U.S. Department of Labor

Mine Safety and Health Administration
Pittsburgh Safety & Health Technology Center
P.O. Box 18233
Pittsburgh, PA 15236

September 29, 2014

MEMORANDUM FOR MICHAEL A. DAVIS
District Manager, South Central District
Metal/Nonmetal Mine Safety and Health

(b) (7)(C)

THROUGH: WILLIAM J. FRANCART
Chief, Pittsburgh Safety and Health Technology Center
(b) (7)(C)

FROM: DONALD T. KIRKWOOD
Chief, Mine Waste and Geotechnical Engineering Division

SUBJECT: Field Investigation of Sinkhole Occurrences at the West Fork Tailings Dam, Impoundment ID No. 23-00409-04 Doe Run Company, West Fork Unit-Fletcher Mine, Mine I.D. No. 23-00409, Reynolds County, Missouri

As requested by your office, we performed a site inspection and an investigation of sinkholes that formed at the subject site between April 4 and 8, 2014, in order to assess their impact on the integrity of the West Fork Tailings Dam and other mine facilities. Following this site visit, additional sinkholes formed near the dam and the mine surface facility coincident with a broad area of surface subsidence over mine workings that had experienced a large fall of back following pillar extraction mining. Pittsburgh Technical Support provided ongoing consultation with the Rolla, Missouri, Field Office personnel as the surface area of the K-order was modified as needed to allow mitigation of the sinkholes and surface subsidence.

It was determined early in the investigation following the April 5 and 6, 2014, site visit that the sinkholes were not due to distress in the dam structure, but rather were likely due to an abrupt decline in ground water levels caused by a ground-fall propagating upward into the Ozark Aquifer within the karstic (solution-cave prone) rock units that overlie the mine.

The results of our investigation are presented in the attached Report MW14-095. This report contains our field observations, the results of our review of follow-up investigations performed by the Doe Run Company's consultant and research in our office. The report also contains recommended measures to mitigate the risk presented by additional sinkholes that may form from this event.

Please contact this office if we can be of further assistance in this matter.

Attachment

cc: G. Fesak – Director, TS
B. Goepfert – Chief, Safety Div., CMS&H

UNITED STATES DEPARTMENT OF LABOR

MINE SAFETY AND HEALTH ADMINISTRATION

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MINE WASTE AND GEOTECHNICAL ENGINEERING DIVISION
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REPORT NO. MW14-095

INVESTIGATION OF SINKHOLE OCCURRENCES
DOE RUN COMPANY
WEST FORK TAILINGS DAM
IMPOUNDMENT I.D. NO. 23-00409-04
FLETCHER MINE
MINE I.D. NO. 23-00409
REYNOLDS COUNTY, MISSOURI

SEPTEMBER 29, 2014

BY

PAUL J. DONAHUE, P.E.
CIVIL ENGINEER

REPORT NO. MW14-095

OWNERSHIP AND LOCATION

The West Fork Tailings Dam is located at the West Fork Unit of the Fletcher Mine. The West Fork Mine and Mill was operated by ASARCO, Inc. then the Doe Run Company between the early 1980s and April 2000 when ore production and concentration was moved to Doe Run's Fletcher Mine shafts and mill located about 1.7 miles to the south of this facility. The dam is located on an unnamed small tributary of the West Fork Black River at geographic coordinates 37°29'16" north latitude and 91°06'36" west longitude, or about 4.5 miles northeast of Bunker, Missouri, on State Route KK.

BACKGROUND

Mining Operations

Information regarding mining operations was obtained from site meetings, phone and e-mail information obtained from Mr. Robert Seelke and Mr. Keith Markeson of the Rolla, Missouri, Field Office of the MSHA South Central District, Metal/Nonmetal Mine Safety and Health (SC District), a mine map furnished to MSHA from the Doe Run Company (Doe Run), and a technical literature and report search and review of information relevant to the Doe Run Company's Viburnum Trend operations.

The West Fork Unit is a formerly producing mine that is now incorporated into the Fletcher Mine whose shafts and mill are located 1.7 miles to the south. The Fletcher Mine produces lead ore and lesser amounts of zinc and copper ore from mineralized breccia zones formed from ancient solution features in the Upper Cambrian aged Bontierre Dolomite. The rock units are flat-lying to very gently dipping. The breccia ore zone in the Fletcher Mine area is generally limited to a stratigraphic unit within the Bontierre Formation 15 to 35 feet thick, but with localized areas up to 80 feet thick. The ore bearing strata ranges from 200 to up to 3,000 feet wide in the east-west direction and extends northward and southward as a near-continuous deposit (the Viburnum Trend) from about 10 miles south to about 17 miles north of the West Fork Unit. The depth to the ore deposit ranges from about 800 feet to about 1,200 feet, mostly reflecting the surface topography. Doe Run operates six mines along the Viburnum Trend that are spaced 2 to 7 miles apart.

The mining method used is mostly a single level of room-and pillar mining using development drifts and crosscuts near the top of the ore zone, then one or more bench cuts are advanced with the final mine back heights of 20 to 35 feet. Where the ore body extends higher or lower than the initial development, additional levels of overcut and undercut mining may be used with pillars and drifts "stacked" over or under the initial development. Depending on the ore grade, the 15- to 20-foot-thick "sills" between the levels may be mined. This or other mining methods result in open stopes as high as 70 feet over areas as wide as two pillar-rows. Pillars are typically 30 to 32 feet square and drifts and crosscuts are 32 feet wide for an average total rock extraction of 75%.

Depending on the ore grade and ground conditions, the final phase of mining is pillar extraction often in conjunction with the placement of cemented rock backfill (CRF) or uncemented tailings fill. This provides back support or pillar confinement as needed to maintain ground stability. Pillar stability is determined using a pillar structural grading system and the mine's proprietary stability computer analyses "NFOLD." As a general guideline, a maximum back free-span of 150 feet (i.e. two pillar rows) is observed in pillar extraction operations, which use remote controlled loaders and drilling and charging equipment for blasting and mucking in the pillared area. Pillar extraction currently represents a major part of the production at the West Fork/Fletcher Mine.

The idled West Fork shafts are located at a low-elevation point in the mine development under the low lying West Fork Valley; thus, the West Fork Unit is used to dewater mine workings which extend to portions of the Fletcher Mine to the south and the Brushy Creek Mine to the north. Various impoundments, including the idled tailings pond, are used for storage and treatment of mine water for discharge into the West Fork of the Black River. The West Fork Unit also includes offices and shop facilities used by about 15 to 20 mine employees, 5 days per week.

West Fork Tailings Dam

Information on the construction and operational history of this dam was obtained from on-site conversations with Dan Buxton, Engineer with Doe Run, Mr. Matt Fuller of Doe-Run's consultant Tierra Group, Inc., field notes during the site visit, a review of aerial photography available on the internet, construction plan and geotechnical boring cross-section drawings furnished by Doe Run, and a copy of the most recent quarterly inspection report for the dams.

The West Fork surface facilities include the West Fork Main Tailings Dam and a smaller adjoining Southeast Dam. These dams span the confluence of two small tributaries of the West Fork of the Black River (West Fork) to create two impoundments. The Main Dam utilizes a bend in its centerline in order to make use of a topographic spur that separates the two tributaries to form its right (east) abutment. The Southeast Dam abuts the downstream side of the Main Dam and the topographic spur on the left and it abuts a ridge separating the small tributary watershed from the West Fork on the right. The crest of the Main Dam is at 1058 feet mean sea level (msl) and rises 150 feet from the downstream toe at a small treatment pond. The Southeast Dam crest is at about 985 feet msl. Stormwater is handled with two open-channel spillways. The Main Dam spillway is a shotcrete-lined channel through the topographic spur with a maximum invert elevation of 1047.6 feet and empties into the southeast impoundment. A second open-channel spillway with a maximum invert at about elevation 975 conveys the stormwater water from the Southeast Pond into the West Fork of the Black River. This spillway is unlined.

Construction of the West Fork Tailings Dams were started in the early 1980s by the previous mine operator ASARCO, Inc., and was used for disposal of tailings from the West Fork Mill from the early 1980s until ore production at the West Fork Unit was halted and moved to the Fletcher Mine. The Main Dam was constructed using a compacted clay starter dam with a crest at elevation 980 feet and raised to the current crest elevation of 1058 feet using tailings which are predominantly medium-to-fine sand and about 10 to 20 percent silt. The dam was raised with both centerline and upstream construction over a settled pumped-tailings beach. An upstream clay core was reportedly extended upward from the clay starter dam as the Main Dam was raised. Both the Main and Southeast Dams also contain foundation drainage blankets extending between the dam centerline and the downstream toe, with cross-valley widths of 350 and 200 feet, respectively.

During periods of active operation following construction to the current dam crest, tailings were pumped into the upper reaches and sides of the impoundment so that about half of the impoundment area is dry tailings beach, with the fine sand and silt-sized fraction filling most of the remaining impoundment volume so that the stored water is 5 feet or less deep in most areas. The pool level is typically maintained at 5 to 10 feet below the spillway elevation by pumping from a tributary of the pool at the midpoint of the impoundments reach. This tributary is mostly free of settled tailings and provides a sump from which the impoundment can be dewatered if necessary.

