DISTURBANCE OF SURFACE STREAM DUE TO LONGWALL MINING[1]

Felicia F. Peng, Zhouming Sun and Syd S. Peng[2]

Abstract: Surface streams over longwall panels, like other surface features, may also be affected by underground mining. Disturbed surface stream beds and surface water bodies may cause surface environmental problems and create potential water hazards to the underground mining operation. When a coal seam is extracted under a surface stream, the stream water may form migratory ponds following the surface waves created by the dynamic surface subsidence process. If a thin overburden exists, the water in a migratory pond may fall into the surface dynamic cracks as it travels across the longwall panel. After the surface has reached the final subsidence stage, the migratory ponds will cease moving and stop near the chain pillar area and form a stationary pond. Loss of water may occurs in a stationary pond, because it is located in the high tension zone (or surface crack zone) where its secondary permeability increases. This paper presents a field investigation, including monitoring the stream flow, stream water depth, and surface subsidence. The results discover the phenomenon of pond formation, identify the major factors contributing to stream disturbance and lead to the development of mitigative measures and remediation activities.

Additional Key Words: subsidence damage, migratory pond, stationary pond, subsidence mitigation

Introduction

A recently observed problem over a longwall mining area is the formation of water ponds along a stream valley. The formation of stream ponds may cause problems for both the surface environment and the underground mining operations if one or more of the following conditions exist: (1) disturbance of water supplies for farming, animal, and domestic uses, (2) changes in stream path and natural appearance as well as loss of stream water, and (3) a large body of water has formed on the surface which may eventually enter into the mine workings. The phenomenon of water ponding over the high-extraction mined areas has been described previously (Ackman and Jones 1988; Stump 1992). However, correlation between the magnitude of ground subsidence and the disturbance of surface stream has not been reported.

Field investigation in this project included monitoring stream flow rate, stream water depth, and surface subsidence along a main stream over three successive longwall panels. Considerable data have been obtained as results of the carefully designed monitoring program. The results discover the formation phenomena of stream ponds, identify the major factors contributing to stream disturbance, and lead to the development of mitigative measures and remediation activities.

Field Investigation

Site Description

Field investigation for the formation process of a number of stream ponds was conducted along a main stream which ran transversely across five longwall panels. These longwall panels were designated as panel 1 to panel 5 according to the mined sequence, as illustrated in figure 1. The panels were 198 to 229 m (650 to 750 ft) wide and 763 to 854 m (2,500 to 2,800 ft) long. The coal seam was 2 m (6.5 ft) thick and was mined from northwest to southeast at face advance rates ranging from 9 to 20 m (30 to 65 ft) per day. The surface around the study site was

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slightly hilly with several houses built on it. The overburden depth was 70 to 107 m (230 to 350 ft). There were also several domestic wells and springs. These wells and spring water stored in cisterns were the main drinking water sources for local residents. The stream water and springs also served as the major water sources for some domestic animals and other usage. The main stream bed was about 1.1 m (3.5 ft) high and 0.4 m (1.2 ft) wide, and its water varied from 0.8 to 0.9 m (2.5 to 3.0 ft) deep. It flowed from the tailentry of panel 1 to the headentry of panel 5 at approximately 315° to the mining direction. The first two panels (longwall panel 1 and longwall panel 2) had been mined out before the commencement of this field investigation. Two water ponds were formed along the main stream inside and near the headentry of the two mined-out panels.

