APPENDIX E

MINE HAZARDS

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REFERENCES

MINE HAZARDS[1]

This technical appendix provides information on strategies to address the potential for subsidence and sealing of existing mine shafts and boreholes.

POTENTIAL SUBSIDENCE AREAS

Summary

Mines in the Tar Creek and Lower Spring River watershed cover 2,540 acres of land and have been abandoned for at least 35 years. A map showing the extensive mine workings is shown in Figure 1. The mines vary in depth from 90 to 350 feet from the surface. Much of the area was mined on multiple levels with some mining voids reaching 125 feet in height from floor to ceiling, increasing the potential risk to populated areas and transportation corridors for collapse. There are 65 existing major collapsed areas in the watersheds between 100 and 650 feet in length. The Oklahoma Plan for Tar Creek (Appendix C, page 26) documents the following mine hazard strategy: Work will begin west and south of Commerce, Oklahoma, where 30 mine shafts, 10 subsidence features, and pockets of undermining exist. The undermined areas in Commerce and Picher/Cardin will be mapped to include more information about the subsurface. This map will be useful to others in the evaluation of subsidence potential. Work will then proceed to perimeter areas.

Using the mapping developed as part of the Oklahoma Plan for Tar Creek, the initial Additional Activity would be to assemble a team of Federal and State experts to review future land use options in the watersheds and identify high priority areas to be assessed. High priority areas include, but are not limited to, highly populated areas, major road corridors, and school bus routes. Using existing information; new technology, such as Interferometric Synthetic Aperature Radar (InSAR) data from the U.S. Geological Survey; and geophysics, the team will conduct a risk assessment to help determine the relative risk of potential subsidence in high priority areas.

Risk Analysis Cost Estimate

The initial cost estimate is $2.11 million over a 6-year period and includes USGS InSAR analysis and data, subsidence monitoring, and a risk assessment for high priority areas (Refer to Table 1).

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[1] The Mine Hazards strategy utilized a significant amount of information from the Governor Keating's Tar Creek Superfund Task Force Mine Shafts and Subsidence Subcomittees reports located at www.deq.state.ok.us/lpdnew/tarcreek/index.html

Figure 1. Mine Workings and Shafts in the Picher Field (provided by the Oklahoma Geological Survey)