Since the end of ore concentration operations, the impoundment has been primarily used for retention of pumped mine water as needed to comply with the mines NPDES discharge requirements.

Appearance of Sinkholes on April 4, 2014

On April 4, 2014, Mr. Michael Davis, District Manager, SC District, contacted
(b) (7)(D) and
requested technical assistance at the site regarding a mine operator's notification that sinkholes appeared near the toe of the West Fork Main Dam on the morning of Friday, April 4, 2014. Mr. Paul Donahue (report author) was assigned to visit the site as soon as travel arrangements allowed if an imminent failure was possible. Mr. Robert Seelke, Field Office Supervisor for the Rolla, Missouri, Field Office reached the site to observe the sinkholes later in the day on April 4, 2014. Mr. Seelke determined that an imminent hazard existed from either distress to the dam structure and/or engulfment hazard to mine personnel due to the enlargement of the existing sinkholes or development of additional sinkholes. Therefore, Mr. Seelke issued a 103(k) withdrawal order for the dam area and the West Fork surface facilities in the low-lying area downstream of the dam. The report author contacted Mr. Seelke after he had the opportunity to observe the sinkholes and obtain information from Doe Run personnel. Based on the information provided, the report author made travel arrangements to meet Mr. Seelke and Doe Run personnel the following day.

SITE VISIT – APRIL 5-7, 2014

April 5, 2014, Observations and Site Meeting

The report author arrived at the West Fork Unit at about 1:00 p.m. on April 5, 2014. The following personnel were present at the site:

Robert Seelke - MSHA SC District – Rolla, Missouri, Field Office Supv.
Paul Donahue– MSHA Pittsburgh Technical Support, MWGED – Civil Engineer

(b) (7)(D)

The personnel above proceeded to the site of the sinkholes which were observed and photographed. Then, following a discussion of events in the mine prior to the formation of the sinkholes, a general inspection of the dam and spillways was performed.

The sinkholes and an associated circular conical subsidence depression are shown on Photos Nos. 2 through 4. The sinkholes were both about 30 feet by 50 to 60 feet in least and greatest dimension respectively and about 18 feet deep. The holes were located on the northwest and northeast periphery of the circular depressed area which is bounded by surface cracks and small scarps about 150 feet in diameter. The materials exposed on the sinkholes were tailings in the upper parts of the hole and reddish-brown silty gravelly clay in the lower part. There was no evidence of water seepage or wet materials in the sinkholes.

Adjacent to the sinkholes and the depression is a concrete valve box which exhibited a tilt toward the center of the depression; however, Mr. Buxton stated that the tilt has been present for years. This valve box is used to regulate flow through a 10-inch-diameter pipe that connects a series of decant inlets in the southeast pond to the treatment ponds. The alignment of this buried pipe is not known with certainty, but the pipe probably passes through the subsided ground associated with the sinkholes and has likely been damaged.

According to the mine personnel accounts, the sinkhole appearance followed a large ground fall in an area of recent pillar extraction near the "18 Vent Shaft", which is an unused 14-foot-diameter ventilation shaft that extends to the mine workings where the mine back is at about 790 feet below ground surface (bgs) and the floor is about 820 feet bgs. The collar of this shaft is located about 550 feet to the east-northeast of the sinkholes. The initial ground fall area and the 18 Vent Shaft is shown on Figure No. 1. Coincident with the ground fall, a heavy inflow of reddish-brown turbid water was discovered in the West Fork mine sump and pumps used for dewatering. The inflows appeared to be coming from the 18 Vent Shaft and heavy water inflow from an uncertain point in the shaft could be heard at the shaft collar. The mine water is pumped up the West Fork production shaft to the first treatment pond at the base of the Main Tailings Dam. The turbid water is the same color of the local residual soils and can be seen in Photo No. 2. The author asked Mr. Moellering and Mr. Buxton if there were any instances of surface subsidence at Doe Run's Southeast Missouri Mines and they replied that none had occurred to their knowledge.

Following the sinkhole observations, a reconnaissance was made of the Main Tailings Dam, the Southeast Dam and the spillways. Photo No. 1 provides a view of the Main Tailings Dam from the left (west) abutment which is the opposite side end of the dam where the sinkhole activity was occurring. The dam is constructed from cycloned tailings consisting of fine to medium sized sand and some silt. Downstream slopes were a uniform 3H:1V (horizontal:vertical), except for a zone of about 2.75H:1V where the dam axis curves southward to join the topographic spur that forms the right abutment. Except for at the crest, the upstream slopes are very flat - generally 8H:1V or flatter due to consolidated tailings on the upstream face. The downstream slopes were dry with no evidence of water seeps. Below the toe of the dam is a treatment pond which is largely an incised structure. Six, 4-inch-diameter corrugated polyethylene pipes, presumably outlets for the Main Dam blanket drain, are present on the treatment pond slopes. Five of the pipes were discharging clear water at generally 2 gallons per minute or less. The easternmost pipe was dry, but it was evident from staining that it had been recently flowing. The reason for the loss of flow was readily apparent as the probable pipe alignment intersected the western sinkhole and the pipe was most likely destroyed. Areas of light clear seepage and wet ground are present between the fourth and fifth drain (from the east). This appears to be a persistent unchanged condition. Mr. Buxton stated that he has occasionally noted a clear "boil" on the pond water surface near the southeast corner, near the sinkhole locations over the past few years. This condition was unchanged over the period since their discovery.

The Main Dam has two standpipe piezometers installed at approximate mid-embankment on the downstream slope at an elevation of 980 feet and 1045 feet. The protective casings were tilted top-end down slope at about 15 degrees, probably due to the down-slope creep of the loose sandy tailings. The piezometers could not be read on April 5th as the water level tape was not available on site.

The Main Dam pool was observed to be about 15 feet lower than the crest and approximately 250 feet from the upstream edge of the dam crest (approximate pool elevation 1042). The pool level appeared to be static or slowly lowering in a controlled manner over the past few days.

The Southeast Dam and the impoundment was also visited. The Southeast Dam is primarily used to provide temporary storage of discharged water from the Main Dam spillway after heavy rain events. The stored water is discharged to the West Fork treatment pond system through a series of decant inlets, using the valve located near the sinkholes to control the flow. At the time of the site visit, the Southeast Impoundment was nearly dry with only a small shallow pool of less than an acre in the area. All decant inlets were well above the pool. This is reportedly the normal condition except for after heavy rain events. The Southeast Dam has been altered by placement of tailings and other miscellaneous rocky fill on the upstream and downstream slopes so that, except for a 10- to 15-foot-wide embankment at the crest, the dam slopes are 8H:1V or flatter. The Southeast Dam spillway was vegetated with weeds, brush and small trees to an area of weathered dolomite bedrock pinnacles which serve as the spillway control section and provide some erosion resistance. The spillway downstream of the bedrock exposure was heavily eroded with a deep gully extending down the hillside to the West Fork River. Precipitation events heavy enough to cause a flow through this spillway are infrequent. According to the most recent quarterly dam inspection report provided by Mr. Buxton, the last occurrence of flow through this spillway occurred in 2011 following 10 inches of rain over a 7-day period. Discharges also occurred in April of 2008 and May of 2002.

<u>April 5, 2014 Meeting</u>

Following the field observations, the site visit attendees met to discuss the field observations and immediate actions to be taken to monitor the sinkhole condition, the risks of future sinkholes, and general options to abate the sinkhole condition.

The report author offered a hypothesis for the cause of the sinkholes. They do not appear to reflect a dam distress condition, but instead appear to be related to the ground fall and associated 18 Vent Shaft liner failure. The resulting groundwater mine inflows caused an abrupt change in groundwater levels or flows in solution (karst) features in the carbonate bedrock of the mine region. Such groundwater changes cause either settlement or erosion of soft soils filling solution cavities that can extend to considerable depths below the water table from the bedrock surface. This creates voids in the residual soils overlying the cavities which collapse to create a surface sinkhole. This implies that the formation of additional sinkholes is possible in the vicinity of the ground fall and shaft liner breach.

The attendees agreed to start the following:

1. Monitor settlement and crack movement of the sinkhole area daily for 1 week, then weekly. Settlement stakes will be installed on Monday, April 7.

2. Flow at the dam drain outlets will be monitored weekly until repairs are completed.

3. Due to the likelihood of damage to the Southeast Impoundment decant pipe, cap the inlets and perform a pipe camera inspection for the segment of the pipe upstream of the valve box under the subsided area.

Doe Run also contacted Tierra Group International (Tierra), their geotechnical consultant for the surface facilities, and they traveled to the site on Sunday, April 6. Mr. England and Mr. Buxton suggested prompt filling of the sinkholes following Tierra's visit. The author generally concurred with this, but pointed out that there are specific procedures and materials for filling karst-related sinkholes which will need to be developed after more detailed exploration of the sinkholes.

Mr. Seelke stated that the existing area under MSHA's 103K order would remain unmodified until after the Sunday site visit by the Tierra engineers.