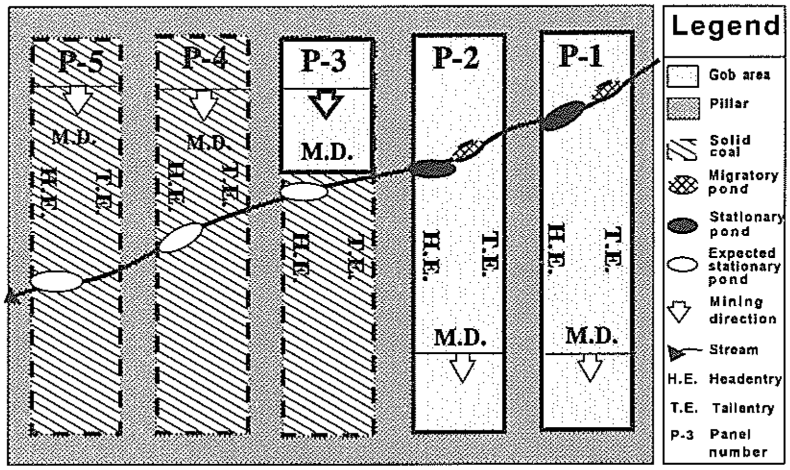

Figure 1. Longwall panel layout and location of stream ponds

To investigate the remaining three panels (panel 3 to 5), three types of monitoring stations, namely, stream flow station, water level station, and subsidence monument, were employed. Two stream flow stations used as reference points were installed in the upstream, R_{up}, about 1434 m (4,700 ft) from the headentry and in the downstream, R_{dw}, about 305 m (1,000 ft) from the tailentry of panel 5. They were used as the baseline to determine water loss at other monitoring stations.

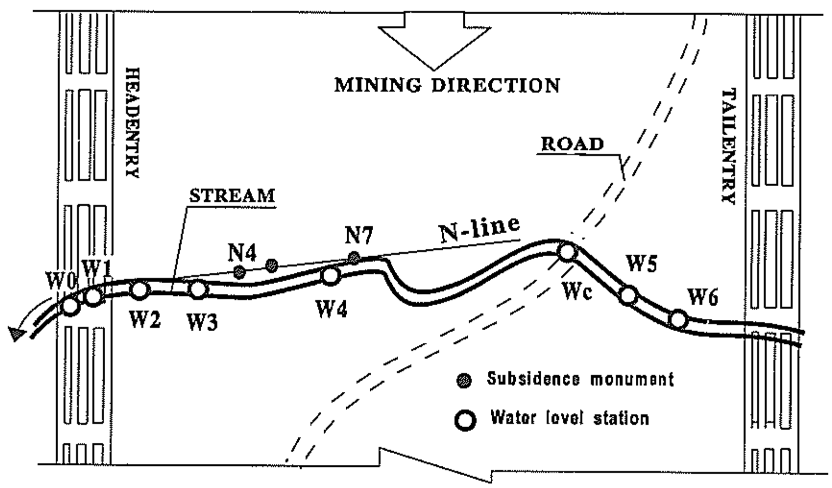

Figure 2. Water-monitoring stations and subsidence line over longwall panel 3

Installation of Water and Subsidence-Monitoring Stations

The stream flow stations consisted of rectangular and V-notch weirs made of wood and earth dam (Bureau of Reclamation 1984). A subsidence monument was made of wood sticks in size of 2.5x5x30 cm (1x2x12 in). A total station was employed for subsidence survey. Various lengths of the wood sticks attached with rulers were used for the water level stations. The installation of the water and subsidence monitoring on each longwall panel are described as follows: *On longwall panel 3*, twelve stream flow stations along the main stream and seven subsidence monuments along the N-line were installed, respectively, as shown in fig. 2. All subsidence monuments were placed a short distance off the main stream close to the headentry of longwall panel 3 so that they would not be flooded as the surface subsided. *On longwall panel 4*, the layout of monitoring stations over the panel is shown in fig. 3. It was a long dry period during the earier stage of the measurement period. A low flow rate at the upstream, R_{up} was recorded. The stream water in the previously

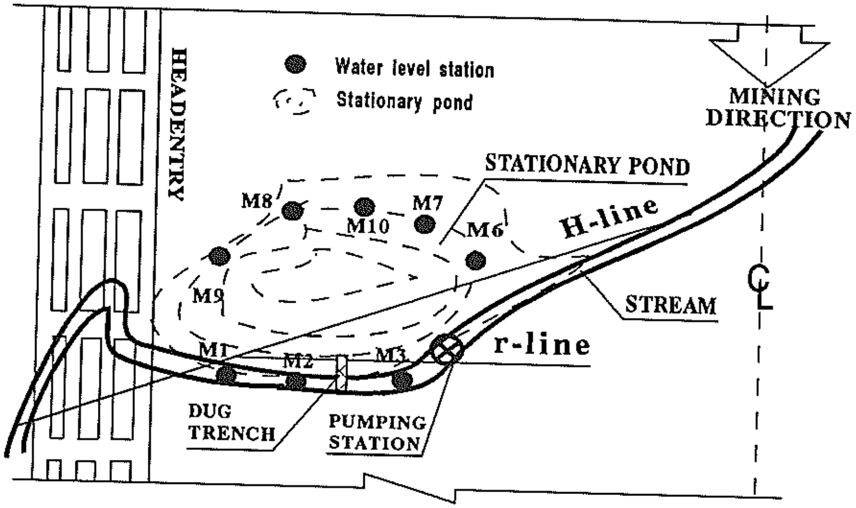

Figure 3. Water-monitoring stations, subsidence lines, and stationary pond over longwall panel 4

