed in the fluid level measurements recorded for this period.

The effects of mining can be divided into two catagories: head loss, and water level fluctuations.

HEAD LOSS

The permanent lowering of the fluid level elevation is termed head loss for this study (fig. 7). During the monitoring of the well array, only well 1 did not rebound to some degree after mining. After being undermined, the well appeared to establish a static fluid level; it then experienced severe fluctuations and went dry. The well remained in this condition throughout the remainder of the study. The fluid levels in wells 1, 3, 4, and 5 did not return to the premining levels. All other wells appeared to have returned to their premining levels or higher.

WATER LEVEL FLUCTUATIONS

Analysis of the water level fluctuations recorded in the observation wells suggest that the magnitude of the fluctuations is a function of both the panel geometry and the proximity of the working face. Wells located near the center of the panels exhibited larger, more defined fluctuations than those located near the edges of the panels or over the chain pillars (fig. 7). This phenomenon appears to be related to the magnitude of the subsidence, which also is greatest at the center of the panel.

Water level fluctuations, like the ground movements associated with subsidence, do not occur until the point of consideration is undermined. Prior to being undermined,

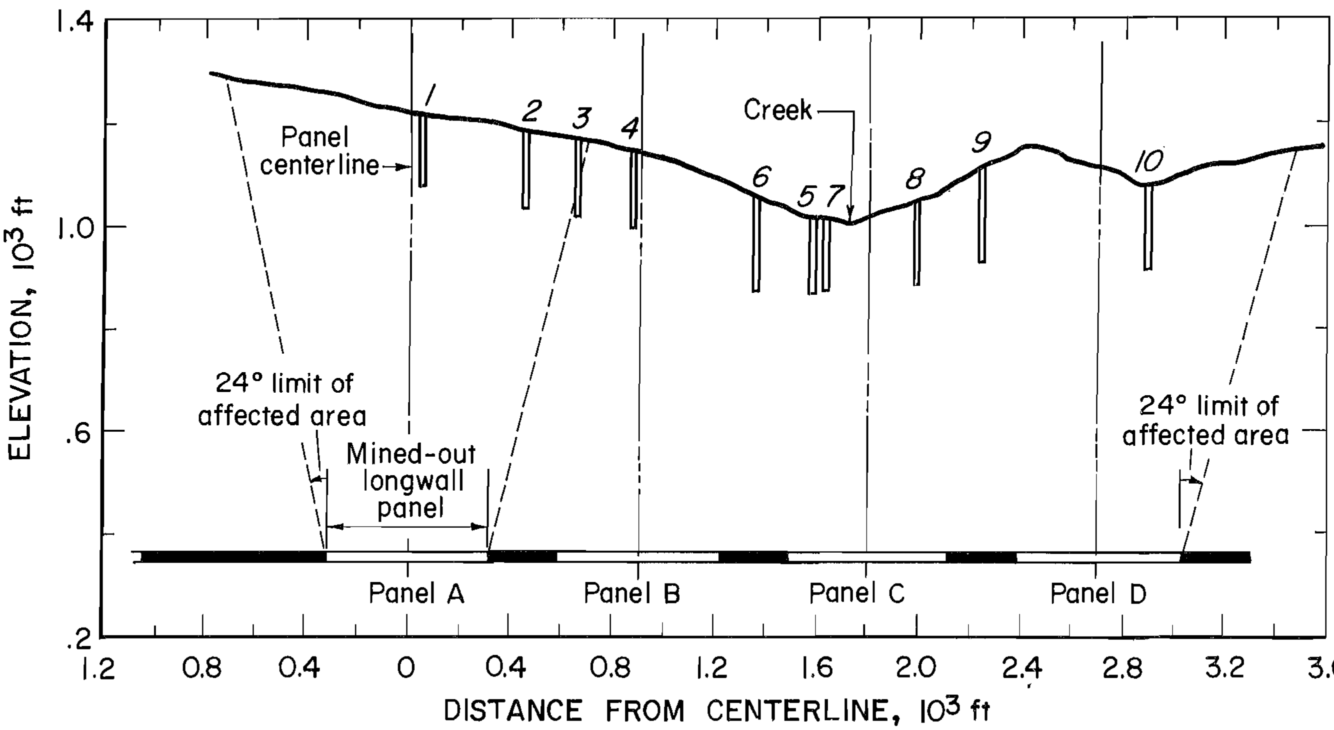

Figure 4.–Water well profiles.

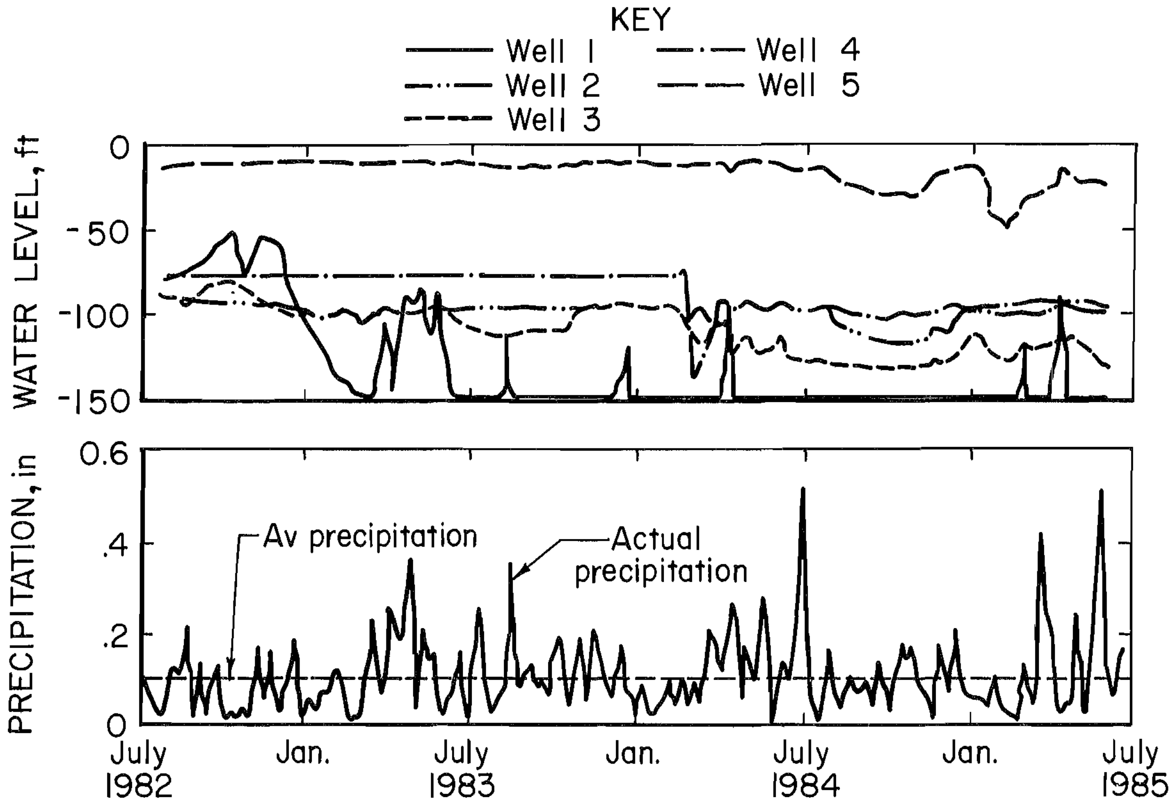

Figure 5.–Water level fluctuations, wells 1 through 5.