<u>April 6, 2014, Site Observations and Site Meeting</u>

The report author returned to the site on Sunday, April 6 to observe changes in the sinkhole condition, attempts to fill the 18 Vent Shaft inflows and to meet with the engineers from (b) (7)(D)
(b) (7)(D)

The sinkholes had changed very little from the previous day except for some collapses around the edges. The broad surface depression had deepened slightly and the cracks around the circumference of the depression had enlarged, as shown in Photo Nos. 3 and 4.

On the morning of April 6, Doe Run began backfilling the 18 Vent Shaft by dumping material through a hole cut in the unused fan structure at the shaft collar in an attempt to reduce or halt the water flow into the mine. Heavy water inflow was audible from the shaft collar. Prior to backfilling, a camera was lowered down into the shaft and reddish-brown turbid water inflow was observed from a large break at a horizontal concrete pour joint in the shaft lining at 405 feet below the shaft collar (approximate elevation 513). Truckloads of quarry-run rock, followed by medium to fine sand, were dumped into the shaft until the shaft was filled with materials to about 650 feet below the shaft collar. The shaft rapidly filled with water, with the water level rising above the inflow point at about 3:40 p.m.

(b) (7)(D) reported abrupt changes in water levels in monitoring wells since ground fall and shaft breach event. A monitoring well adjacent to the shaft dropped from 25 feet bgs to dry on the previous Friday, and a monitoring well at the mill building fell from the normal level of 15.8 feet down to 25.3 feet bgs on Sunday.

Upon arrival of the Tierra engineers in the early afternoon, a meeting was held at the mine office to provide a briefing on the sinkholes and events leading up to the sinkhole development.

The following attendees were present:

Robert Seelke
Paul Donahue
(b) (7)(D)

The following timeline of events leading to the sinkhole occurrence was established.

April 2, 2014

At about 1:00 p.m., a failure of pillars occurred in an area of recent pillar extraction resulting in a large fall of back in the mine. The mine floor is approximately 810 to 830 feet bgs and the back is about 790 bgs in the vicinity of the 18 Vent Shaft. The miners could not view the vertical extent of caving and gob from safe vantage points, but Doe Run provided a sketch of the estimated horizontal extents. This sketch depicted a rectangular area (approximately 300 feet north-south by 460 feet east-west) drawn on a Google Map view of the site.

April 3, 2014

Increased water flow was reported underground at the West Fork Mine in the early morning hours. The flow rate increased by approximately 1,000 gallons per minute (gpm) above the normal 2,000 gpm at the dewatering sump and pumps are located approximately 1,000 feet from the vent shaft at the West Fork production shaft. The water was reported to be turbid and reddish-brown in color. The flow increased and by the evening of April 3, water flow was estimated to have doubled since the morning. The water flow appeared to be coming from a breach in the liner of the 18 Vent Shaft, as heavy water flow down the shaft could be heard from the top of the shaft.

April 4, 2014

Additional pumps were brought underground, with pumping increased 3,200 gpm, but water levels continued to rise into the workings beyond the sump since the pumps were unable to keep up with the inflow. Opinions of the total new turbid inflow varied, but there was general agreement that it was about 3,500 gpm. At 10:00 a.m. the sinkholes were discovered at the toe of the Main Dam abutment near the Seepage Collection Pond southeast corner.

Following the meeting, the report author accompanied (b) (7)(D) (b) (7)(D) on an inspection of the Main and Southeast Dams. During this inspection, the two Main Dam piezometers were read. The lower piezometer was dry at a depth of 58.2 feet (approx. elevation 920) and the upper piezometer water level was at a depth of 116.5 feet (approx. elevation 928). These elevations are near or below the base of the dam embankment, indicating a phreatic surface is present only at the base of the dam embankment in the blanket drain. As was discussed the previous day, the decant risers at the Southeast Pond were capped by bolting plates to the flanges of the riser pipes. No other changes to the dams were noted.

A brief meeting was held after the field observations where the consensus among the (b) (7)(D) engineers and the report author was that the sinkhole was not a result of, nor contributing to, distress to the Main Dam. In light of the very favorable phreatic conditions indicated by the piezometers, it was believed that no elevated risk of dam failure existed. Based on this conclusion and a following phone discussion with Mr. Davis in the SC District, it was decided to remove the downstream buildings and facilities from the area under the 103k order, but keep the order in place for the area of two dams.

April 7, 2014, Site Visit

A brief site visit was made on the morning of April 7 to check the sinkholes for changes and attend a closeout meeting with the Tierra engineers to discuss their preliminary findings and review the available geotechnical boring data and design plans for the dams. The attendees of the April 6 site meeting were present plus (b) (7)(D) (b) (7)(D)

Little change was evident to the sinkholes or the scarps and cracks in the subsided area. Moderate rain had started about 4 hours earlier, but had no apparent effect of the features. Some widening and increase in the offset of the crack between the southeast sink hole and valve box was noted.

At the meeting, the group agreed that the sinkholes should be promptly filled and discussion ensued as to the best way to safely and effectively backfill them. (b) (7)(D) proposed an initial bentonite-soil mixture in the bottom of the sinkholes. The report author pointed out that when it is practical to excavate to the bedrock of the sinkhole a rigorous repair procedure involves locating the bedrock cavity below where the soil void developed and constructing a coarse-to-fine graded plug of materials over the cavity. The specific materials used depend on the size of the cavity and the gradation of the overlying soils. However, the boring indicated that the top of bedrock rock was too deep to make this a practical solution, and because later settlement is not an issue in the area where the sinkholes occurred, simply filling them in is adequate. The benefits of the use of bentonite in the backfill were not clear, but would not be deleterious.

(b) (7)(D) also presented a recommended settlement monitoring stake layout around the sinkhole and subsided area. He also proposed geophysical exploration to locate possible locations of hidden voids in the dams for follow-up exploration with borings. Mr. Seelke explained that modifications to the K-order could be made to allow the sinkhole backfilling and exploration activity, provided that Doe Run submit a specific plan detailing safety precautions to be used for these activities. (b) (7)(D) agreed to provide MWGED with copies of geotechnical boring logs, cross sections and plans for the dam prepared by (b) (7)(D) the original mine owner in 1980.

SUBSEQUENT EVENTS – APRIL 8 TO JUNE 30, 2014

Several significant events occurred for 3 months following the site visit for which the MWGED provided technical assistance to the SC District which are describe below.

<u>April 8, 2014</u>

Following observations of ground cracking late on April 7, a sinkhole developed on the crest of the Southeast Dam crest overnight or on the morning of April 8. This sinkhole is shown in Photo No. 5. The sinkhole was 15 to 18 feet wide, up to 30 feet deep, and centered in a subsided area with tension cracks is visible in the photo.

<u>April 10-14, 2014</u>

In response to an MDNR order to immediately start filling the sinkholes, Doe Run submitted a request on April 10 for a modification of the 103(k) order with a brief written plan describing a procedure for filling the sinkholes using long-reach excavators and visual spotters.
Mr. Keith Markeson sent a copy of the plan to the report author for review and comment via e-mail. The plan was found to be satisfactory except that Doe Run needed to provide a description of the route for the trucks hauling the backfill material to the sinkhole. This concern was conveyed in response to the e-mail.

Filling of the Southeast Dam sinkhole started on April 11. Thirty-three truckloads, each reportedly carrying 30 cubic yards of material, were required to fill the sinkhole. The ground at this sinkhole continued to subside, and on April 12, an additional 22 truckloads were required to bring the sinkhole area up to original grades. The original sinkholes at the Main Dam were also filled on April 12 and 13.

April 15-16, 2014

A geophysical resistivity survey was performed by Geotechnology, Inc. on eight survey lines at the toe of the Main Dam and crest of the Southeast Dam.

MDNR performed a video camera survey on the Southeast Dam decant pipe. The camera tractor could not be advanced beyond 92 feet from the valve box due to an apparent constriction in the pipe, but video images in the water–filled pipe were poor so this could not be confirmed. The constriction location corresponds to the cracks and scarps in the depression associated with the first (toe of Main Dam) sinkholes.

On April 15, pumps were installed in the 18 Vent Shaft over the previously placed rock and sand plug and pumping begun at a rate of approximately 700-800 gpm. Turbid discharge was noted from the pumps late in the day, just before failure of the pumps. The pumps were repaired and pumping resumed the next morning.

On April 16, the previously backfilled Southeast Dam sinkhole area subsided an additional 5 to 6 feet.

May 7, 2014

(b) (7)(D) received geotechnical boring data from the original site investigation for the dam and a report titled Doe Run – West Fork Mine Sinkhole Investigation prepared by (b) (7) and dated May 2014. The report summarizes (b) (7)(D) field observations and the regional geology and includes the results of Geotechnology, Inc.'s resistivity survey performed in an effort to delineate possible sub-surface voids to investigate with drilling.

The boring data shows widely varying depths of residual or overburden soils at the site, with the sinkholes occurring in areas with relatively thin (15 to 25 feet) alluvial soils over dolomite rock containing clay-filled or open cavities. Similar conditions occur under the West Branch facility buildings, raising the possibility of sinkholes under the grade-supported floor slabs and footings. The report author sent an e-mail to Robert Seelke recommending the "sounding" of all site building ground floor slabs with hammers or heavy bars in order to detect possible voids under the slab for further exploration by drilling through the slab. The boring data also suggests that sinkholes are less likely on hills outside of the valley bottom because stiff residual soils from 60 feet to in excess of 100 feet thick occur in these areas. Soil voids originating at the bedrock surface are unlikely to reach the surface through these soils. Doe Run had earlier reported that no evidence of sinkholes had been found on hillsides above the dam abutments.