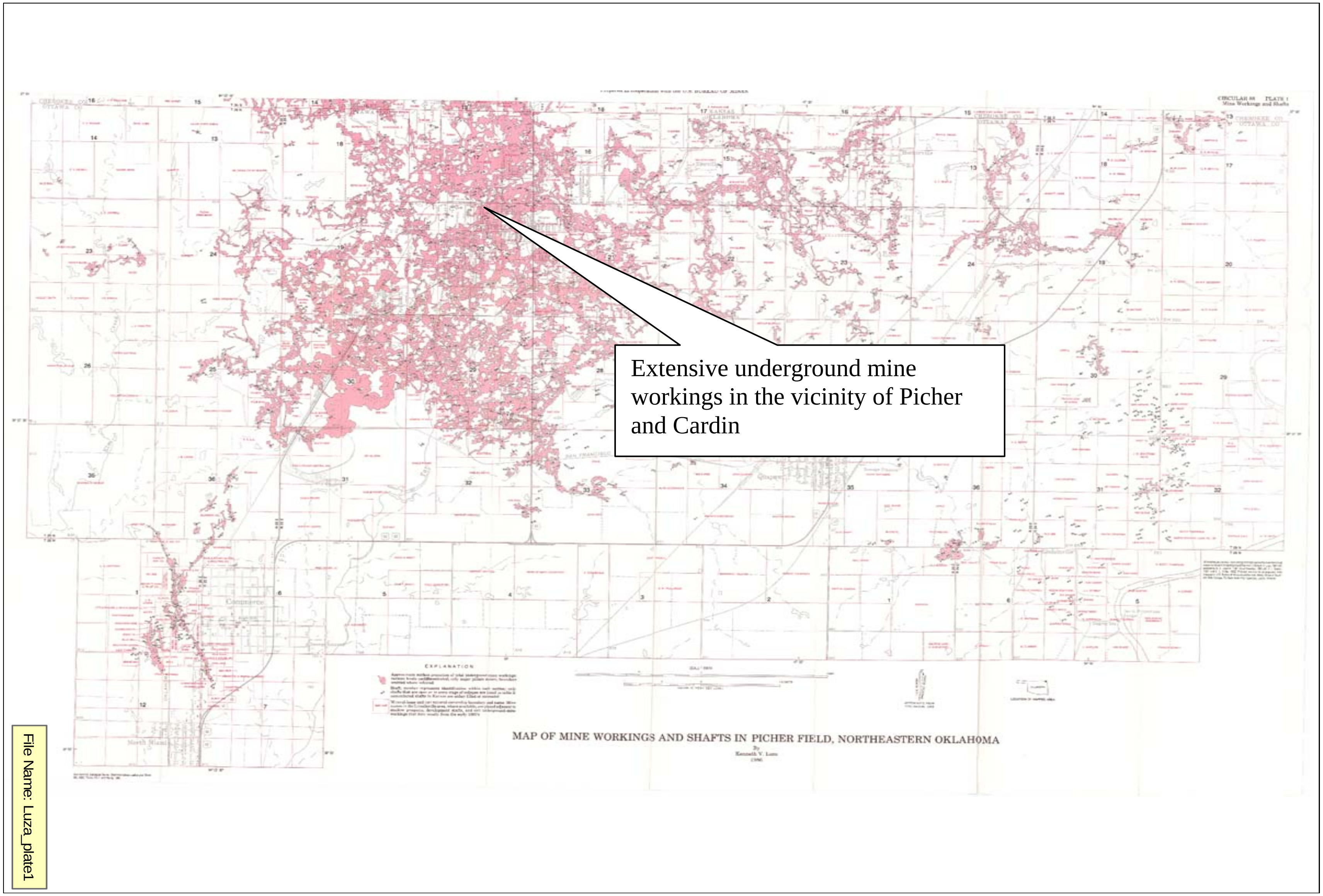

Table 1. Risk Assessment Costs in $1,000,000

Activity	Y1	Y2	Y3	Y4	Y5	Y6	Total
1. Risk Assessment	1.200	0.050					1.250
2. USGS Subsidence Monitoring and InSAR							
Install/maintain 5 extensometers. Measure relative land-surface elevation changes real time.	0.271	0.030	0.030	0.030	0.030	0.030	0.422
InSAR	0.100	0.043	0.046	0.048	0.051	0.145	0.433
Totals	1.571	0.123	0.076	0.078	0.081	0.175	2.105

The following paragraphs provide additional information on conducting a risk assessment. The methodology will be updated as new information becomes available.

Geology of the Site

There are numerous publications describing the geology of the Oklahoma portion of the former Tri-State Mining District. Ken Luza's book, *Stability Problems Associated with Abandoned Underground Mines in the Picher Field Northeastern Oklahoma* provides a concise description of the geology of the Picher Field. To simplify the description of the geology, excerpts from Dr. Luza's book are provided in Reference A.

Background

Picher Field is situated in northeastern Oklahoma and southeastern Kansas. Greater mining occurred in the Oklahoma portion of the field than in Kansas. In addition, Oklahoma led the nation in zinc production almost every year from 1918 to 1945. Approximately 187,000,000 tons of crude ore were mined from the Picher Field. More than 1.3 million tons of lead and 5.2 million tons of zinc were produced since mining began in 1891 near the small community of Peoria. Lead and zinc production from the Picher Mining Field ended in late 1970. Although small amounts of lead and zinc concentrates were produced until 1977, the large mines and concentrating mills were abandoned in 1970.

The Oklahoma portion of the mining field is situated in Ottawa County, Oklahoma. The principal towns in the area include Picher, Cardin, Quapaw, and Commerce. Picher and Cardin are located near the center of the field. North Miami and Miami are located on the southern end of the mining field. Approximately 45 sections of land contain mine workings in the Oklahoma portion of the field. The mined areas cover approximately 2,540 surface acres of land.

Surface subsidence associated with abandoned underground zinc-lead mines occurred during the mining era, and a few have occurred since cessation of mining. For example, between 1961 and 1967 when mining was resumed under the Small Operators Lead and Zinc Stabilization Bill, five major subsidence events occurred as follows: Fox, Farmington, Domado, Blue goose, and Netta White. As of 1982, there were 65 major (exceeding 95 feet in diameter) subsidence features identified in the Picher Field. Since 1967, some effort has been expended to better understand the mechanics of subsidence; however, no significant work has been initiated to assess the current stability of the mine workings to determine the potential for future subsidence.

In 1979, three U. S. Congressmen representing the citizens of their respective states in the Tri-State area (Kansas, Oklahoma, and Missouri) expressed concern for the safety of their constituents. They requested the U. S. Bureau of Mines and the State geological surveys of Oklahoma, Kansas, and Missouri to investigate the mine-related problems of the Tri-State area. The principle objectives of the investigations were: (1) to compile on a series of maps the location and extent of past mining activities and the resulting surface effects (underground and open-pit mine workings, shafts ground subsidence, accumulation of mine waste, and tailings ponds); (2) to identify hazardous areas with potential for future damage to persons or property; and (3) to consider methods to protect the public from hazardous and potentially hazardous conditions. The U. S. Bureau of Mines released the results of these investigations as a series of open-file reports.

Very few of the recommendations contained in the Oklahoma report on the Picher Field were implemented since no funds were provided to address the problems identified. Some open mine shafts have been filled, but mostly by private citizens. In the mid-1980's, attention was focused on the Tar Creek diking and diversion project and plugging of abandoned water wells penetrating the Riboudoux Aquifer. Some fencing was installed around a few hazardous sites, and the Bureau of Indian Affairs initiated a program to fence all Indian-owned former mining lands under their control.

Oklahoma Governor Frank Keating established a Tar Creek Task Force in 2000 to assess the extent of the problems at Tar Creek and provide appropriate recommendations. The Task Force focused on eight areas of concern; health effects, mine shafts, subsidence, chat use, water quality, Native American issues, drainage and flooding, and natural resource damages. The final report was issued in the fall of 2000. Although numerous recommendations were included in the final report, funds were not appropriated to address the recommendations.

In November 2003, the <u>Oklahoma Plan for Tar Creek</u> was issued to address many of the Tar Creek problems, primarily on the outer perimeter of the site. The plan includes funding for filling some subsidence pits and open mine shafts. The plan had strong support from Senator Jim Inhofe who was instrumental in providing $45 million for its implementation. The plan is currently being implemented.