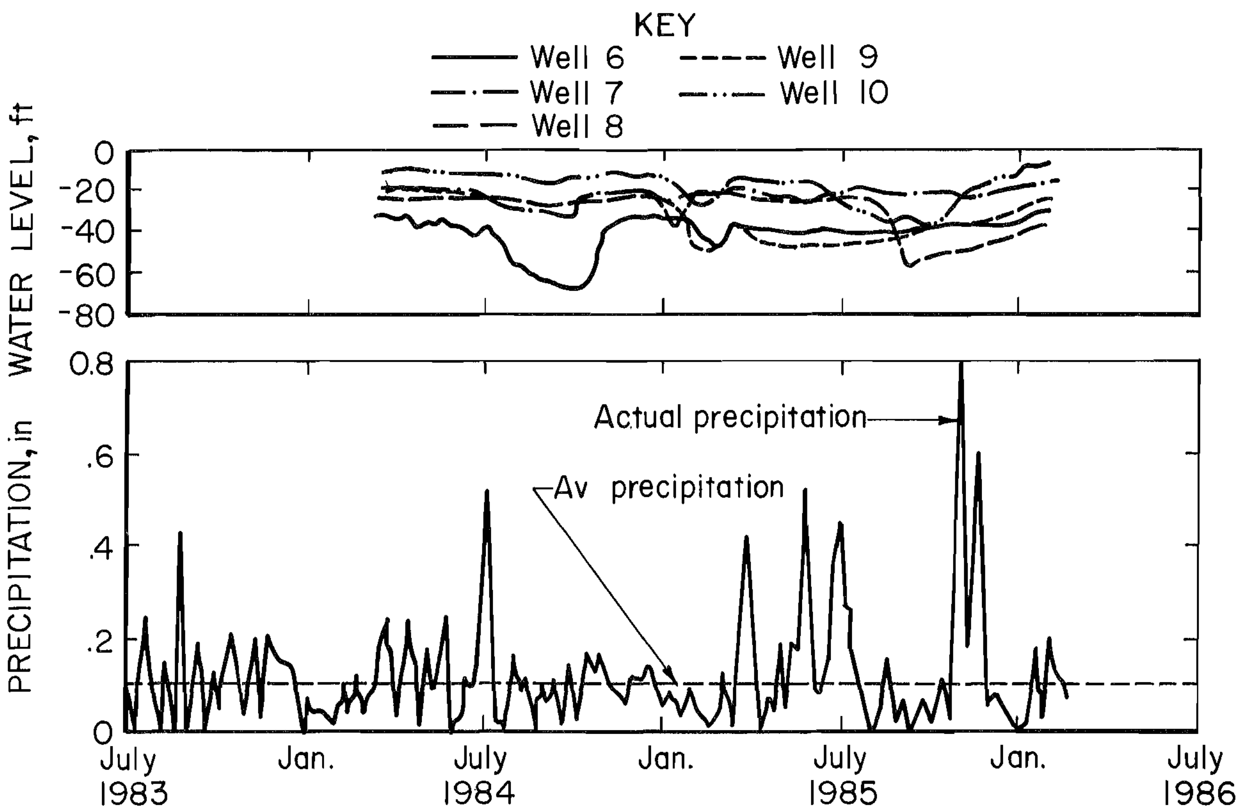

Figure 6.–Water level fluctuations, wells 6 through 10.