The geophysical resistivity survey data did not conclusively locate additional voids in the areas investigated, but did locate high resistivity zones representing possible voids in the soil and underlying bedrock for additional exploration with borings. These were most notable under the backfilled April 4, 2014, sinkholes.

The report also included a generalized geologic cross-section through the 18 Vent Shaft showing the principal geologic units overlying the mine workings, and a handwritten note indicating "Encountered cave several hundred feet long and 7 feet high." This is presumably referring to a feature encountered during shaft construction.

May 23, 2014

Doe Run submitted an e-mail request to Robert Seelke, which was forwarded to the report author to modify the 103(k) order to allow access for further exploration of the sinkhole locations and other suspected areas revealed by the geophysical-resistivity survey. This exploration would include additional unspecified geophysical testing and test borings using a truck-mounted rig from the access roads that cross both sinkhole locations. The areas to be traversed by the truck and personnel would be first probed by applying full weight on a track excavator bucket with the boom extended and spotters to observe the test. Mr. Seelke requested that MWGED review and comment on the proposal. An e-mail reply was sent the same day stating that the plan was satisfactory, but the probing for hidden near-surface voids would be more effective if the excavator "thumped" the ground with the bucket during the probing activity.

Results of any follow-up drilling or geophysical exploration of the dam have not been provided to MWGED as of the date of this report.

June 12 to June 21, 2014

On June 12, Keith Markeson, Inspector, Rolla, Missouri, Field Office, reported a large new sinkhole near the previous April 4 sinkholes at the toe of the Main Dam. More significantly, a large area of surface subsidence had rapidly developed over a large area of the West Fork site. The subsidence area was bounded by tension cracking in the ground enclosing approximately 20 acres, as shown on Figure 1, although vegetation and ground relief made the northeastward extent of the subsidence uncertain. The subsidence was reported by Doe Run to be up to 6 feet in the vicinity of the finishing pond located between the mill building and the South Fork River, which ponded in the subsided area to form a slack pool against the toe of the east pond dike. Some foundation settlement and wall cracking was visible in the mill building. Mr. Markeson expanded the area under the 103(k) order to once again include the entire West Fork facility. With this subsidence, Doe Run reported that inflows into the mine increased by a significant amount with 12,000 gpm being pumped from the mine and water levels still rising in the now-large pool within the mine. The (b) (7)(D) reported 8,000 gpm loss of stream flow from the South Fork from one side of the subsided area to the other.

On June 19, (b) (7)(D) issued a Hazardous Substance Emergency Declaration and suspended the operating permits for the Main and Southeast Tailings Dams due to concerns that mine subsidence may be threatening the stability of the tailings dam. The declaration mandated a number of specific actions, including monitoring surveys of ground subsidence, West Fork stream flows and water quality, and the immediate removal of all hazardous and toxic chemicals stored on site. Most of the chemicals are stored in the mill building. Due to evidence of structural distress, Mr. Markeson modified in 103(k) order for removal of the chemicals on the condition that a qualified structural engineer inspect the building and declare it safe to enter.

On June 20, structural engineers retained by Doe Run inspected the building, installed crack monitor gauges on selected wall cracks and declared the building safe to enter. Doe Run submitted an inventory of the chemicals and a removal plan including personal protective equipment requirements, which was approved by the SC District.

In conjunction with the events during this period, the SC District forwarded the following electronic format information to MWGED:

1. A document with the file name: "West Fork Overlay.pdf" containing a mine map, estimated ground fall extents on April 2 and June 13, 2014, and sinkhole locations, including six new sinkholes not previously reported. The map and sinkhole locations are overlain on a Google Map image of the West Fork surface facilities and surrounding area. This document is used in Figure 1 of this report.

2. A document with the file name: "West Fork Overview.pdf" showing a Google Maps image of the impoundment overlain over a mine map. The recent impoundment pool extents and estimated water depth is sketched onto the document.

3. A document with the file name: "West Fork Topo.pdf" which is a topographic survey of the West Fork Site. The date of the survey is unknown, but it is from before the subsidence event.

4. An AutoCAD file with the name "061314 New Hole.dwg," depicting survey points installed at the area of the Main Dam old and new sinkholes and elevation readings taken from the stakes on June 13 and June 15, 2014.

5. A document titled "West Fork Emergency Action Plan" which is the most recently filed emergency action plan, dated August 12, 2014, for the West Fork Main Tailings Dam.

The subsidence coincided with a large expansion of the ground fall area about five pillar rows northwestward from the original ground fall area. Unlike the earlier ground fall, the expanded ground fall occurred in an area of intact pillars as a result of an apparent progressive "chain reaction" failure of the pillars. The new ground fall area was roughly 700 feet in width, which apparently was large enough to result in surface subsidence.

The six new sinkholes generally formed around or near the subsidence perimeter with the exception of one sinkhole which was about 1,700 feet east-northeast of the center of the subsidence.

Mr. Markeson stated that Doe Run engineers had analyzed subsidence from the ground fall and predicted about 6 feet of subsidence. This is approximately the amount of subsidence that occurred based on a comparison of the post-subsided elevations with the old survey. (b) (7)(D) performed a separate estimate of the expected subsidence based on available geologic and mining information and the extents of the ground fall using the computer application "SDPS." This program is primarily developed using empirical data from coal mining rather than hard-rock mining, so its results should be used with caution. However, SDPS predicted about 7 feet of subsidence, a peak horizontal strain of 12 milli-strains (1.2 percent) and peak horizontal ground displacements between the edge and center of the subsided area of about 2.8 feet. This is in reasonable agreement with the observed subsidence. No horizontal-displacement survey data was available, but the degree of predicted strains and horizontal displacement is consistent with the observed ground cracking around the perimeter of the subsided area.

On June 21, Mr. Markeson also reported that Doe Run is proposing to relocate the West Fork river channel away from the subsided area to an alignment along the northern side of the flood plain and was pursuing the necessary permits from the Army Corps of Engineers and U.S. Fish and Wildlife Service to do this.

June 24 to June 26, 2014

The removal of the chemicals from the mill building was completed during this period. Also, Doe Run reported no additional settlement in the subsidence area since June 22. Therefore, on June 24, with (b) (7)(D) concurrence, an additional modification to the 103(k) order was granted to allow placement of riprap on the finishing pond east dike which is necessitated by a pool in the West Fork River impinging in this dike due to the subsidence. Additional electric pumps were also installed in the finishing pond in order to keep up with pumping from the mine.

On June 24, 2014, in a phone conversation with the report author and (b) (7)(D) Mr. Davis reiterated his concerns regarding inundation hazards to miners underground in light of increasing water flow into the mine from the West Fork River possibly other surface sources. Doe Run had responded that the pool in the West Fork Mine had grown to an area of 43 acres with 36 feet of "freeboard" remaining before water would spill over southward into the Fletcher Mine. The water volume of the tailings pond could be accommodated with a mine pool rise of only 2 feet, so a hazard due to its failure did not exist. Mr. Davis asked the (b) (7)(D) to verify Doe Run's estimate. A mine map of the relevant area and mine levels, showing floor and back elevations, would need to be furnished. Mr. Markeson was contacted about furnishing this. He stated that Doe Run has been reluctant to provide mine maps to MSHA in the past, but he would pursue the issue further.

June 30 to July 14, 2014

On June 30, Mr. Markeson forwarded two additional 103(k) order modification requests to (b) (7)(D) These included a proposal to use a remote control bulldozer to fill the large June 12 sinkhole and a request to extend the pump discharge further downstream due to likelihood that some of the pumped water is ending up back in the mine from the slack river pool in the subsided area. (b) (7)(D) concurred with both of these measures. On July 9, (b) (7)(D) was also forwarded a request to modify the 103(k) order to install larger pumps and associated electrical service upgrades in the finishing pond near the 18 Vent Shaft. At this point, it has been 4 weeks since any new sinkholes or measured subsidence, so this request was found to be satisfactory.

During this period, Mr. Markeson forwarded the following information to (b) (7)(D)

1. An AutoCAD file with the name: "WFDAM and 9 Stakes.dwg." The file was attached to an e-mail from (b) (7)(D) f Doe Run and sent to Mr. Markeson on July 8, 2014, and forwarded to MWGED on July 9, 2014. This drawing file contained settlement stake locations and elevations for the stakes taken from June 22 to July 6, 2014. No settlement is apparent from the readings over this period.

2. An Excel spreadsheet with the file name "WF_MMWM_Wells_and_Toe_Drains.xlsx," forwarded tc (b) (7)(D) in an e-mail from Keith Markeson on July 1, 2014. This spreadsheet contained weekly flow measurements from the Main Dam toe drains and daily level measurements from site environmental monitoring wells between April 4 and June 28, 2014.