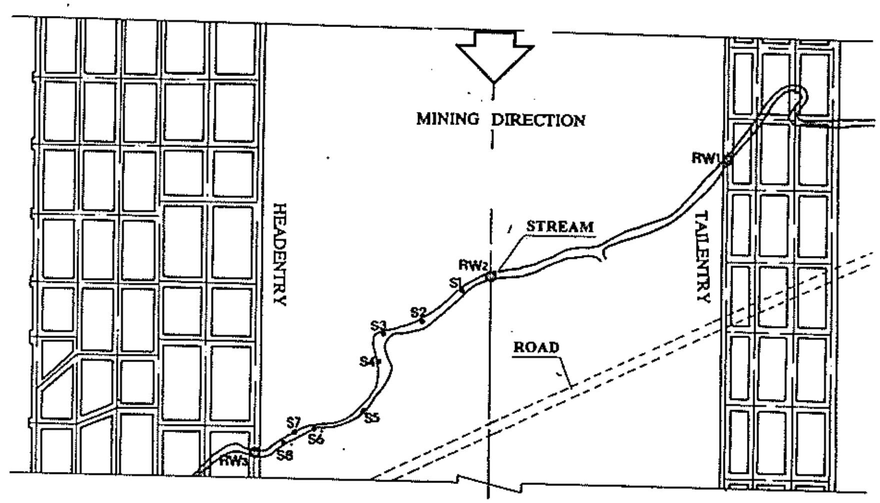

Figure 4. Water-monitoring stations along S-line over longwall panel 5

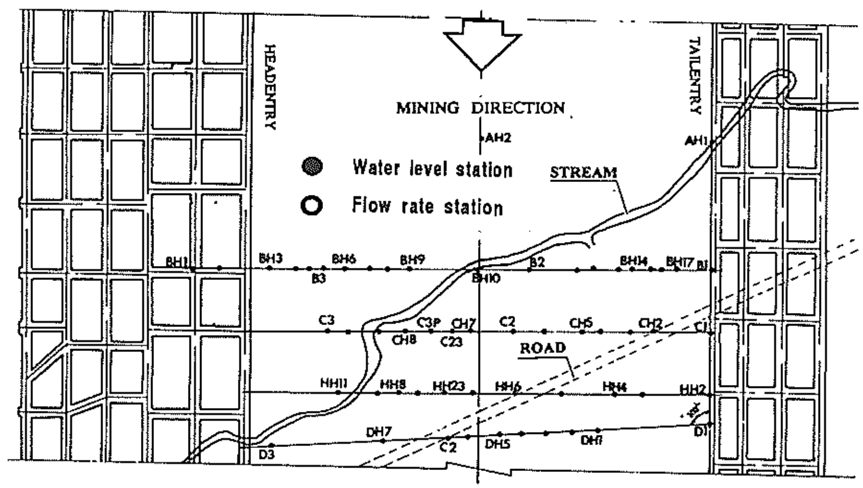

Figure 5. Subsidence monuments over longwall panel 5

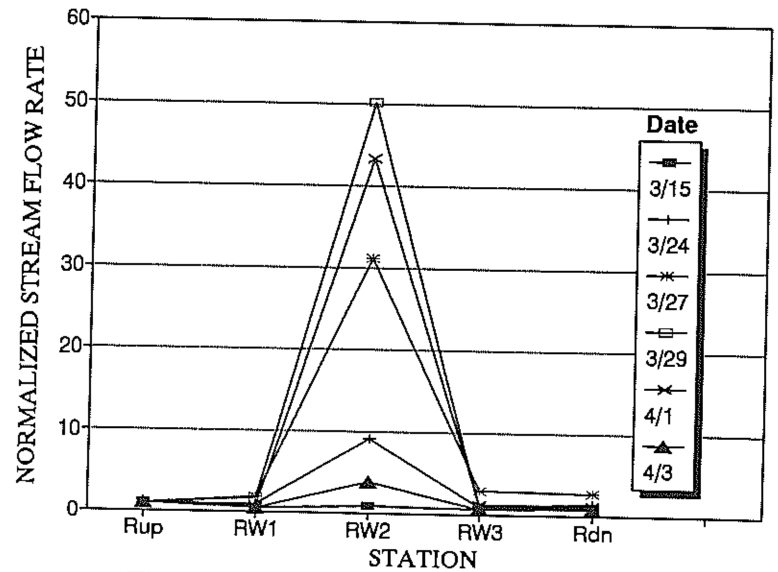

Figure 6. Normalized stream flow rate at RW1, RW2 and RW3 over longwall panel 5

mined-out longwall panel 3 was also dry out due to the lost of the water to the surface cracks. In later stage of the measurement period, the accumulated stream water near the headentry of longwall panel 4 was observed after the crack closures in longwall panel 3. As a mitigative measure, the accumulated stream water was pumped over to the adjacent longwall panel 5 using the sump, pump and a 10 cm (4 in) ID vinyl hose. The monitoring was focused on the flow rate of the springs and the reference stations, the changes of water levels, and surface subsidence on the r-line along the main stream. *On longwall panel 5*, the stream flow stations, stream water level stations, and subsidence monuments were systematically installed over the longwall panel 5, which covered a rectangular area 229 m (750 ft) long by 122 m (400 ft) wide, as illustrated in figures 4 and 5. Periodical surveys of stream ponds and subsidence were performed over the area.

Results and Discussion

Normalized Stream Flow Rate

The measured stream flow rates over the three panels have considerable fluctuation from day to day and from station to station (Sun 1993). The unstable stream flow rates may be caused by the following factors: movement of stream bed due to surface subsidence, change in precipitation, varying sources of stream water, feeding of small tributaries into the main stream, and errors in measurements of the head of stream water. Among these factors, surface subsidence plays a major role in the fluctuation of the stream flow rate.