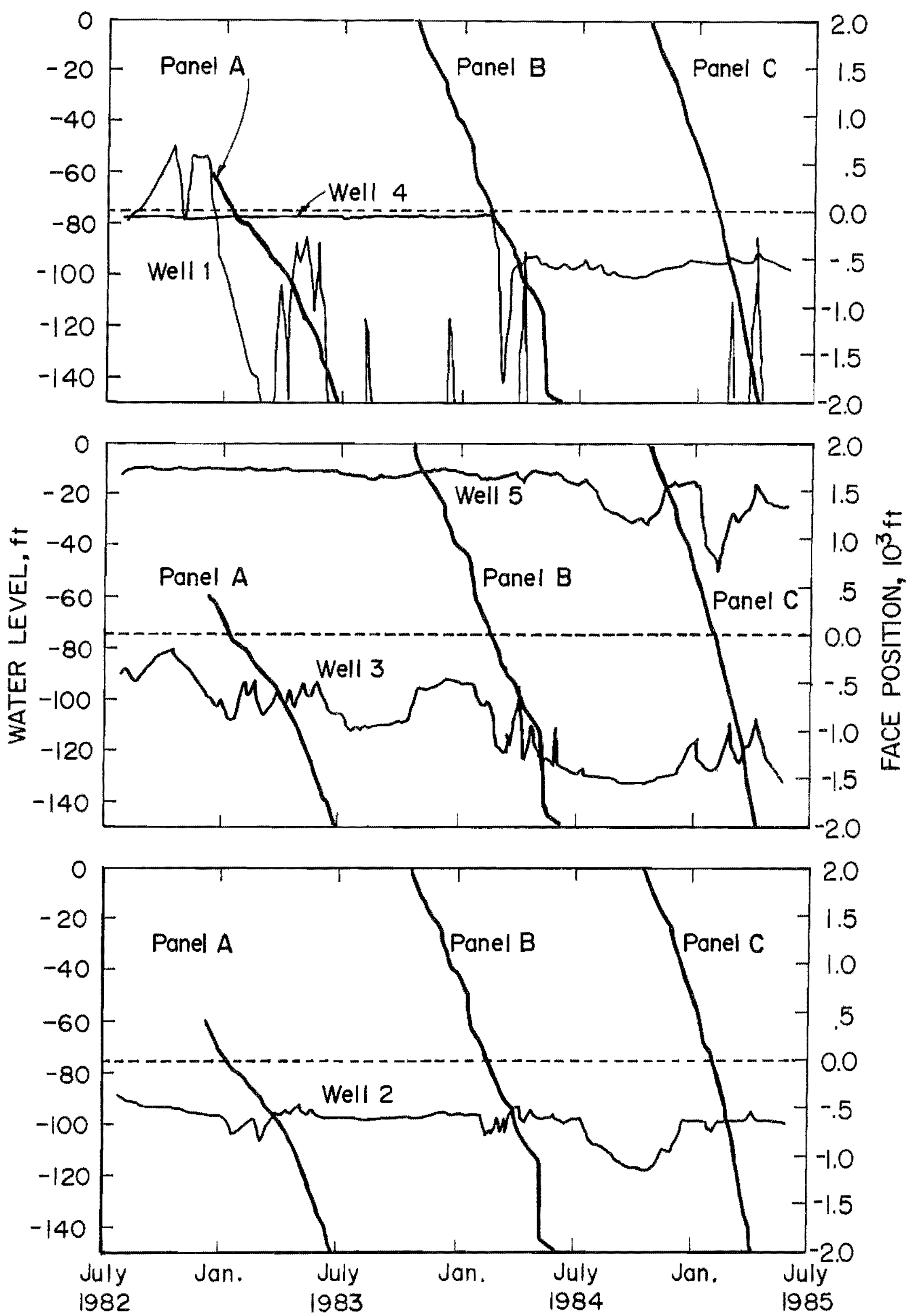

Figure 7.—Water level fluctuation and face position versus time.

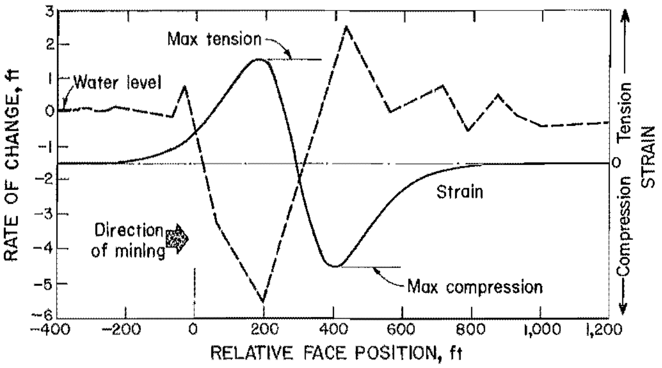

Figure 8.–Rate of water level fluctuation and strain as a function of relative face position.

water levels in the wells remained fairly stable. At this site the first water level fluctuations attributable to mining occurred when the advancing face was approximately 400 to 600 ft (approximately equal to the depth of the overburden) ahead of the well. The fluctuations continued until mining had progressed to a similar distance beyond the well. At a distance of approximately 200 ft (one-third the depth of the overburden) the rate of water level fall increased sharply.

Similar observations were made by Jeran and Barton (*8*), indicating that the progression of subsidence was a function of the face advance to overburden thickness ratio. By investigating this relationship further, a broad relationship between the rate of water level fluctuations and the strain developed by the advancing longwall face can be suggested.

The data indicate that the rate of water level decrease in the wells is the greatest when the ground surrounding the well is in tension.

Figure 8 shows the rate of fluctuation for well 4 and the derived strain curve as a function of overburden thickness. It can be observed from this figure that the rate of decline decreased as the dynamic development of strains was changing from tension to compression. The rate of recovery was the greatest when the ground was subject to maximum compressive strain. In this well only the tensile strain affected the fluid levels. The compression phase of the derived strain curve did not appear to significantly control either the rise or decline of the fluid level; only small fluctuations were encountered during this phase, which may be attributed to local strata adjustments.

By approaching the cause of water level fluctuations using the idea that the magnitude of the fluctuations is controlled by strain, the less severe fluctuations observed toward the edges of the panels and beyond can be easily explained. As the distance from the panel centerline increases, the magnitude of subsidence decreases, as does the related ground strain. This reduces the induced stresses and allows a smoother, more gradual fluctuation. The timing of the fluctuation, relative to the face location, also changes slightly as the distance from the centerline increase.

Fluctuations attributed to the mining of preceding and succeeding longwall panels were observed during the study and may also be related to subsidence-induced strains. A well is generally unaffected by mining in a preceding panel unless it is located within the angle of draw for that panel. The fluctuations observed for wells 3 and 5, shown in figure 5, describe this relationship. Generally, fluctuations are the greatest when the longwall face passes beneath an observation well and are smaller when the face passes in an adjacent panel. Fluctuations occurring during the mining of a succeeding panel may be related to the slight residual ground movements associated with the reactivation of the gob over a mined out panel.

SUMMARY AND CONCLUSIONS

This study has described the effect of mining a series of longwall panels on shallow water sources. Figures 9 and 10 illustrate the general results. The idealized premining and postmining ground surface and water levels in the observation wells after completion of mining of each panel are shown. The most pronounced effect on the local ground water system was the temporary lowering of the piezometric surface in most of the observation wells in response to mining. Wells 6 through 11, located in stream valleys, exhibited a lesser response to mining.

Relationships appear to exist between subsidence-induced strain and the water level changes recorded in the observation wells. The water level fell only when the ground near the well was in tension. The rate of the decline decreased as the sense of the strain was reversed and the water levels were found to be near the premining level before the ground was subject to maximum compressive strain. It should be kept in mind that the results of this study may not be applicable to other geographic regions having different topographic, geologic, and hydrologic characteristics. Much additional research must be performed to establish the degree to which such relationships may exist.

The results of this study support the following conclusions:

1. The fluctuation of the water levels appears to be a function of both the position of the well relative to the layout of the panel and the proximity of mining. A well is generally unaffected by mining of a preceding panel unless it was positioned within the angle of draw for that panel. Wells positioned at the centerline of a longwall panel exhibit the greatest fluctuations and head loss.