The Bureau of Mines conducted one of the most comprehensive investigations of subsidence in the Picher Field in 1967. The report by James Westfield and Ernest Blessing titled, *Report of Investigation of Surface Subsidence and Safety of Underground Employees in the Picher, Oklahoma, Field of the Tri-State District*, provides a comprehensive assessment of the mining techniques that contributed to weakened support structures in the mines. Excerpts from the investigation are worth repeating and are provided as Reference B.

Natural pillars, 25-50 feet in diameter and commonly spaced 30-100 feet apart, were left in place to support the mine workings. As much as 15-30% of the underground ore body was left in place for support pillars. It was a well-documented practice for the mining companies to completely remove natural support pillars containing significant amounts of lead and zinc from the mines when it became apparent that a mine was no longer productive. Natural support pillars were also "shaved" or "trimmed" to remove available ore without completely removing the pillar. After the larger mining companies were finished with mine leases, they would often sell the lease or sublease the mine to independent mining companies or miners called "gougers" who would often remove additional support pillars and/or mine the roof in a final effort to remove remaining lead and zinc ores.

Many mines in the Picher Field were mined on multiple levels, leaving voids of up to 125 feet in height. Numerous subsidence events occurred following removal of natural support pillars beginning in the late 1920's. Most large subsidence events (greater than 95 feet in diameter) occurred in the field prior to 1952. Most mining maps, including half section and detailed mine maps, do not identify those pillars removed nor do they identify the areas mined by the gougers.

The geology of the mining field varies throughout the field. For example, in the eastern part of the field near Lincolnville, the Pennsylvanian units are absent or very thin, resulting in shallow mining depths. Mining depths were 80-100 feet while mining depths near Scammon Hill mine north of Commerce were over 300 feet. Typical mining depths were 180-250 feet. The stability of the mine workings was affected by the depth of shale overlying the mined areas, the thickness or absence of various beds, and the type of ground where the ore was located such as ground containing multiple sizes of boulders, natural fractures, etc.

Past mining practices and the long period of time passed since mining ceased adds to the uncertainty of the structural integrity of the rock formations, in particular pillars, remaining in the abandoned mines. Uncertainty remains as to:

- which additional pillars were removed/shaved
- which additional roof areas were mined by independent mining companies and miners
- the location of all rock (roof) falls that have occurred and how many of the ones identified on mine maps have been evaluated
- deterioration of structural pillars due to long term immersion in acid mine water
- structural integrity of roof structures in large mining voids

Risk Assessment Methodology

Several steps should be taken to address the potential for future subsidence. The following list is not complete, but can serve as a starting point to begin the assessment.

1. The first step is to assemble a small, highly qualified, multi-disciplinary technical team to conduct the assessment. The team should be kept as small as possible to be manageable and to provide the appropriate focus on the assessment.

   The multi-disciplined team should be assembled from Federal and State agencies and possibly national laboratories, universities, and contracting organizations. The minimum technical disciplines required by the team are geologists with hard rock mining experience, engineers, geophysicists, geohydrologists, etc. Contingent on approval, the following agencies are potential participants on the team.

- U. S. Army Corps of Engineers
- Department of the Interior
  1) U. S. Geological Survey
  2) Bureau of Land Management
  3) Office of Surface Mining
  4) Bureau of Indian Affairs
- Department of Agriculture
  1) Natural Resource Conservation Service
- State of Oklahoma
  1) Oklahoma Geological Survey
  2) Oklahoma Conservation Commission
  3) Oklahoma Department of Transportation
- Others as determined necessary

Representatives from State, Federal, and other agencies/organizations not having a clearly defined long-term contributing role should not be assigned as permanent members of the team. Their expertise and/or contributing information could be called upon at the specific time it is required.

2. The technical team should assemble for the first meeting in Picher to begin formulating a more detailed approach for assessing the potential for future subsidence at Tar Creek. The initial meeting would include a series of presentations on the history, geology, past mining practices, history of subsidence in the area, and initial areas of focus by the team. A tour(s) of the site would also be conducted.

3. The initial meeting should also include discussions to further refine the scope of the assessment. The following suggested draft scope is offered for consideration.

   - It is impractical to assess the entire mining field for the potential of future subsidence. Since the structural integrity of most mined areas is unknown, it is important to assess residential areas and transportation corridors as the first priority. Non-residential areas where significant past mining practices and/or geological considerations indicate possible weakened support structures (pillars/roof) may be added to the list as areas of secondary concern.
   - The residential areas to be considered are the communities of Picher-Cardin, Hockerville, and Quapaw. Mining records show that neither Commerce nor North Miami was significantly undermined. In addition, open and collapsed mine shafts and subsidence pits are being addressed in areas around Commerce.
   - Transportation corridors to be considered include from the junction of Highway 69-69A north through Picher to the Kansas State line; Highway 69A through Quapaw to the Kansas State line; East 20 Road (‘A’ Street) from 1 mile west of Picher to the junction with Highway 69A; East 40 Road from Highway 69 to

Highway 69A in Quapaw; State Line Road east of Highway 69A; bus routes; and the Cardin Road from the junction with Highway 69 in Picher to the junction north of Commerce.