3. An AutoCAD file with the name "WF_MSHA_MAP.dwg." This file was attached to an e-mail from (b) (7)(D) of Doe Run on July 9, 2014, and forwarded t((b) (7)(D) on July 11, 2014. This file is a mine map for the portion of the West Fork and Fletcher Mines extending northward from the topographic spillover point into the Fletcher Mine for any water accumulating in the West Fork Mine.

The mine map information was used to calculate the mine water storage volume for the West Fork pool area as previously requested and the results were sent by e-mail to Mr. Markeson, Mr. Seelke and Mr. Davis on July 14, 2014.

The calculation results are summarized below:

- Elevation of "spillover point" into the Fletcher Mine approximately 150 feet msl
- Elevation of mine pool reported by Doe Run on June 20, 2014: 114 feet msl
- Pool area at elevation 114: 48 acres (Doe Run estimated 43 acres)
- Incremental Storage at elev. 114: 48 acre-feet/ per foot
- Incremental storage at elev. 122 (elevation where the lowest back begins to "roof-out"): 110 acre-feet/feet
- Total mine pool storage available between elevation 114 and elevation 150: 3,060 acre-feet

The maximum storage volume of the West Fork Impoundment is about 4,200 acre feet, but the volume of water in the impoundment has been reduced to roughly 600 acre-feet based on measurements of the most recent 2012 Google Earth photo of the impoundment. This impoundment volume could be stored in the West Fork Mine with a pool rise of about 7 feet, leaving 29 feet of freeboard.

Also, using an approximate assumption for the average base flow of 65 cfs (1 cfs per sq. mi watershed in humid temperate areas), the mine can store the average "sunny day" discharge of the West Fork River over about 24 days.

Therefore, even for a very improbable breakthrough of surface waters into the mine from the subsidence and sinkhole area, a rise in the West Fork Mine pool would not be large enough or rapid enough to create a hazard to miners.

July-August 2014

Doe Run completes the relocation of the West Fork River channel outside of the subsided area to a location paralleling State Route 844 bordering the Doe Run property. Water levels in the mine are reported to be subsiding, although the degree that this is due to the increased pumping capacity or reduced inflow is not certain.

DISCUSSION AND CONCLUSIONS

The Viburnum Trend mining district lies in a region known for the groundwater aquifer development in Karstic (solution prone) dolomite and limestone stratigraphic units. The West Fork/Flecher Mine lies in the St. Francois aquifer which is a lower aquifer where water flow occurs in the relatively tight joints, fractures and breccia zones within the Bonne-Tierre Dolomite. Overlying the Bonne Tierre Dolomite is the approximately 150-foot-thick Davis Shale and the approximately 100-foot-thick Derby-Doe Run Dolomite zones. These two low-permeability rock units provide an aquiclude (barrier) between the mine workings and the overlying Ozark Aquifer. The Ozark Aquifer lies within the Potosi and Eminence Dolomite rock units which underlie the surficial soils at the West Fork site. These units are known for solution cave development and consequently the Ozark Aquifer is capable of high-discharge flows through solution widened open joints and conduit caves which develop in a favorable strata. Maintaining the integrity of the overlying (b) (7)(D) has been an important objective of ground control in the Doe Run Mines in order to prevent a breach into the overlying Ozark Aquifer.

Sinkholes are a common hazard in karst areas, particularly, if disturbances to groundwater levels and flows occur. In areas of hard limestone or dolomite bedrock, sinkhole formation is only rarely a result of the collapse of cavities in the bedrock. Instead, most sinkhole occurrences are a result of conditions at the soil/weathered bedrock interface. Limestone and dolomite weathers primarily by dissolution to produce a volume of residual soil much smaller than the original rock volume. A consequence of this is that zones of very loose or soft soil are often present at the soil-rock interface. Another characteristic of solution weathering is an irregular, pinnacled rock surface with cavities in the rock extending to considerable depth. The cavities typically develop along existing vertical joints and are filled with soft or loose soils, but may connect to open conduits for groundwater flow at the depth. Groundwater flows or gradual raveling of soil into cavities can create a void in the soil above the cavity, which propagates to the surface to form a sudden surface collapse. This is illustrated in Figure 2. The development of sinkholes is normally a gradual process and the development of sudden collapses is infrequent. However, the process can be greatly accelerated by abrupt changes in groundwater levels and flow gradients. There are a large number of documented cases of rapid development of sinkholes due to well pumping or mining activity disrupting groundwater conditions.

The most likely sequence of events causing the sinkholes is as follows:

1. On April 2, 2014, a ground fall occurred in the West Branch Mine in an area where 24 pillars were extracted from a 5 by 9 pillar area (about 300 by 500 foot). These pillars were mined between late 2013 and early 2014 with the last pillar being shot on March 13, 2014. The area of the ground fall was approximately 460 feet by 300 feet.

2. The vertical extent of the ground fall is not known, but tensile stress from the ground fall in overlying strata apparently resulted in rock bed separation and fracturing at an elevation at least as high as 405 feet bgs (400 feet above the mine workings), resulting in a tensile break in the shaft liner at this depth. This depth would be in the lower Potosi Formation which had large solution features documented during construction of the shaft.

3. Heavy water flow from solution features intersecting the shaft breach rapidly depressed the water table. This is documented by abrupt water level drops at the four site environmental monitoring wells on April 4, with a well near the vent shaft going dry.

4. A steep "cone of depression" in the groundwater surface created an erosive water flow through cavities near and at the soil/bedrock interface. This rapidly created voids at the soil/rock surface leading to a collapse in the overlying soils, which in turn formed the sinkholes observed on April 4 and April 8.

5. With the removal of the most easily erodible subsurface soils after April 8, and partial plugging of the vent shaft, sinkhole formation is temporarily stabilized. Pumping from water-filled vent shaft re-started the erosion process as evidenced by the re-appearance of reddish brown turbid water. This may have caused the additional subsidence at the Southeast Dam sinkhole on April 16.

6. No new sinkholes or significant additional settlement of existing sinkholes were noted from mid-April until June 12, probably due to stabilizing groundwater conditions. However on June 12, 2014, a progressive failure of several pillar rows occurred, propagating northwestward from the original ground fall. This ground fall area was large enough to reflect to the surface as subsidence and tension cracking. This created a much larger mine breakthrough into the overlying Ozark Aquifer and ultimately surface waters via tension fractures. Six additional sinkholes formed around the periphery, but not within the subsided area. This is consistent with the groundwater flow gradients being greatest around the perimeter of the ground fall area, analogous to water flow into a riser-type spillway.

7. No new sinkholes were reported after the mid-June subsidence event. This is consistent with a stable, lowered water table that will persist indefinitely in the area of the ground fall.

RECOMMENDATIONS

A continuing, but gradually decreasing risk of sinkhole ground collapses will continue at the West Fork surface facilities. Sinkhole collapses are most likely in the areas of moderately thick soil cover (15 to 40 feet over the bedrock surface) and less likely in areas of deep soil cover such as the hillside and hilltop areas where borings show 100 feet of stiff clays over the bedrock. In such thick soil areas, voids originating at the bedrock surface are unlikely to break to the surface due to bulking of caved materials. Where soil cover is thin, a void cannot reach a substantial size before breaking to the surface, and therefore presents less of a hazard. Most of the West Branch surface facilities are in areas of moderate soil cover from 20 to 25 feet thick in which substantial collapses could develop. Therefore, precautionary measures should be put in place to minimize sinkhole hazards as follows:

1. Sinkholes developing under grade-supported slabs, footings and rigid pavements in regularly occupied work areas present a particular hazard because the slab or footing may bridge over the underlying void until a sudden failure occurs. To monitor for this possibility the following measures are recommended:

    a. Floor slabs and pavements should be "sounded" by striking with a heavy object (a heavy bar typically works better than a hammer) for "hollow" sounding areas for further probing by drilling through the slab.

    b. Building exterior and interiors should be regularly inspected for the new appearance of wall or floor cracks, distorted walls, sticking doors, and other evidence of foundation settlement. Crack monitors such as Avongard ™ devices should be placed on existing cracks in concrete or masonry surfaces to check for new movement.

    c. Other evidence of settlement such as ponding of rainwater in formerly dry areas should also be noted.

2. If evidence of new settlement to any part of a structure is found, entry to the area should be prohibited until the cause of the settlement is determined by a qualified geotechnical engineer and an assessment of the stability of the structure is made by a qualified structural engineer.

3. The repair of sinkholes which potentially could occur where low settlement-tolerant structures are founded requires specialized methods. A geotechnical engineer with experience in construction in karst regions should be consulted.