The normalized stream flow rate (*NSFR*) is employed to represent the relationship between any station of interest i and a reference station r in any given day j. *NSFR* is defined as $Q_{i,j} = q_{i,j}/q_{r,j}$, where $Q_{i,j}$ is the normalized stream flow rate at station i on day j; $q_{i,j}$ is the measured stream flow rate at station i on day j, and $q_{r,j}$ is the measured stream flow rate at reference station r on day j. Before the longwall face approached the stream, the initial flow rates at every station were measured. If *NSFR* at any given station i is greater than the initial *NSFR*, the stream water is considered to have water accumulated around that station. On the other hand, the stream water is considered to have water lost if the *NSFR* is less than the initial one. The *NSFR* of longwall panel 5 is shown in figure 6. The results indicate that the *NSFR* at stream flow station RW2 was greater than that at other stations. It increased first and then gradually decreased. This phenomenon was contributed by the movement of the body of water along the main stream as a result of the moving surface subsidence waves. When surface subsidence was over, the *NSFR* for RW2 was still higher than its initial measurement. This is because RW2 was located at the panel center, where the maximum subsidence occurred.

Migratory and Stationary Ponds

The migratory (or transient) and stationary (or relatively stable) stream ponds were observed over all five longwall panels during the longwall mining. The development of these ponds can be described by the variations of the water depth measured in the vicinity of the stream, as shown in figures 7 to 8 for panel 4 and 5, respectively. The data show that the water depth increased first, and then gradually decreased until it reached a relatively stable level. This process results in the formation of the migratory and stationary ponds. The migratory pond moves from the tailentry (upstream) until it reaches the stable stage to form a stationary pond close to the headentry (downstream). The water depth of a stationary pond may change, but the geometrical center of the pond is relatively constant. For example, the formation of the stream ponds (i.e. pond 1 to pond 5) in panel 5 is schematically shown in figure 9. Pond 5 is a stationary pond settled by the headentry of panel 5.