2. Water levels in shallow wells will generally return to or near premining levels after the completion of mining.

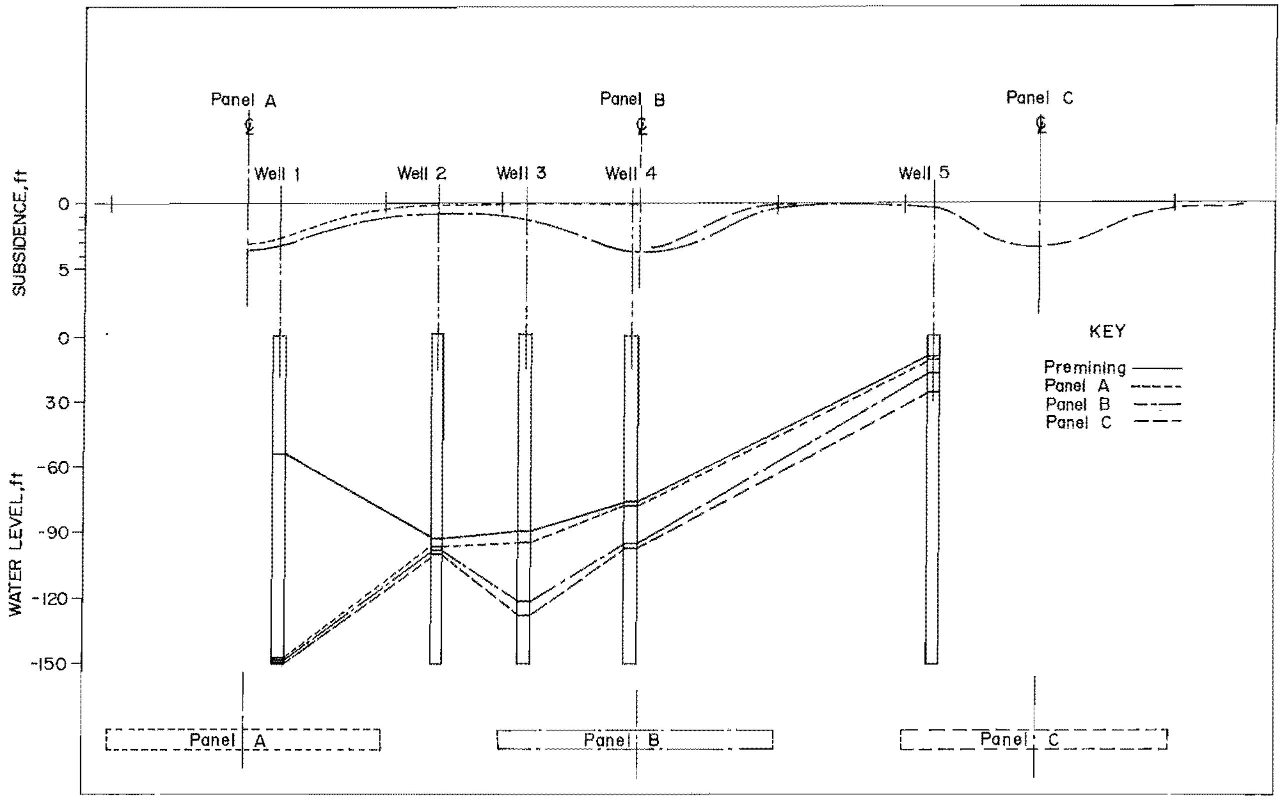

Figure 9.–Idealized premining and postmining ground surface and water levels, wells 1 through 5.

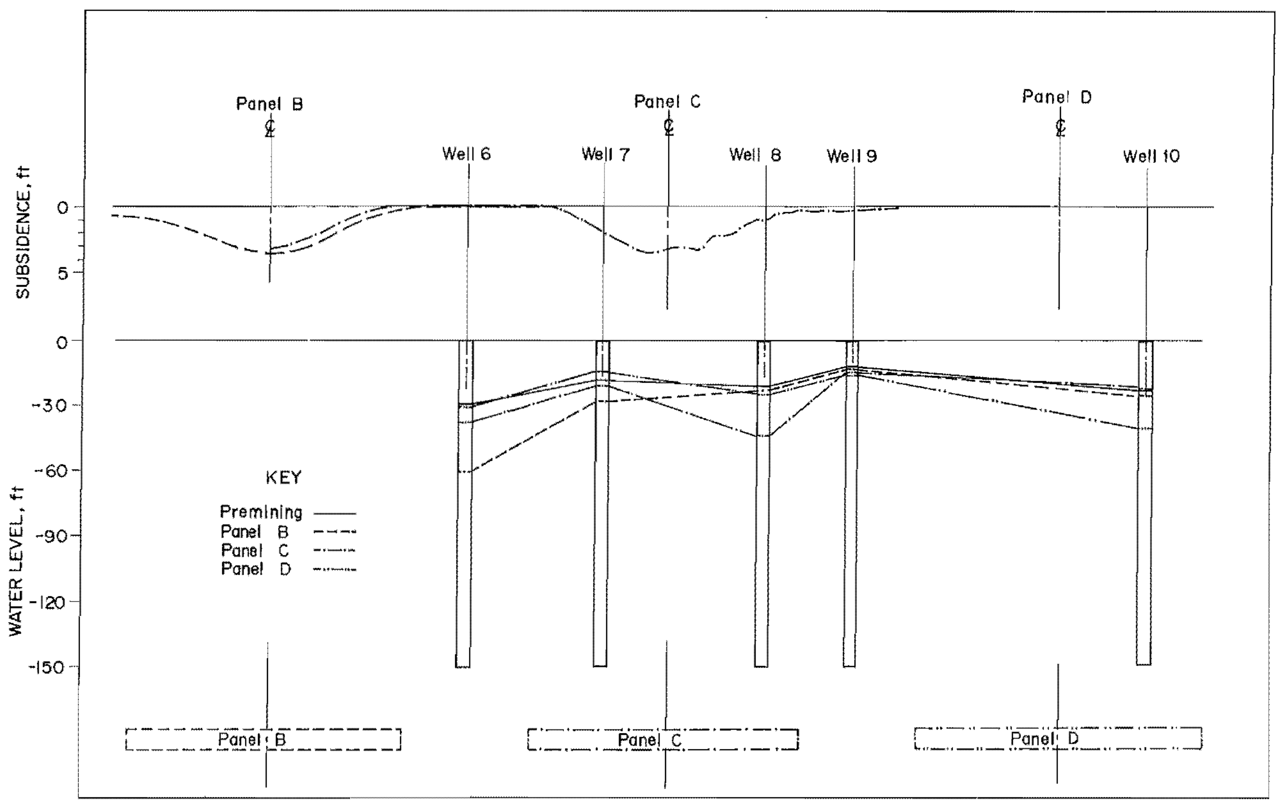

Figure 10.–Idealized premining and postmining ground surface and water levels, wells 6 through 10.