4. Due to the thickness of cohesionless materials comprising the Main Tailings Dam and the tailings deposit on the upstream face of the dam, a sinkhole under the dam is less likely to produce a surface collapse except on the lower downstream portions of the dam. The primary risk is due to sinkhole voids and loose zones causing preferential routes for piping erosion from seepage water within the dam. Fortunately, the phreatic surface at the West Fork Main Tailings Dam is located below the piping-susceptible dam embankment materials so the risk of a seepage-related failure precipitated by loss of embankment material into a sinkhole void is low. However, rapid settlement of the dam crest and loss of storm freeboard are possible. Therefore, the following additional operating and monitoring measures for the West Fork Dam should be started.

    a. The dam pool should be maintained as low as practicable.

    b. A visual sighting of the dam crest and downstream slope for evidence of settlement of deformation should be performed from suitable vantage points on a daily basis.

    c. More thorough examinations, including drain outlet and piezometer readings, should be performed on a weekly basis.

    d. Settlement monuments should be established on the dam crest at a minimum of 100 foot intervals and read on a weekly basis.

e. Stockpiled fill materials and haulage equipment should be available at all times on site so rapid backfilling to original grades can be performed should subsidence or sinkholes develop.

f. If the impoundment is no longer needed for tailings disposal or water storage, a plan should be developed and implemented to close the impoundment and remove its capability to impound water.

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(b) (7)(C)

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FIGURES

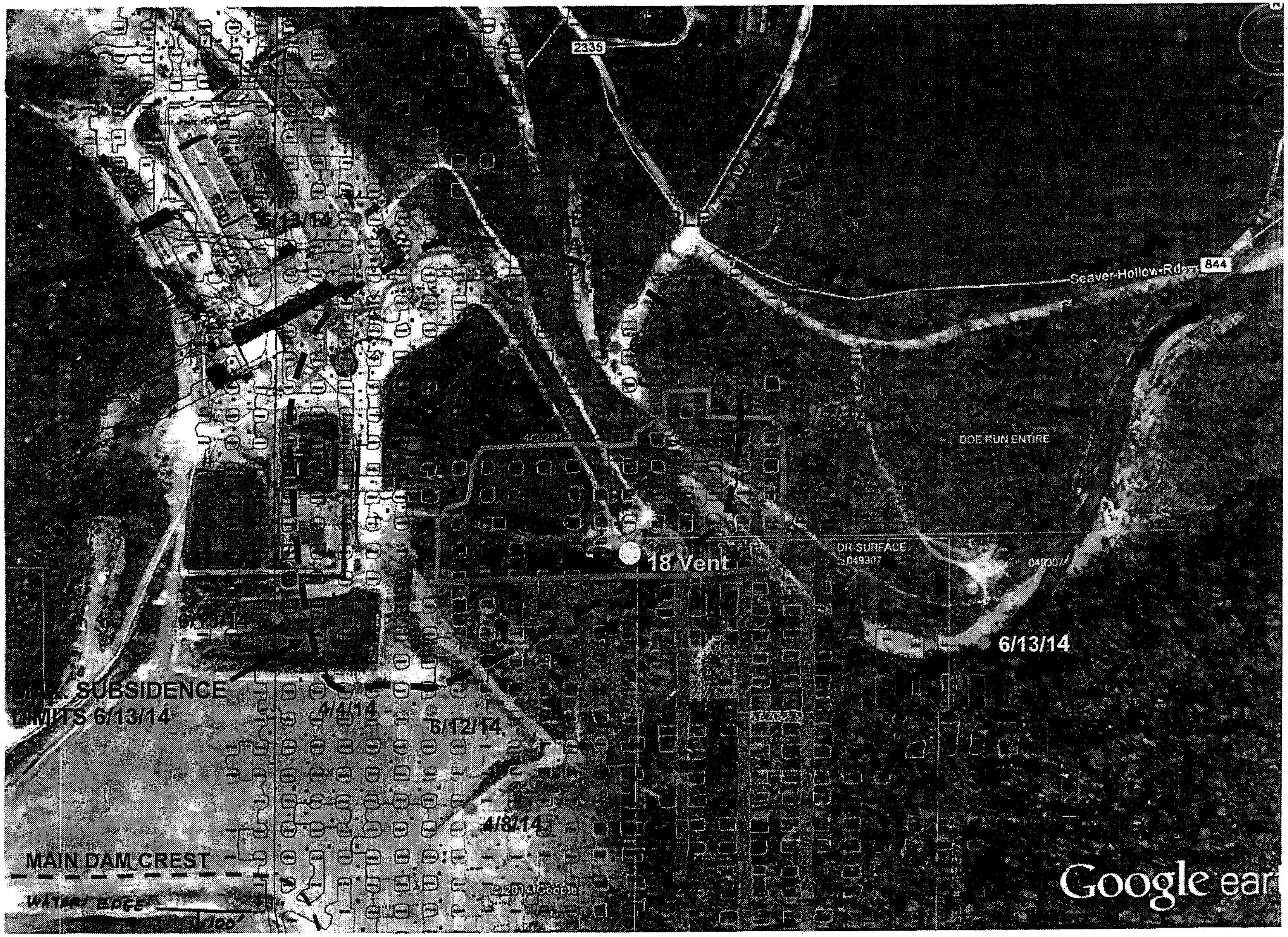

Figure 1 - Mine map overlain over aerial view of site, furnished by Doe Run. Red dots are sinkhole locations with latest date of appearance indicated.

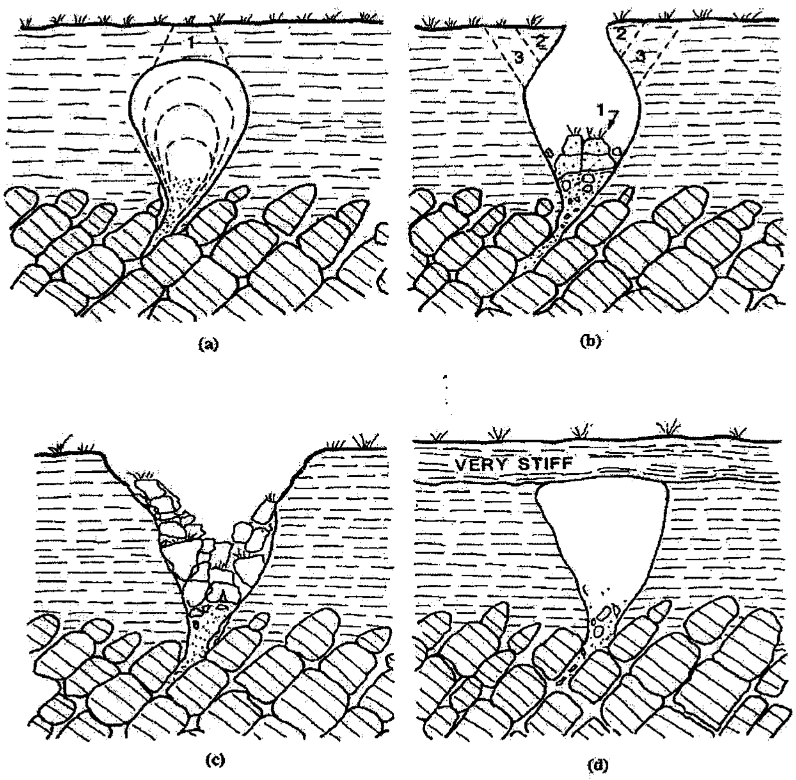

FIG. 3.9. Ravelling Erosion Dome Progression and Roof Collapse in a Cohesive Soil: a. Usual Inverted Tear-drop Shape with Potential Initial Dropout, 1; b. Initial Roof Dropout; Overhanging Rim and Successive Additional Dropouts, 2 and 3; c. Final Rim Collapse with Debris in Dome; d. Flat Dome Roof Beneath a Very Stiff Pedologic Horizon

Figure 2 - Sinkhole collapse mechanisms (excerpted from Sowers, G. (1996) *Building on Sinkholes: Design and Construction of Foundations in Karst Terrain,* ASCE Publication.