Impact of Surface Subsidence on Stream Ponds

The disturbed stream flow rate and water depth over longwall panels are quite different from a pure channel flow. A significant movement of the stream bed caused by surface subsidence leads to a pronounced change in stream flow rate and water depth. Surface subsidence was surveyed for all three panels as shown in figures 10 to 12. Surface subsidence propagates like a wave and causes the formation of the stream ponds. Correlation of the

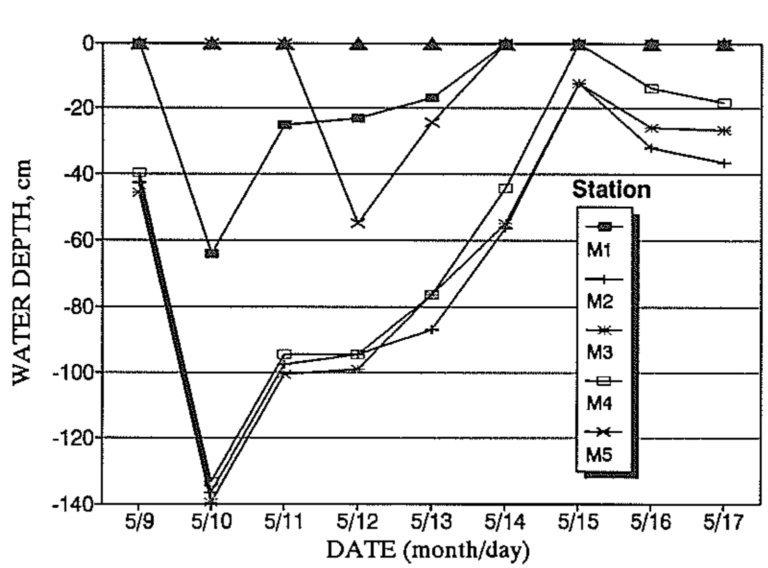

Figure 7. Water depth as function of time along M-line over longwall panel 4

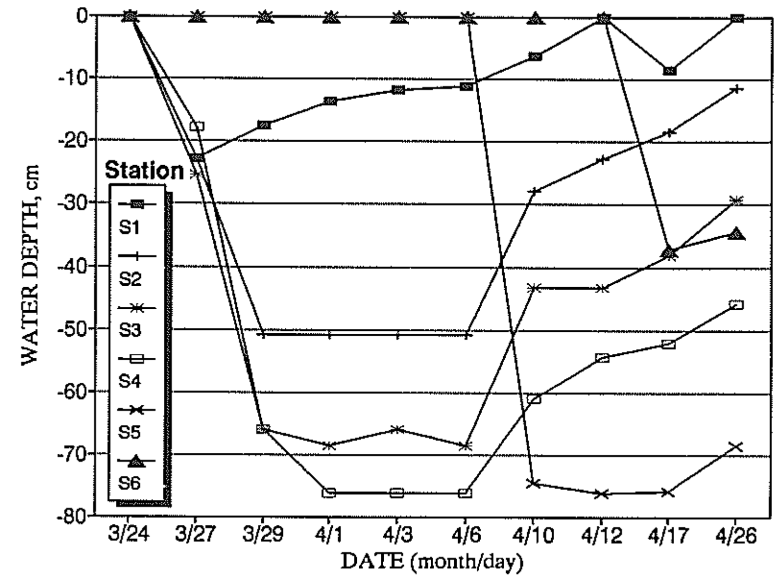

Figure 8. Water depth as function of time along S-line over longwall panel 5

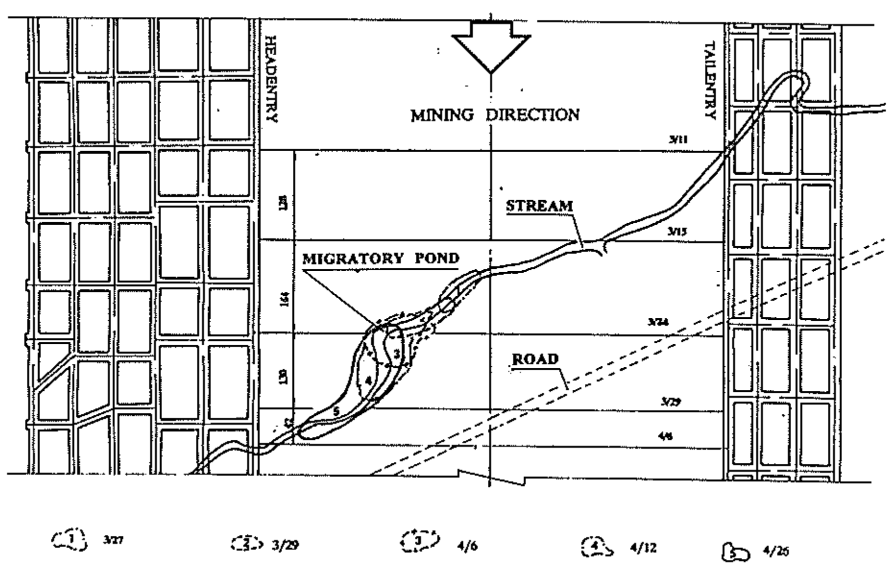

Figure 9. Formation process of migratory ponds over longwall panel 5

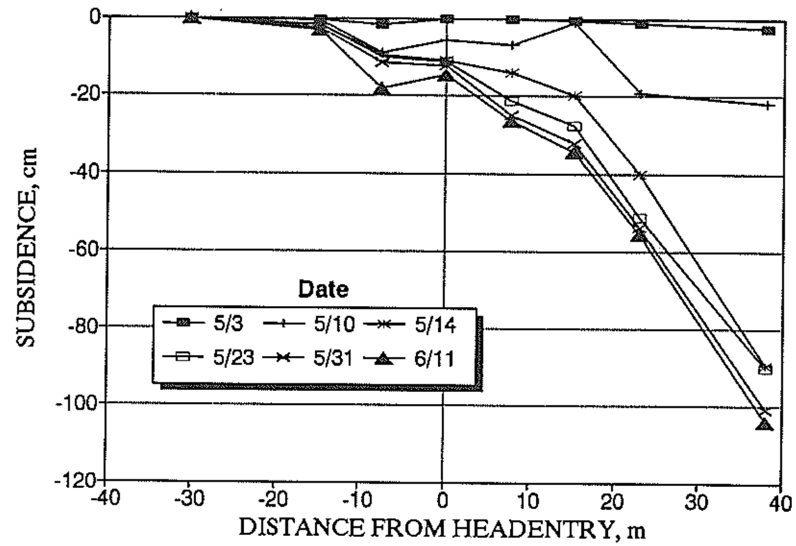

Figure 10. Subsidence profile along N-line over longwall panel 3

formation process of a stream pond at W4 with the surface subsidence at monument N7 over longwall panel 3 shows that the formation of the migratory pond corresponds to the stage 1 of the dynamic subsidence process (Peng 1993) as illustrated in figure 13. At the end of stage 1, surface subsidence at N7 had reached about 85% of its maximum amount, and the migratory pond approached a stable stage. Both the pond and subsidence were stabilized during stage 2 (85 to 90% of maximum subsidence). Surface subsidence increased slightly during stage 3 (more than 90% of maximum subsidence), but the water depth of the stationary pond kept almost the same as the previous level, or decreased slightly at the end of stage 3.

Effect of Angle of Stream Flow

The orientation of a flowing stream over a longwall panel can be classified into four types of patterns based on the angle of stream flow. The angle of stream flow is defined as the angle between the advancing direction of the longwall face and the flowing direction of the surface stream (measured clockwise) as shown in figure 12. From these four types of stream flow patterns (table 1), the formation of the migratory and stationary ponds for a given longwall panel can be predicted.

Accordingly, the defined angle of stream flow takes into account the surface stream flow conditions, and surface subsidence as well as the mining direction. It is a method to determine the severity of stream ponding under various mining conditions. The development of the angle of stream flow and its application have been described in detail elsewhere (Sun 1993).