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APPENDIX A.–WELL WATER ANALYSIS

TABLE A-1. - Well water analysis, wells 1 thrugh 10, parts per million

	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8	Well 9	Well 10
Alkalinity as $CaCo_3$:										
Premining	211.0	207.0	252.0	176.0	218.0	204.0	170.0	215.0	168.0	156.0
Postmining	161.0	164.0	162.0	166.0	193.0	194.0	208.0	146.0	153.0	21.0
Calcium as $CaCO_3$:										
Premining	245.0	184.0	197.0	157.0	101.0	58.0	36.0	4.8	98.0	42.0
Postmining	195.0	155.0	155.0	176.0	117.0	65.0	43.0	13.0	39.0	45.0
Chloride as NaCl:										
Premining	17.0	17.0	23.0	12.0	29.0	10.0	18.0	10.0	14.0	11.0
Postmining	20.0	25.0	25.0	33.0	45.0	11.0	17.0	19.0	13.0	10.0
Chromium as Cr:										
Premining	.2	.2	.2	.2	.2	NA	NA	NA	NA	NA
Postmining	ND	ND	ND	ND	ND	NA	NA	NA	NA	NA
Dissolved solids:										
Premining	502.0	207.0	252.0	176.0	218.0	ND	124.0	320.0	134.0	106.0
Postmining	386.0	236.0	210.0	250.0	256.0	242.0	215.0	237.0	246.0	94.0
Ferrous iron as Fe:										
Premining	.4	1.2	ND	ND	.7	NT	NT	NT	NT	NT
Postmining	ND	ND	ND	ND	ND	NT	NT	NT	NT	NT
Manganese as Mn:										
Premining	.1	.2	.2	.1	.1	ND	ND	ND	.2	ND
Postmining	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Magnesium as $CaCO_3$:										
Premining	80.0	94.0	80.0	43.0	38.0	NT	8.7	1.8	36.0	8.7
Postmining	88.0	62.0	50.0	36.0	38.0	11.0	3.2	3.0	7.0	4.1
Nickel as Ni:										
Premining	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Postmining	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nitrate as NO_3:										
Premining	1.0	1.6	2.4	2.5	4.4	.2	ND	.1	ND	1.8
Postmining	2.1	2.2	1.7	2.5	1.8	.1	.1	.3	.2	.2
Potassium as K:										
Premining	2.0	2.0	2.0	2.0	2.0	NT	NT	NT	NT	NT
Postmining	ND	ND	ND	ND	ND	NT	NT	NT	NT	NT
Sodium as Na:										
Premining	13.0	11.0	12.0	21.0	53.0	17.0	39.0	101.0	26.0	24.0
Postmining	9.0	8.0	7.0	17.0	41.0	5.0	88.0	61.0	32.0	11.0
Sulfate as SO_4:										
Premining	101.0	57.0	48.0	62.0	12.0	20.0	37.0	30.0	32.5	32.0
Postmining	89.0	41.0	36.0	48.0	29.0	20.0	45.0	25.0	35.0	25.0
Total iron as Fe:										
Premining	.4	1.2	.4	.7	.7	.1	.7	.5	1.0	.5
Postmining	1.3	.2	.2	.2	.3	.4	.1	.7	1.6	.5
Zinc as Zn:										
Premining	.5	.2	.1	.1	.2	NA	NA	NA	NA	NT
Postmining	ND	ND	ND	ND	ND	NA	NA	NA	NA	NT
pH:										
Premining	6.8	7.0	7.0	7.4	7.3	8.7	7.3	9.0	7.8	7.9
Postmining	7.9	7.4	7.4	7.5	7.7	8.8	7.5	9.1	7.9	8.1
Specific conductivity:										
Premining	410	600	600	350	560	370	360	450	360	350
Postmining	440	440	390	440	450	395	460	340	365	180

NA Not available.
ND Not detected.
NT Not tested.

APPENDIX B.– INDIVIDUAL WELL DATA

WELL 1

Well 1 is at the highest elevation of all the wells in the study. It is located on the top edge of an incised stream valley at an elevation of 1,220 ft, approximately 200 ft above the nearest perennial stream. The depth to the mine from this well is approximately 855 ft. The water level in well 1 began an unexplained rise in August 1982, prior to the beginning of mining in panel A (fig. B-1, top). The rise continued for 3 months until the face was approximately 500 ft away from the well; the water level then began a gradual decline. The water level in the well continued to fall until the well went completely dry. Once the face had passed the well by approximately 500 ft, the well recovered to its original water level for approximately 2.5 months before going dry for the remainder of the study period. Of the 10 wells investigated, well 1 was the only well observed to exhibit a total head loss.

WELL 2

Well 2 is located on a hillside at an elevation of 1,175 ft, approximately 155 ft above the nearest stream valley. The overburden at this well is approximately 810 ft. Relative to the mine, well 2 is located above the chain pillars between panels A and B. Water level fluctuations occurred during the mining of both panels A and B (fig. B-2 middle). The fluctuations began just as the face undermined the line of wells and continued until the face had advanced an additional 1,000 ft. The magnitude of the fluctuations was approximately equal for each panel. A large depression in the water level was observed during the summer and fall of 1984. This is attributed to a drought that occurred during that summer. No additional fluctuations attributed to mining were observed in this well during the remainder of the study.

WELL 3

Well 3 is located at an elevation of 1,143 ft on a hillside approximately 120 ft above the major perennial stream for the area. Relative to the mine, it is located at the edge of panel B, approximately 320 ft from the ribline of panel A. The overburden depth at this well is 774 ft. The water levels in well 3 were unstable for most of the monitoring period; water level changes were as much as 33 ft, with apparent head losses occurring after the mining of each panel (fig. B-1, bottom). The fluctuations could not be attributed to subsidence with any certainty; however, they follow the general pattern established by the other wells. The water level in the well began to fall as the face was approximately 900 ft ahead of the line of wells and continued to fall until the face had passed 1,500 ft beyond the well. The severe depression in the water levels observed during the summer and fall of 1985 is attributed to a drought. Fluctuations occurred during the mining of panel C, most likely as a result of gob reactivation in panel B; however, no specific correlations could be made because of the masking effect of the drought.

WELL 4

Well 4 is located on the edge of a perennial stream valley at an elevation of 1,068 ft, approximately 40 ft above the stream. Relative to the mine, it is located at the edge of panel B closest to panel C, 580 ft outside of the ribline of panel A, beyond the 24° angle of detectable surface subsidence. No water level fluctuations were observed in this well during the mining of panel A (fig. B-2, top). The only fluctuations attributed to mining occurred during the mining of panel B. This well gives a good impression of what is believed to be the typical water level response to mining. The water level dropped sharply as the well was undermined, recovering after the face had advanced a distance past the well that was approximately equal to the depth of the overburden (693 ft). No additional fluctuations occurred during mining of panel C; however, they may have been masked by the summer drought.