4. Develop a ranking system to describe the relative risk of future subsidence. For example, categories such as very high, high, moderate, low, and very low could be assigned specific definitions

5. Establish the criteria to evaluate selected sites. For example:

   - Areas mined on multiple levels
   - Areas where large rock falls occurred
   - Suspect areas where the rock structure is questionable
   - Review those areas identified by former miners in the Subsidence Subcommittee Report of 2000.

6. Determine if and/or how the independent subsidence projects underway by the Oklahoma Conservation Commission and the Oklahoma Geological Survey for the Meteor and Town Site mines and the Picher Reunion Park can be incorporated into the overall technical assessment.

7. Establish a local repository for maintaining the maps and records required by the team. Data from drill logs, ore production records, half section maps, and individual mine maps will be routinely used by the team to assist in assessing the current condition of mined areas. These mining record and maps are currently maintained at several locations, including MSSU Archives, Picher Mining Field Museum, Baxter Springs Museum, BLM in Tulsa, Oklahoma Department of Mines in Oklahoma City, Joplin Mining Museum, and in private collections. Some of these records have been microfilmed and scanned by the OCC.

   There will be a need for a central point for obtaining access to the various records and maps required by the technical team. It is suggested that this central point be located at the Picher Mining Field Museum in Picher. The museum currently has over 200 mining maps in its collection and extensive mining records. Copies of the OCC scanned CD's and copies of microfilm could be provided to the museum for use by the technical team. The maps and records available at the other locations should be inventoried so that copies required by the team could be readily obtained. The museum staff could conduct the inventory and be available to obtain the necessary copies on short notice. The cost would be minimal.

8. The State of Kansas has recently completed a comprehensive drilling project along State Highway 69 across the State line north of Picher to assess the stability of the highway. The Kansas data should be reviewed by the technical team and discussed with the Kansas officials to determine if the methods used have applicability in the Picher Field.

9. Evaluate the use of Interferometric Synthetic Aperture Radar (InSAR) to assess slight changes in elevation in the mining field as a possible indicator of future subsidence.

10. Evaluate the use of geophysical methods (ground penetrating radar, seismic reflection or refraction, magnetics, resistivity, etc.) in assessing future subsidence. Although these methods have not been considered highly useful in the Picher Field in the past, new technologies may be available.

11. Explore the possible use of side scanning sonar and mobile underwater cameras to determine the presence or absence of pillars and to determine the physical condition of pillars in the underground mine workings.

12. Determine the contribution a Geographical Information System (GIS) might provide to the assessment.

13. Seek out former miners and engineers/surveyors for personal interviews to obtain first hand information on mining techniques used in the field and the condition of the mines they were familiar with.

14. Assess the use of core drilling in specific areas of concern and develop a plan to identify the location and type of drilling required.

15. Prepare a final team report of findings and recommendations.

Potential Activities Following a Risk Assessment

If analysis indicates the potential for subsidence is a serious concern, alternative solutions could be evaluated and compared to identify cost-effective solutions for consideration. Social affects and impacts are part of the evaluation process. Types of alternative solutions to address high-risk potential subsidence in populated areas include structural and non-structural measures. Structural alternatives are physical modifications designed to reduce the occurrence of potential subsidence events. Examples of structural alternatives include geotextile soil nets, pneumatic stowing, hydraulic flushing, grouting, grout bags, reverse roof bolting, dynamic compaction, and backfilling.

Non-structural alternatives reduce the impacts of subsidence independent of the occurrence of subsidence events. The October 2000 Governor Keating's Tar Creek Superfund Task Force (Subsidence Subcommittee) identified special building codes, city/county planning, and voluntary relocation as being viable non-structural alternatives for consideration. Structural and non-structural alternatives are discussed in the following paragraphs.

Mine Subsidence Abatement Techniques

In 1983 and 1986, the Bureau of Mines, in cooperation with State Geological Surveys, issued reports on stability problems and hazard evaluations in the Oklahoma, Missouri, and Kansas portions of the Tri-State Mining area. Among other things, these reports identified five methods of hazard abatement for mine subsidence. Backfilling, grading to gentle slopes, fencing, controlled collapse with explosives, and public education were all suggested. Around the nation, other methods have also been used for abating hazards associated with subsidence. These include backfilling mine workings using various methods of grouting, pneumatic stowing and hydraulic backfilling, enhancing roof support using reverse roof bolts or grout bags (artificial pillars), and reinforcing the ground surface using geotextile soil nets beneath the ground surface.

Following is a comprehensive list of subsidence control, protection, and prevention methods for situations where shaft closure will not, by itself, control the subsidence.

- Surface stabilization using geotextile soil nets
- Pneumatic stowing
- Hydraulic flushing
- Grouting
- Gravity grouting
- Pressure grouting
- Compaction grouting
- Grout bags
- Controlled collapse
- Reverse roof bolting
- Dynamic compaction
- Daylighting and backfilling
- Caissons, grade beams, soil nails, driven piers, and rock anchors
- Relocation and demolition
- Zoning
- Special building codes

A more detailed description of these methods is provided below. Many have been used in mine stabilization throughout the country. However, the presence of water filled mines in the Picher Mining Field eliminates the use of some of the methods and others have seen only limited application.