Table 1 Relationship between angle of stream flow and stream ponds

Stream flow pattern	Angle of stream flow φ(°)	Migratory pond	Stationary pond
Flow 1	$0 <= \varphi < 90$	Yes	Yes
Flow 2	$90 <= \varphi <= 180$	No	Yes
Flow 3	$180 <= \varphi <= 270$	No	Yes
Flow 4	$270 < \varphi <= 360$	Yes	Yes

For example, if the angle of stream flow belongs to the flow 1 (or flow 4) pattern and the adjacent new panel is on the south (or north) side of the panel being mined, the migratory pond will occur and travel along the stream. The stationary pond will then be formed by the headentry of the panel being mined. The migratory pond will disappear if the angle of a stream flow is in flow 2 or flow 3 pattern. In flow 2 pattern, the stationary pond by the headentry has more influence on mining the adjacent new panel than the flow 3 pattern, if the adjacent new panel is on the south side. The optimum angle of stream flow is 90° or 270°, provided the adjacent new panel is located in the opposite direction to the stream flow. In this configuration, the migratory pond will not occur and the stationary pond will settled by the tailentry instead of the headentry.

Based on the field data, a subsidence-controlled computer model has been developed for predicting the formation process of the stream ponds (Sun 1993). The trend surface analysis technique and Knothe's theory (Knothe 1957) are employed to determine the static stream water elevation. By using this model, the location, size and volume of the stream ponds can be predicted. Furthermore, the potential water problems caused by stream ponding can be assessed. The results may be used to (1) serve as a guide for designing the longwall panel layout to minimize the influence of stream ponding, including prevention of water loss, and (2) develop mitigative measures for restoration of the stream and land to meet required environmental standards.

Conclusions

From the field investigation and data analysis, the following conclusions can be reached:

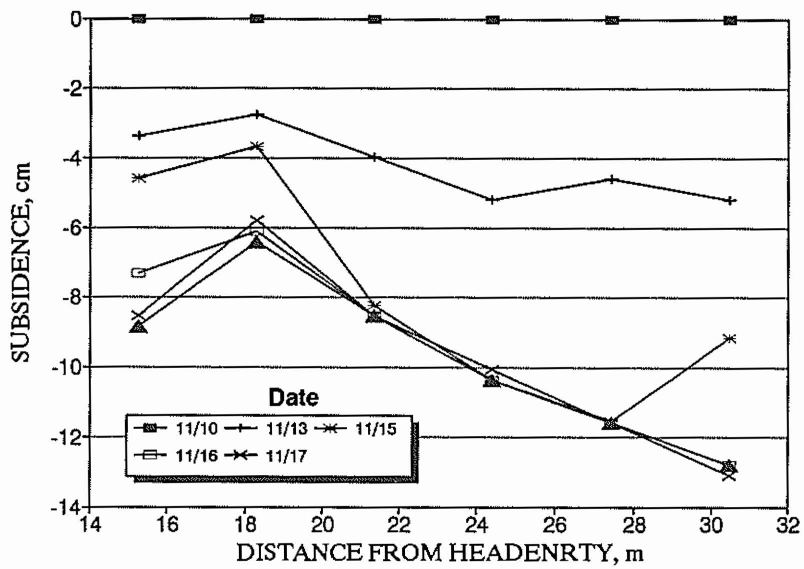

Figure 11. Subsidence profile along r-line over longwall panel 4

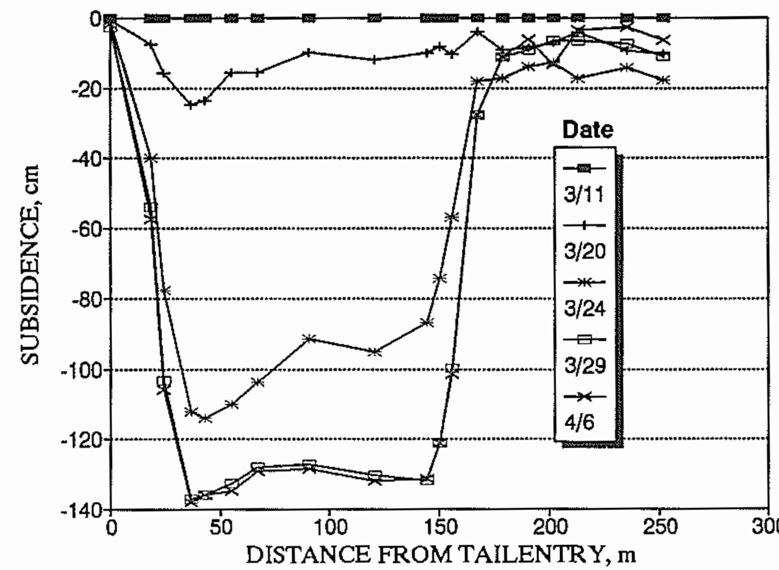

Figure 12. Subsidence profile along BH-line over longwall panel 5

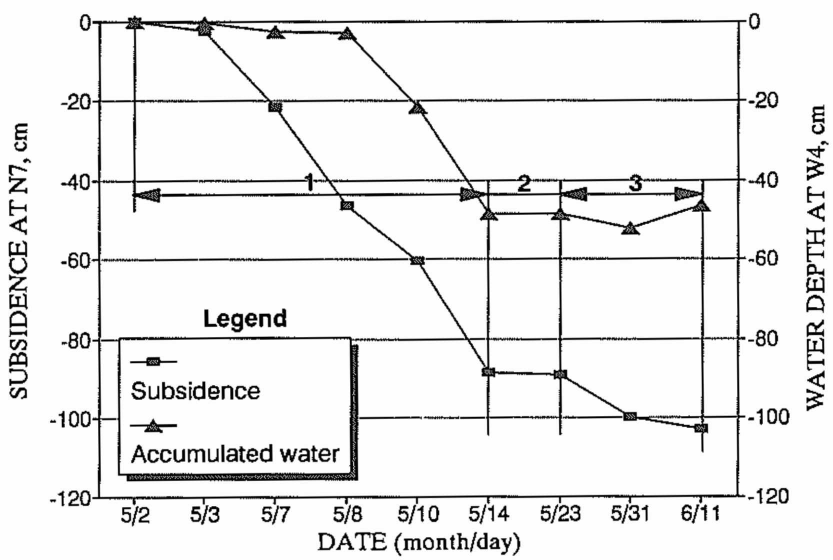

Figure 13. Subsidence at N7 and water depth at water station W4 over longwall panel 3

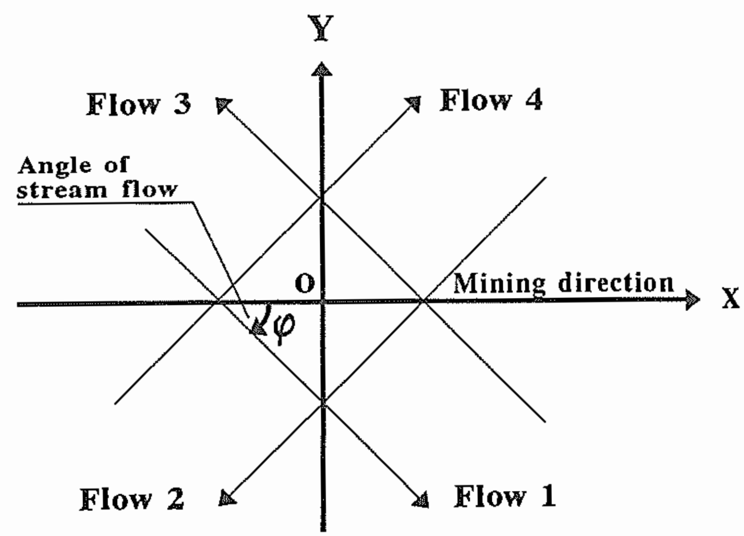

Figure 14. Angle of stream flow and flow patterns

• The presence of stream ponds may create water problems for surface environment and underground mining operation, especially when a large stationary pond is formed in the tension zone by the headentry.

• The formation process of the stream ponds may be affected by many factors, including precipitation, soil properties, vegetation, variation of water source upstream, etc. However, the topographic change resulting from surface subsidence plays a major role in governing the distribution of the stream ponds.

• The migratory pond is created by a dynamic surface subsidence process. If the dynamic strain exceeds the limiting value, water loss to dynamic cracks may occur in the migratory pond when it travels across the longwall panel.

• A stationary pond is formed as the migratory pond reaches a stable stage, when the local subsidence reaches about 80% to 90% of the final subsidence. The location and size of the stationary pond depend mainly on the topography and magnitude of the final subsidence basin.

• The defined angle of stream flow can be used to guide the longwall panel design to minimize water problems caused by a disturbed surface stream. The optimum angle of stream flow is 90° or 270°, based on the configuration of the adjacent new longwall panel. The mitigative measures-pumping the water, digging trenches, sealing the bottom of the stream bed, etc.-can also be designed based on the study.

Acknowledgements

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