WELL 5

Well 5 is located in a perennial stream valley adjacent to the stream at an elevation of 1,020 ft. Relative to the mine it is located at the edge of panel C closest to panel B. The overburden at this well is 623 ft. No effects of mining were observed in this well during the mining of panel A, and only a very short period of fluctuations occurred during the mining of panel B (fig. B-2, bottom). During the mining of panel C the well was observed to exhibit typical behavior. The water level began to fall as the line of wells was undermined and rebounded after the face had passed approximately 700 ft beyond the well. The 1985 summer drought is reflected in the well observations; this may be an explanation as to why no fluctuations were observed during the mining of panel B and the apparent head loss occurring after the mining of panel C. No additional fluctuations attributed to mining were observed during the remainder of the study.

WELL 6

Well 6 is located in a perennial stream valley adjacent to the stream at an elevation of 1,070 ft. The thickness of overburden at this well is 696 ft. Relative to the mine, it is located above the chain pillars separating panels B and C. This well was not completed until after the completion of mining in panel B. An unexplained drop in water level occurred several months after the well was drilled (fig. B-3, top). This drop is believed to be unrelated to subsidence at the observation well. However, it is not difficult to visualize that the cause of the lowered water level is related to the quantity of flow in the adjacent stream, which may have been affected for a short time while the panel B was being mined. A typical drop in

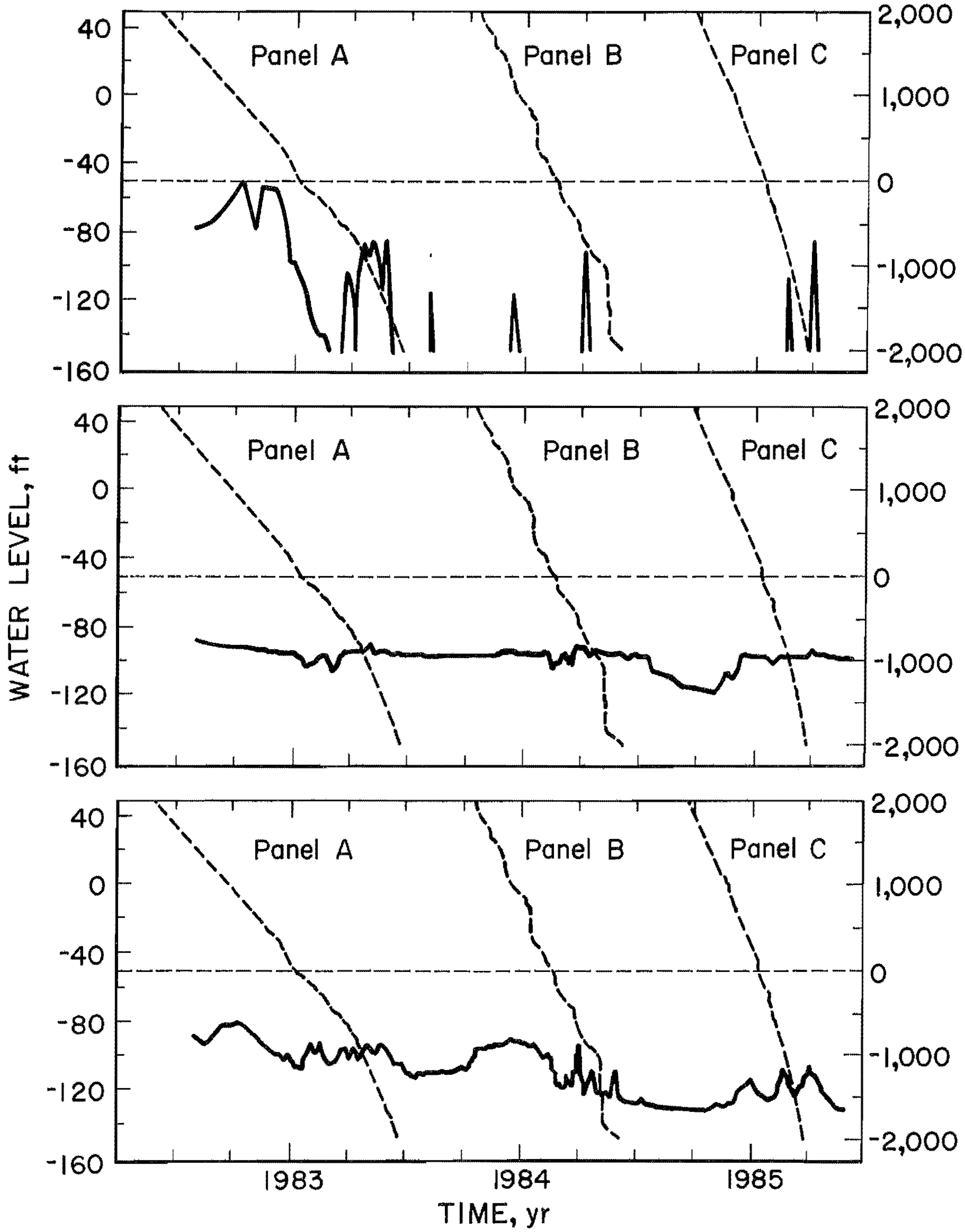

Figure B-1.–Water level fluctuations, well 1 (top), well 2 (middle), and well 3 (bottom).