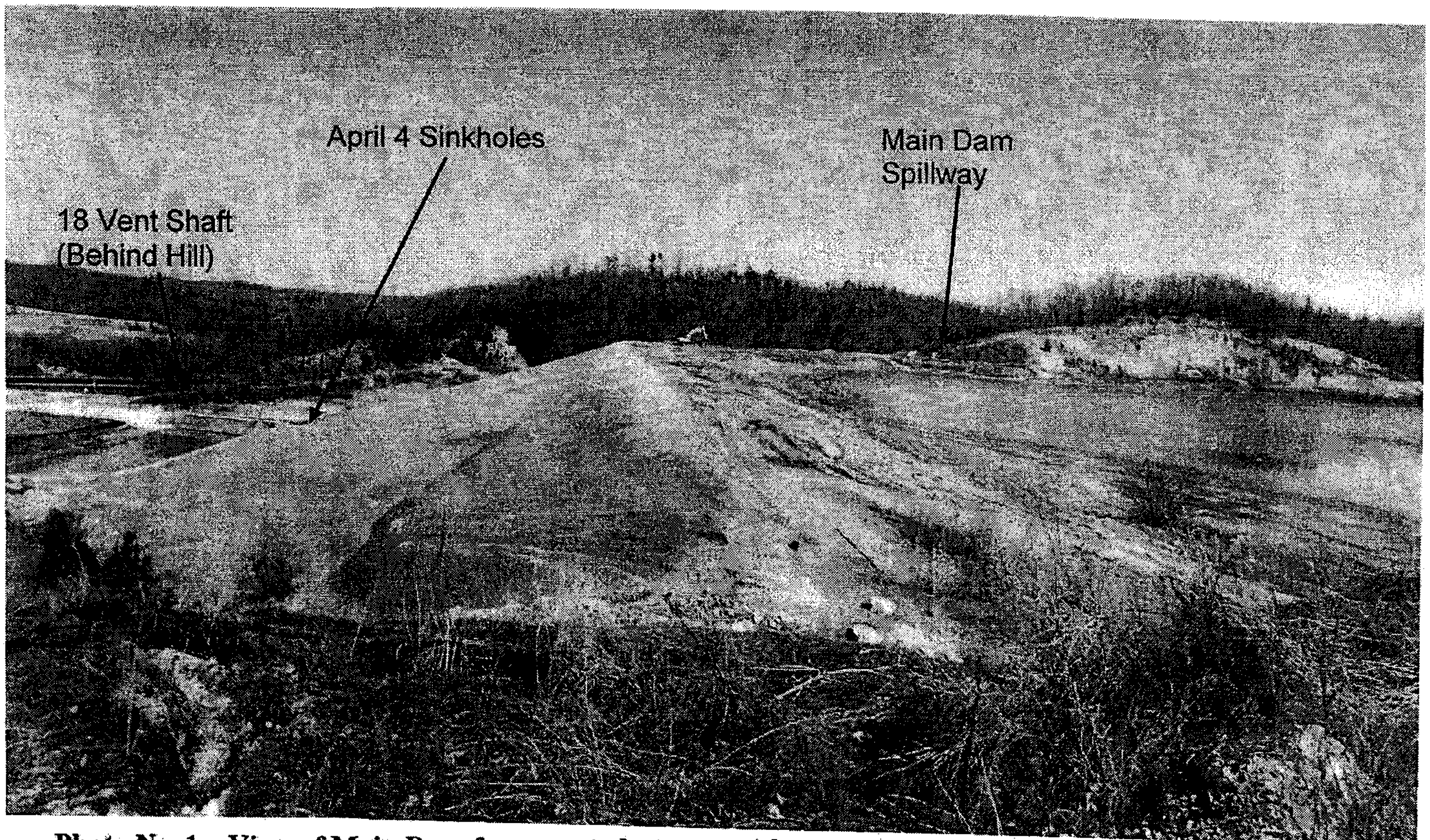

Photo No. 1 – View of Main Dam from west abutment with open-channel spillways and location of sinkholes shown.

Photo No. 2 – Photo of sinkholes and depression that formed on April 4, 2014, taken on April 5, looking northwest. Note the muddy mine water discharge into pond with similar color as residual soil exposed on hill in background.

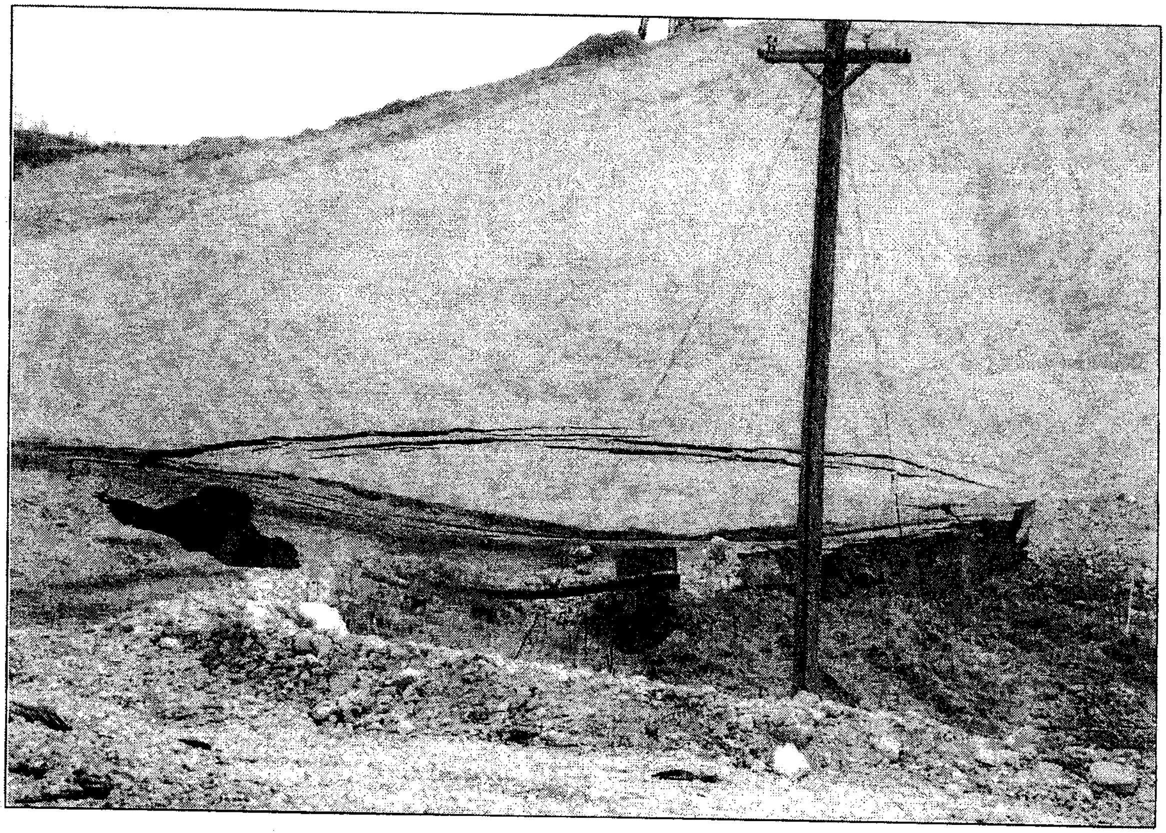

Photo No. 3 – April 4 sinkholes and depression, looking south, photo taken on April 6.

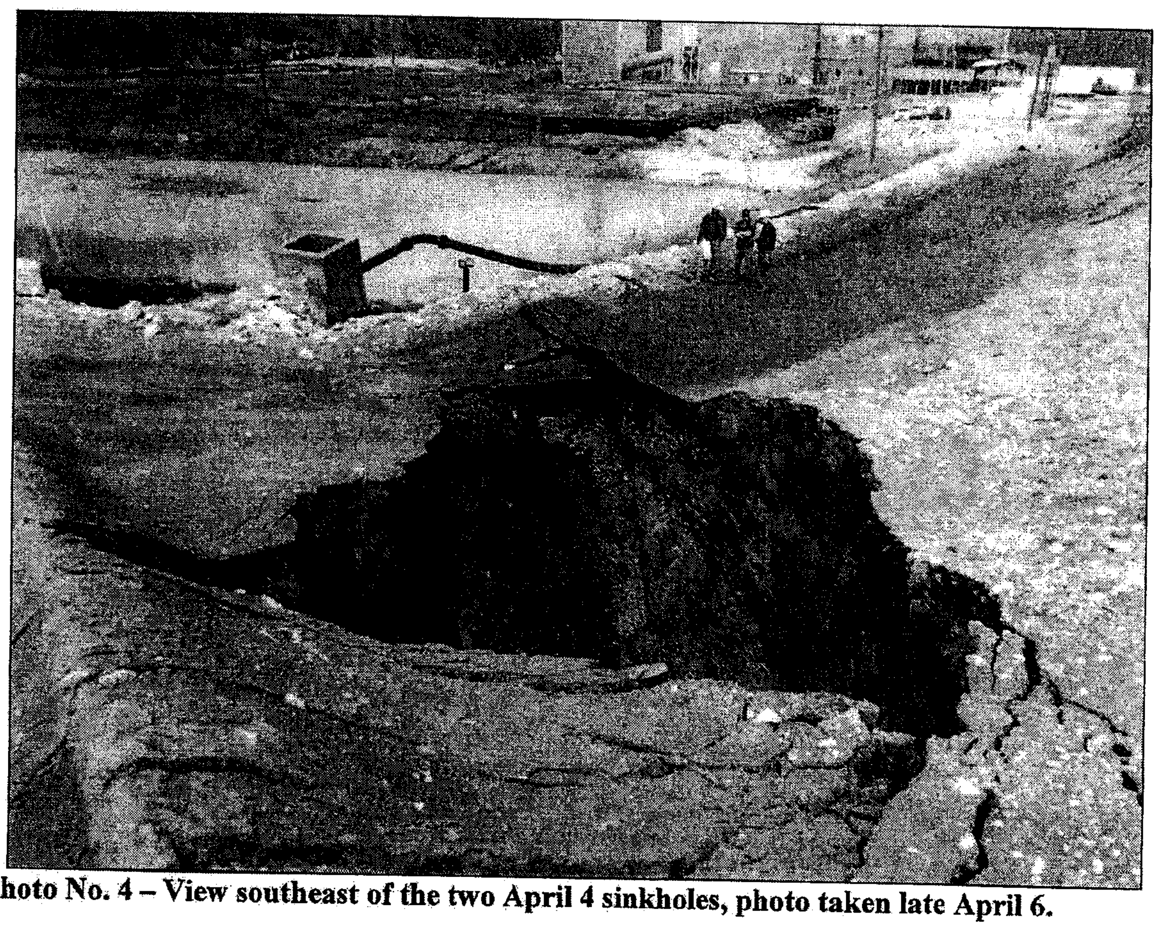

Photo No. 4 – View southeast of the two April 4 sinkholes, photo taken late April 6.