Surface Stabilization Using Geotextile Soil Nets. Geotextile materials such as high strength webs and nets have been used to reduce the risk of catastrophic ground failure under roads. The Kansas Department of Transportation is currently considering using this method to stabilize a road on the State line between Pitcher, Oklahoma, and Baxter Springs, Kansas. The method involves excavation of the soil material under the area to be protected to a depth several feet below final grade. The geotextile is unrolled and anchored along the edges, then backfill materials are placed over the material and compacted. It has been suggested, in some cases, that the ground be excavated to a solid geologic formation and the geotextile deep anchored to increase stability.

Pneumatic Stowing. This is the filling of mine voids with granular materials transported by air. This method is most effective when direct access to the mine workings is available to workers. However, remote pneumatic stowing has been used successfully to inject airborne granular materials into mines. When mines are open and unobstructed, this method can result in up to 100% of void fill, effectively eliminating the risk of future subsidence. Complete surface after completion of work to determine if roof contact is made. This method has been used in coal mines effectively because of the even mine roof conditions. Pneumatic stowing is less expensive than grouting for filling large areas but may not be effective in northeast Oklahoma where mine workings have tall or uneven roofs, and roof contact is unpredictable. In addition, the method can only be used in dry mines.

Hydraulic Flushing. This is filling of mine voids with granular materials transported in water slurry. Material placement is controlled by use of grout curtains or aggregate bulkheads constructed remotely from the surface through drill holes. When mines are open and unobstructed, this method can result in up to 100% of void fill, effectively eliminating the risk of future subsidence. Complete fill is verified either by personnel working in the mine or by drilling confirmation holes from the surface after completion of work to determine if roof contact is made. This method has been used in Wyoming and other states to back fill coal mines under entire subdivisions. However, the process requires large volumes of material and water.

Grouting. This is the process of placing a mixture of cementitious material and fine aggregate as a fill material into the mine void. The grout is placed at a low volume rate. Many states and the Office of Surface Mining (OSM) use gravity grouting to stabilize coal mines that begin to subside under homes, buildings, and roads. This is often a cost-effective method of ground stabilization where mine voids are not too tall (less than 8 feet) and the area to be stabilized is limited to structure or roads. However, it can be used in mine voids or nearly any size and configuration. Cost may become a problem for larger mine areas.

A. ***Gravity Grouting*** consists of placing a mixture of cementing agent (generally Portland cement) and fine aggregate into the mine level by means of a borehole. The most commonly used combination for mine grouting in the Midwest is a mixture of sand, Portland cement, and Type-F fly ash. The pressure of the gravity head is the driving force used to place the grout. This is used frequently for abatement of subsidence under roads and structures associated with abandoned coal mine sites in Kansas and Missouri and would be effective in certain situations in the Tri-State lead/zinc mines.

B. ***Pressure Grouting*** is the process of pumping the grout mix into the mine area and overburden. Packers are used to seal the borehole so that pressure can be exerted on the grout. Pressures range from one-half to one psi per foot thickness of overburden. This is used frequently for abatement of subsidence under roads and structures associated with abandoned coal mine sites and would be effective in certain situations in the Tri-State lead/zinc mines. Pressure grouting enables the operator to force grout into fractured and rubblized zones, providing enhanced protection from subsidence.

C. ***Compaction Grouting*** is the injection of a stiff (low slump) grout at high pressure, up to 500 psi. The grout forms a ball at the point of injection and compacts the surrounding material. This method is being used to stiffen foundation soils that have lost strength and bulk due to subsidence. It is also being used to compact unstable fill in old mine shafts that were filled with trash or poorly back filled in the past. It is cost effective for poorly filled mine shafts and structure-size stabilization projects, but is not suited for area wide projects.

Grout Bags are heavy fabric bags designed to be placed through a borehole, then filled with grout to build artificial mine pillars. As the bags fill, they form a column in the mine void to add additional support to the mine roof, reducing the risk of subsidence. They have been used successfully in Pennsylvania where abandoned coal mine roof heights may reach 16 feet. Dennis Boehm of Hayward Baker, Inc., speculated that grout bags may be effective in mine rooms up to 30 feet tall (KDOT Abandoned Mines Workshop, April 27, 2000). We understand that grout bags are being considered for use in 2000 by the Kansas DOT for stabilization of a road along the State line between Picher and Baxter Springs, Kansas. This method may also be used to construct underground barrier walls to contain pumped grout or hydraulic backfill materials.

Controlled Collapse uses explosives to collapse the mine roof in a predictable manner. Collapsed areas are normally backfilled afterward. This technique has been used in the Tri-State Mining Area at least once, according to the 1983 BOM Study of Kansas. According to the report, in the late 1950's, the Kansas Department of Transportation (KDOT) had a situation where a particularly collapsed mine was open to the surface. Contractors used a small bulldozer to push dumped fill into the uncollapsed portion of the mine room to reduce the height of the planned roof fall. The roof was drilled and shot down with a series of timed delays between the lines of holes to prevent vibration damage to adjacent buildings. The KDOT decided not to use the method on another area at the time because the mine roof was 80 feet above the floor, and it was feared that the hydraulic ram effect of the falling rock might collapse mine openings off the road right-of-way.