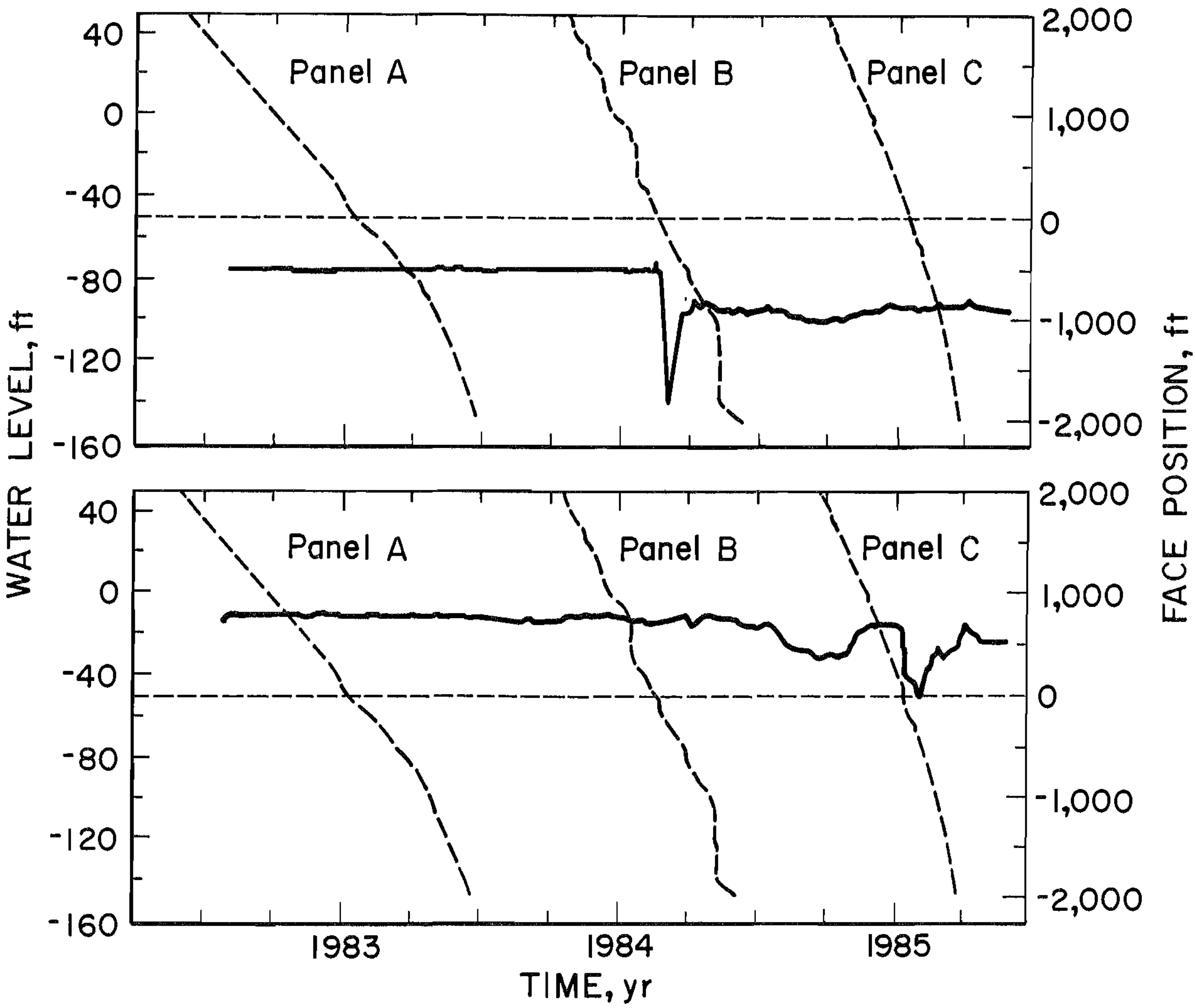

Figure B-2.–Water level fluctuations, well 4 (top) and well 5 (bottom).

water level was observed during the mining of panel C. No additional fluctuations attributed to mining were observed during the remainder of the study.

WELL 7

Well 7 is located in the same stream valley as well 6, also adjacent to the stream at an elevation of 998 ft. The depth to the mine at this point is approximately 620 ft. Relative to the mine, the well is located on the edge of panel C closest to panel B. This well was not completed until after the mining had passed the well line on panel B. A depression in the water levels occurred shortly after the installation of the well; this depression is attributed to the lowering of the water level in the stream as described for well 6 (fig. B-3, middle). Typical water level fluctuations were observed in this well during the mining of panel C. No additional fluctuations attributed to mining were observed during the remainder of the study.

WELL 8

Well 8 is located along a intermittent stream valley at an elevation of 1,175 ft. Relative to the mine the well is located at the edge of panel C closest to panel D. The thickness of the overburden at this point is approximately 636 ft. This well was not completed until mining had passed the well line in panel B. Fluctuations attributed to mining were observed only during the mining of panel C (fig. B-3, bottom). The fluctuations were typical of those observed in other wells except that the water level did not rebound to the premining level until after the mining of panel D. This is attributed to the drought during the summer of 1985, which may have slowed the recovery and masked the succeeding fluctuations.