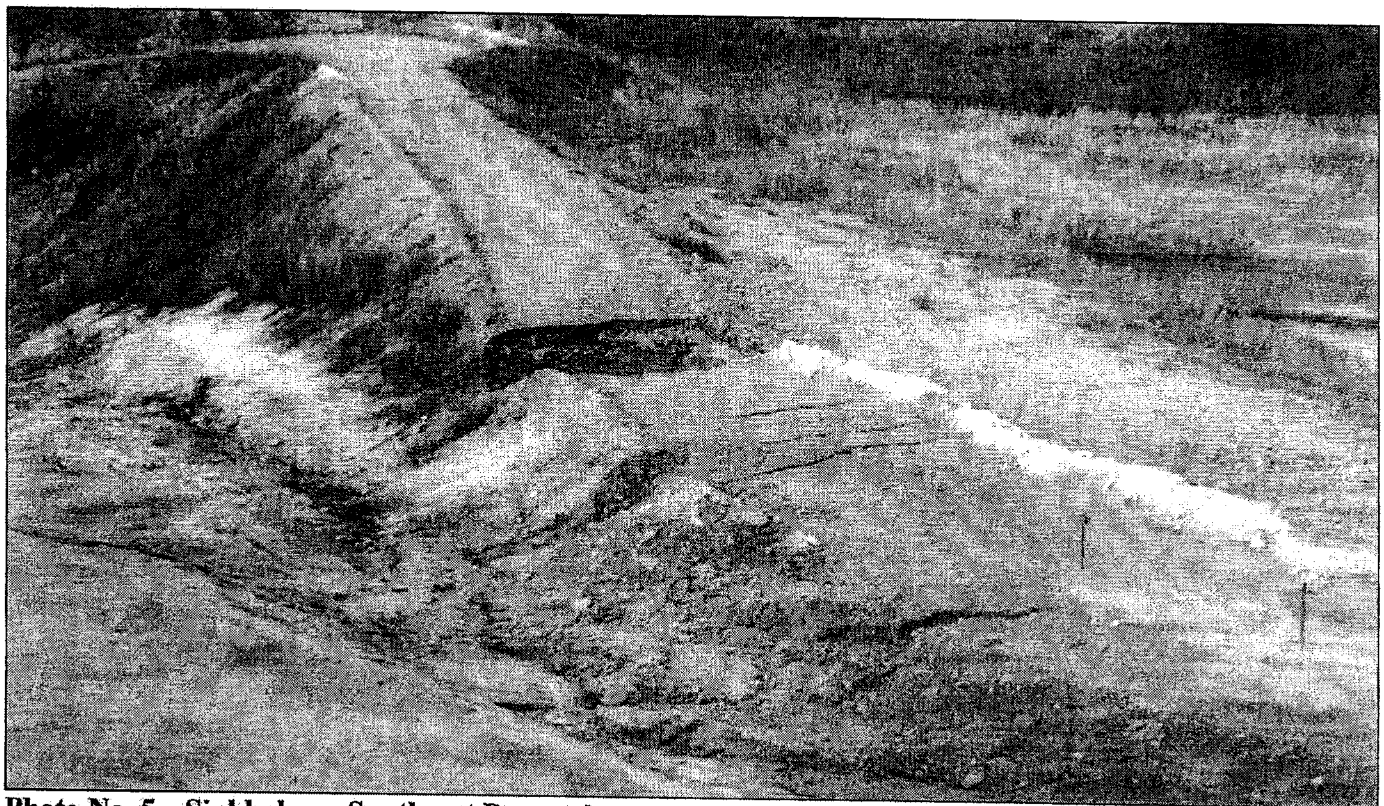

Photo No. 5 – Sinkhole on Southeast Dam, taken on April 7. Photo courtesy of J. Knudsen, Tierra Group

Photo No. 6 – New June 12, 2014, sinkhole located to southeast of filled April 4 sinkholes, note the linear tension cracks possibly associated with large area of subsidence formed on this date. Photo courtesy of Keith Markeson, MSHA.

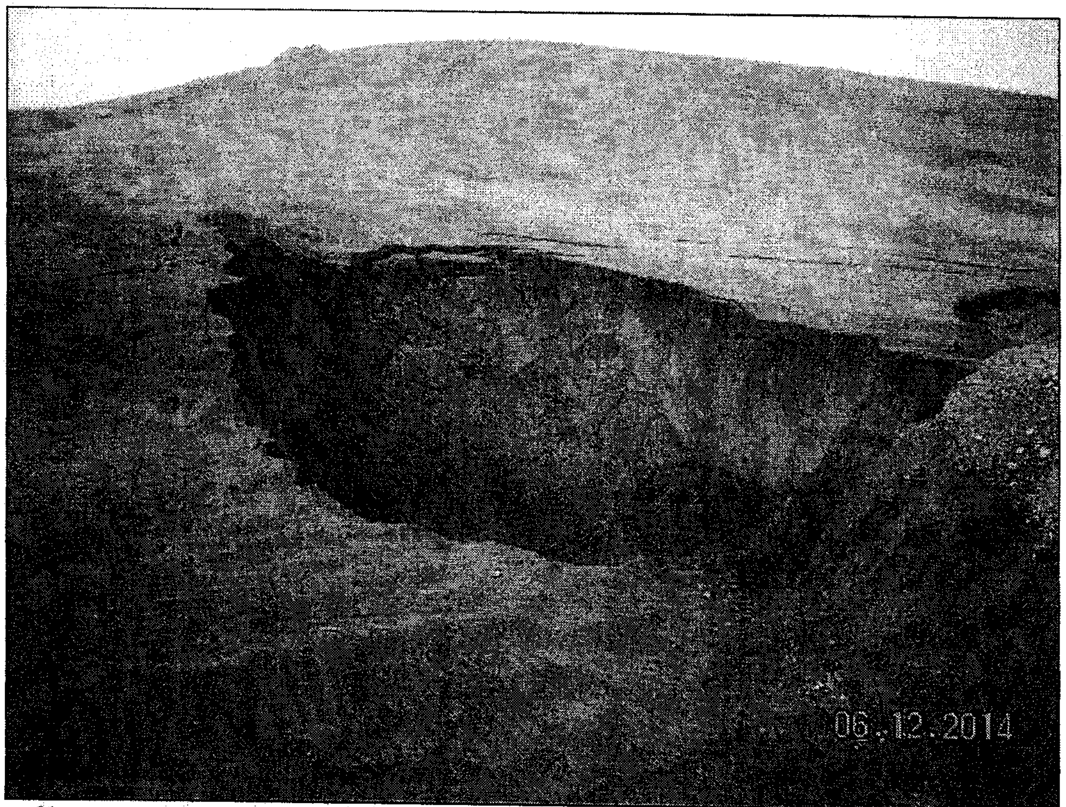

Photo No. 7 – Closeup of June 12 sinkhole (left side of Photo No. 6). Photo courtesy of Keith Markeson.

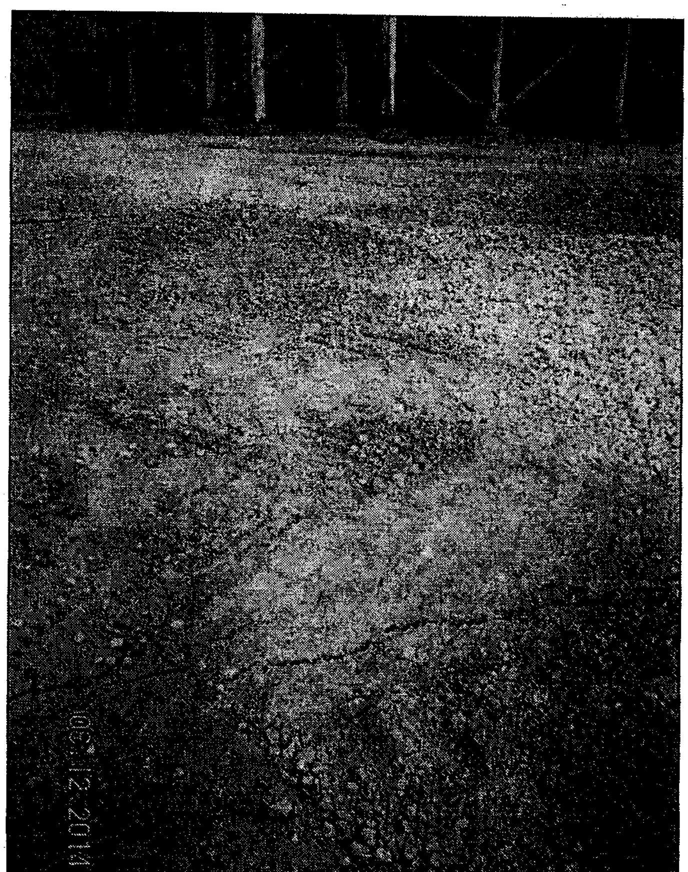

Photo No. 8 – Ground cracking in periphery of subsided area adjacent to Mill Building, taken June 12, 2014. Photo courtesy of Keith Markeson.