Concerns about using this method in populated areas stem both from the possibility of setting up a hydraulic ram effect in flooded mines and the possibility that vibrations from the blast might collapse other portions of the mine. The 1983 BOM study states, "in general, there are few other places where blasting could be used without incurring possible liability and is not recommended." A recent discussion with a Missouri DOT geotechnical engineer working on Range Line Road around Joplin stated that they are not using controlled blasting to collapse the mines for similar reasons.

Reverse Roof Bolting attempts to increase the stability of an undermined area by drilling from the surface and installing roof bolts into the mine roof strata, tying the roof rock to the overlying layers. Information regarding this method was not reviewed, but we understand that it is being considered for use in 2000 by KDOT for stabilization of a road along the State line north of Picher, Oklahoma. Possible drawbacks of the method include increasing the rate of water infiltration due to the drilling and installation of roof bolts, which might lead to increased erosion and reduced stability of the mine.

Dynamic Compaction is a process for compacting soils at depth. The process involves dropping a weight in excess of 10 tons on a grid pattern from a given height. This method is sometimes used for highways work and may have application for stabilizing abandoned exploratory holes dug by early miners. The method has the potential to induce subsidence in areas where mine roof structure has deteriorated substantially, so thorough knowledge of geologic conditions is important when planning its implementation. The Missouri Department of Transportation is currently considering the use of dynamic compaction for the Range Line Road project at Joplin, Missouri.

Daylighting and Backfilling is used where mines are shallow and where roof rock is thin or soft. This method utilizes excavation equipment to remove the geologic materials overlaying the worked-out mine, and then fills in the mine workings from the surface to the ground surface level. The method results in 100% closure of the mine with only a risk of soil settlement to deal with. Because large voids are positively eliminated, the risk of catastrophic collapse is nearly eliminated.

Caissons, Grade Beams, Soil Nails, Driven Piers, and Rock Anchors are all methods that may be used to stabilize structures built over subsidence prone areas. They may reduce dangers of building collapse and costs of repairs after minor subsidence events occur. However, these do little to stabilize the ground and do not stop or slow the progress of subsidence events.

Relocation and Demolition. Relocation has been used in a few situations across the country where no other alternative existed to protect the public from extremely dangerous situations. Many residents in the Picher/Cardin area have expressed interest in considering voluntary relocation because of the enormity of health, safety, and economic issues. The National Environmental Policy Act and the Corps planning process requires that consideration be given to a voluntary relocation alternative and other alternatives as component features of a Watershed Management Plan. Cost effectiveness and incremental analysis are methods that could be used, along with consideration of social impacts, to compare various alternatives. Additional ongoing initiatives to address the health and safety concerns in the Picher/Cardin area are summarized below.

To address short-term critical health needs, Oklahoma Governor Brad Henry signed legislation that will provide State funding for volunteer relocation assistance to those families in the most affected area with children age 6 and under.

The Tar Creek Restoration Act (HR 2116) introduced into the House of Representatives directs the Administrator of the EPA to provide relocation and other assistance for residents at the Tar Creek Superfund site.

Zoning. Zoning laws may be very effective at reducing new public exposure to subsidence prone areas. With reliable mapping of subsidence risk areas, zoning can be used to designate areas suitable for new developments of various types. Zoning based on risk maps can designate the highest risk areas as off limit areas, lower risk areas for open space uses, and still lower areas for parking lots of commercial developments where structural considerations made development a low risk issue. Areas with the lowest risk for subsidence may be zoned residential and retail. Zoning will not eliminate the possibility of subsidence, but it can reduce the public and private costs when subsidence does occur.

Special Building Codes. The safety and structural integrity of buildings constructed over subsidence prone areas may be significantly improved by using certain construction practices. Counties and local governments can implement building codes that require these practices for new construction in subsidence risk areas. Similar to zoning in that they allow for more construction and development in higher risk subsidence areas.

MINE SHAFTS AND BOREHOLES

Summary

It is estimated that there are over 1,320 mine shafts, thousands of drill holes, and other related mine openings in the Tar Creek and Lower Spring River watersheds. Many of the openings are closed, but the stability and ability to prevent infiltration to the underground mine workings need to be verified. Many of the remaining open mine shafts are extremely dangerous, could cause future subsidence events, and provide conduits for surface water to mine workings interaction, which aggravate conditions for contaminated mine seeps.

The initial Additional Activity will locate, geo-reference, and develop a prioritized mine shaft closure and sealing plan for remaining mine shafts not addressed by the Oklahoma Plan for Tar Creek. This information would be integrated with the Oklahoma Plan for Tar Creek into a comprehensive closure program. Items that will be considered when prioritizing the closing and sealing of mine shafts include, but are not limited to, human exposure, location in relation to streambeds and floodplains, ability to convey water back to the underground mine workings, and physical condition. Appropriate closure and sealing methods would be selected based on site characteristics. Potential closure methods include backfill, concrete cap, concrete plug, wedge, polyurethane foam plug, and hollow core plug. The final step would be to close the prioritized mine shafts using the appropriate method and plug open drill holes.

Cost Estimate

The initial cost estimate is $1.77 million (Table 2) to locate, map, prioritize, and seal mine shafts and boreholes that may not be addressed by the Oklahoma Plan for Tar Creek.