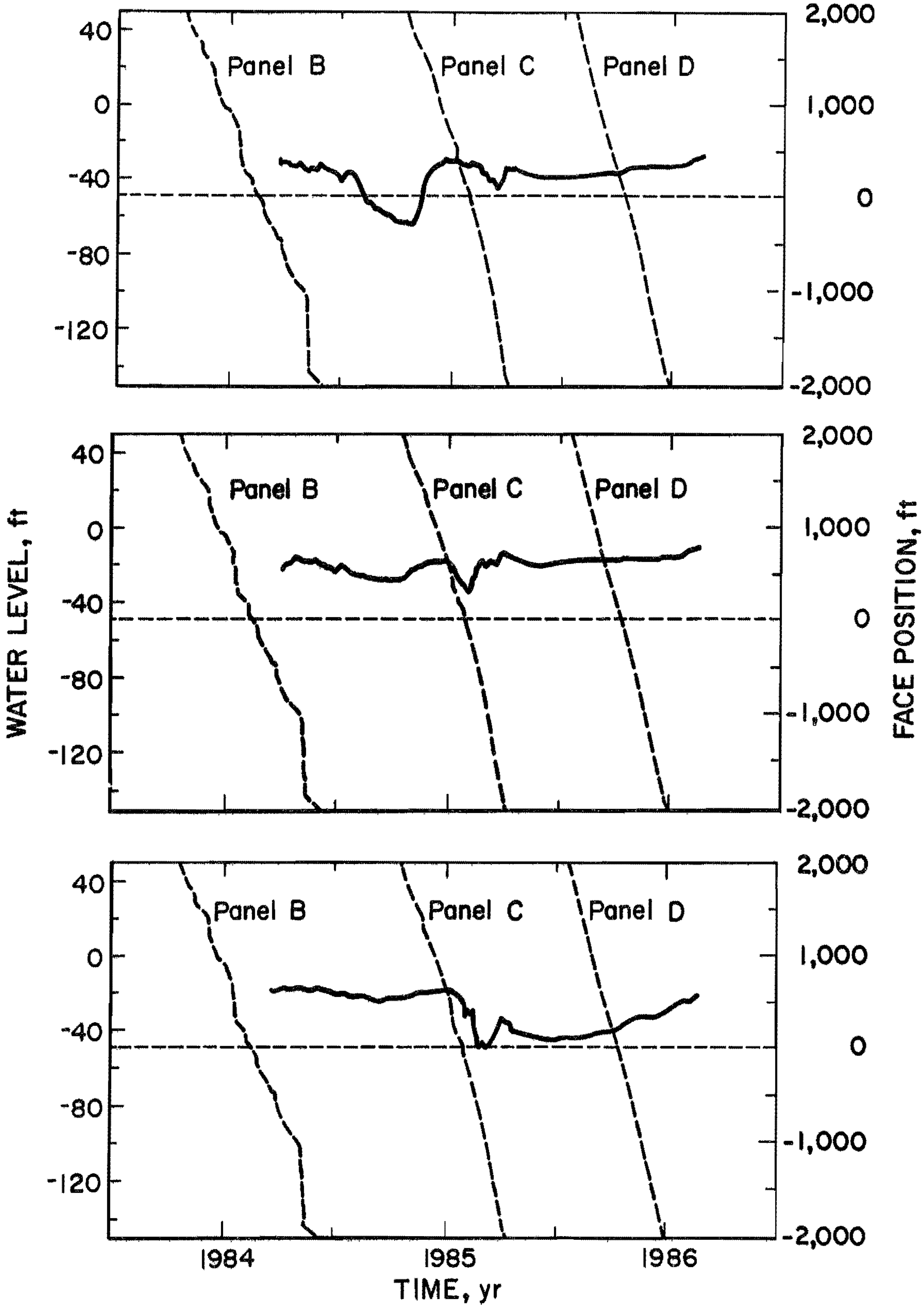

Figure B-3.–Water level fluctuations, well 6 (top), well 7 (middle), and well 8 (bottom).

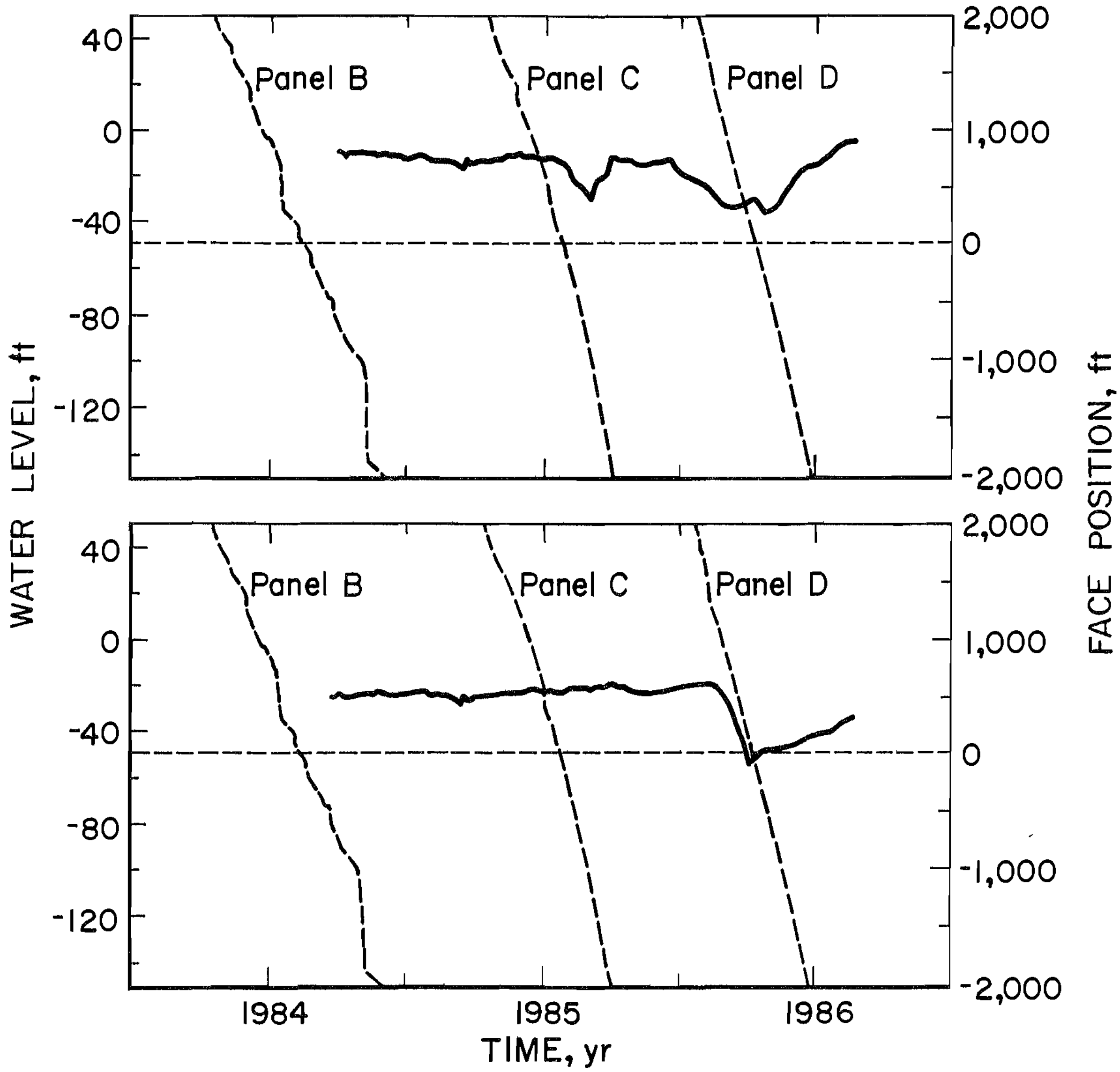

Figure B-4.–Water level fluctuations, well 9 (top) and well 10 (bottom).

WELL 9

Well 9 is located along an intermittent stream valley at an elevation of 1,150 ft. Relative to the mine the well is located above the chain pillars between panels C and D. The thickness of the overburden at this well is approximately 630 ft. The well was not completed until the mining in panel B had passed the well line. Fluctuations attributed to mining were observed only during the mining of panel C (fig. B-4, top). The fluctuations were typical of those observed in other wells except that the water level did not rebound to the premining level until after the mining of panel D. This is attributed to the drought during the summer of 1985, which may have slowed the recovery and masked the succeeding fluctuations.

WELL 10

Well 10 is located near the head of an intermittent stream valley adjacent to the stream at an elevation of 1,195 ft. Relative to the mine the well is located above the edge of panel outside the 24° angle of detectable surface subsidence for panel C. The depth to the mine at this well is 764 ft. This well was completed after the mining in panel B had passed the well line. No significant changes in the water level were recorded until the summer of 1985 when mining approached panel D (fig. B-4, bottom). Prior to the well being undermined, the water level began to drop rapidly until the face passed the well. The well then began to recover at rate that was the slowest of all wells monitored. Similarly, during the period of recovery the flow in the adjacent stream was reduced to only wet weather drainage. The significance of these observations is complicated by the fact that the effect of the summer drought may contribute more to the decrease of the water level in this well than the mining, as is evidenced by the uncharacteristic gradual decrease in the water level.

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