Table 2. Mine Shaft Sealing Costs in $1,000,000

Activity	Y1	Y2	Total
Mine Shafts			
Identify, map, and prioritize mine shaft hazards	0.161		0.161
Stabilize and seal remaining mine shafts and boreholes		1.610	1.610
Totals	0.161	1.610	1.771

Mine Shaft Closure Methods

The following are descriptions of various mine shaft closure methods.

<u>Backfill Method</u>.

Definition. On-site or imported soil material, gravel, rock or grout entirely filing the shaft from bottom to top using either dry or wet material placed by gravity or under pressure.

Pros

Life span: Permanent

Degree of hazard elimination: Total

Maintenance: Maintenance-free

Construction safety: With proper equipment, workers' exposure to the mine hazard is low. Exposure to bad air is low with some conveyance methods.

Environmental concerns: If on-site material is used, spoil piles may be eliminated.

Design concerns: Generally low-tech or standard technology used (grout pumps).

Cost: Can be cheap if on-site material is used.

Cons

Life span: NA

Degree of hazard elimination: NA

Maintenance: NA

Construction safety: Workers must be protected from falling in the shafts. Shaft collars are often unstable.

Environmental concerns: Source material must be reclaimed. Backfill material must be benign.

Design concerns: Backfill material must fill the entire shaft. False plugs must be avoided. Heavy equipment access is necessary.

Cost: May be expensive if grout or imported material is required.

Concrete Cap Method

Definition. A structural concrete cap either cast in place or using precast panels and beams.

Pros

Life span: Permanent (100 years)

Degree of hazard elimination: Total

Maintenance: None required

Construction safety: Workers do not need to work in the shaft.

Environmental concerns: Minimal site disturbance.

Design concerns: Can prefab panels for standardized closures. Minimal site-specific engineering required.

Cost: Relatively low cost.

Cons

Life span: NA

Degree of hazard elimination: NA

Maintenance: NA

Construction safety: NA

Environmental concerns: Prevents bat access

Design concerns: Need competent rock to bear slab. Cap must be large enough to overlap all sides of shaft. Doesn't prevent collapse of sidewalls. Need access for concrete trucks or prefab panels.

Cost: NA

Concrete Plug Method

Definition. Concrete and rock plug formed over caved material or temporary forms.

Pros

Life span: Permanent (100 years)

Degree of hazard elimination: Total

Maintenance: None

Construction safety: No hazard to workers if no work is required.

Environmental concerns: Disturbs only a small area around shaft.

Design concerns: Provides support of sidewalls of shaft near surface. Plug remains functional should cave material below plug fail.

Cost: Low to moderate cost

Cons

Life span: NA

Degree of hazard elimination: NA

Maintenance: NA

Construction safety: May require workers to construct a bulkhead inside shaft with unstable sidewalls and hazardous atmospheres.

Environmental concerns: NA

Design concerns: Bulkhead must be constructed in competent rock.

Cost: Can be high if shoring required to safely install bulkhead.

Wedge Method

Definition. Steel cone or wedge fabricated on-site and filled with concrete.

Pros

Life span: Permanent (100 years)

Degree of hazard elimination: Total

Maintenance: None

Construction safety: Wedge can be fabricated remotely and lifted into shaft. No workers in shaft.

Environmental concerns: Small surface disturbance if competent rock near surface.

Design concerns: Concrete and wedge can be placed with helicopter in remote location.

Cost: NA

Cons

Life span: NA

Degree of hazard elimination:

Maintenance: NA

Construction safety: NA

Environmental concerns: Large excavation if competent rock greater than 15 feet deep.

Design concerns: Need competent rock to bear wedge form or increase size of structure on unconsolidated material. Either needs access for steel and concrete trucks, or use helicopters to fly in materials.

Cost: Relatively expensive.

Polyurethane Foam (PUF) Plug Method

Definition. Two-part polyurethane foam plug formed in place and covered with earth or waste rock. A detailed description can be found in "Shaft Closures Using Polyurethane Foam," *Proceedings: Symposium of Evolution of Abandoned Mine Land Technologies, Riverton, WY, June 14-16, 1989.*

Pros

Life span: Permanent

Degree of hazard elimination: Total

Maintenance: Maintenance-free

Construction safety: Workers can install closure from ground level.

Environmental concerns: Once mixed, PUF is inert. Can be installed in historic structures without damaging them.

Design concerns: Can accommodate poor access situations. Can be used as framework for concrete closures.

Cost: Installation costs are relatively low.

Cons

Life span: Fairly new technique with only about 10 years of history.

Degree of hazard elimination: NA

Maintenance: Potential for vandalism if cover material removed.

Construction safety: Exposure to falling because of necessity to work around collar of shaft. Exposure to toxic materials and fumes.

Environmental concerns: Unmixed chemicals are toxic. Exposed PUF will support combustion and will degrade in ultraviolet light.

Design concerns: Installation procedures are critical to closure success.

Cost: Material expense is high.

Hollow Core Plug Method

Definition

Life span: Permanent

Degree of hazard elimination: Total

Maintenance: Generally maintenance-free

Construction safety: NA

Environmental concerns: Minimal disturbance away from shaft

Design concerns: Accommodates unstable shaft collars by settling down/jamming as collapse occurs. Allows access to and ventilation of mine working if necessary.

Cost: NA

Cons

Life span: NA

Degree of hazard elimination: NA

Maintenance: Cap/grate over opening may be vandalized.

Construction safety: Exposure to falling and collapsing shaft collars. Must work down in the shaft to install formwork.

Environmental concerns: NA

Design concerns: Requires reinforced formwork to accommodate massive concrete.

Cost: Fairly high

Reference A

Description of the Geology of the Picher Mining Field

The Picher Field straddles the Cherokee Platform-Ozark Plateau boundary in northeastern Oklahoma. Other major geologic features include the Bourbon Arch, Nemaha Ridge, and the Arkoma Basin.

The rock formations exposed in the mining field include the Mississippian and Pennsylvanian units that are nearly flat with a low regional northwestern dip of about 20-25 feet/mile. Cambrian and Ordivician formations, primarily dolomite and chert with some sandstone and minor shale, are encountered only in deep drill holes and water wells in the area.

Mississippian rock units, principally the Boone Formation, are the host for most of the ore deposits. The Boone Formation is composed of fossiliferous limestone and thick beds of nodular chert. The term Boone is commonly used to describe the sequence of Mississippian interbedded limestone and chert units that crop out in northeastern Oklahoma. The Boone Formation is 350-400 feet thick in the Picher area and is divided into seven members (in ascending order): St. Joe Limestone, Reeds Spring, Grand Falls Chert, Joplin, Short Creek Oolite, Baxter Springs, and Mocassin Bend. These members are further divided into 16 beds. Letters of the alphabet were used to distinguish individual beds, beginning with B near the top of the Mocassin Bend Member and ending with R in the Reeds Spring Member. In the Picher Field, most of the mine workings are within the M bed. Other important ore zones occurred within the K, G, H, and E beds and sheet ground or low-grade blanket deposits within the Grand Falls Chert Member.

The Boone Formation is overlain by the Quapaw Limestone near Lincolnville and in part of the main Picher Field. The Chesterian Series, represented by the Hindsville Limestone, Batesville Sandstone, and Fayetteville Shale, generally forms a disconformable contact with the Boone Formation and /or Quapaw Limestone. Chesterian rocks are exposed on the east side of the Picher Field. However, the Batesville and Hindsville also crop out at Douthat. Both the Hindsville and Batesville are locally mineralized, especially in the eastern part of the mining field near Lincolnville.

Pennsylvanian formations of the Krebs Subgroup (lower division of the Cherokee Group) overlie the Boone Formation. The Krebs Subgroup was deposited on a post-Mississippian erosion surface. The formations, as mapped by Branson (Reed and others, 1955), include the McAlester Formation, the Savannah Formation, and the basal Bluejacket Formation Sandstone Member of the Boggy Formation. These formations consist of alternative terrestrial fine-grained sandstone, shale, and thin coal beds. The sandstone units are discontinuous and vary significantly in thickness where they are laterally continuous.

At a few places, sharply defined structural features are accompanied by appreciable dips. The Miami Trough, Bendalari Monocline, and Rialto Basin are three prominent structures that dominate the main part of the Picher Field.

Reference B

1967 Bureau of Mines Investigation

Mining in this area might be termed a random room and pillar method. Usually the mines were opened by two shafts sunk to the bottom of the ore body and spaced from 100 to 250 feet apart. From the shaft bottom, stopes were driven radially in all directions to the full height of the ore body, leaving pillars from 20 to 50 feet in diameter and spaced 20 to 100 feet apart depending on roof conditions and the grade of the ore. Regulations for pillar spacing, size, and pattern had not been established and this decision was left to operating personnel at each mine, often delegated to the ground boss (foreman). The size and spacing of pillars varied with the competency of the rock and richness of the ore in the mined area. About 12 to 20% of the ore was left in the pillars after first mining, which was followed usually by a limited amount of pillar trimming and pillar removal by the original operating company. After this mining was completed, the mines were subleased to smaller operations or individuals for cleanup work, which consisted of loading loose high grade ore, mining bright spots in the roof, walls, and floor and slabbing or removing existing pillars.

Some of the sublease and cleanup operators began as early as 1930 and all mines except two could be considered cleanup operations in 1966. Most of the mines have been subleased to many different cleanup operators over the years with each operator removing a little more support and in some cases finally removing enough support to cause cave-ins, some of which extended to the surface. Subleasing of the Indian lands was started on a large scale in 1961 or 1962 after the Small Operators Lead and Zinc Stabilization Bill was passed. Even though the field had been mined over several times, the subleases were available to recover large quantities of ore from cleanup and pillar work. After many years of this type of operation, most of the district had been mined over several times and the surface over mined areas is resting on minimum support. The underground openings vary from the large size mentioned previously to small haulage drifts 6 feet wide by 8 feet high. While most openings are more than 50 feet wide and 20 to 70 feet high, many are more than 100 feet wide and some exceed 200 feet in width.

Where more than one bed has been mined at the same location, several different conditions exist. In some instances the floor from the upper level and roof from the lower level have been mined out to make a high opening. Some superimposing of pillars in the upper level over pillars in the lower level has been practiced but generally little regard was given to this. In some instances pillars in the upper level rest on unsupported roof of the lower level either because they were located that way originally or because the lower level pillars were removed. The rock thickness between the levels varies from 2 to 3 feet to many feet, depending upon the ore formation. As a result of these mining practices, eventual subsidence affecting the surface is inevitable.

On Indian land, work on pillars already turned requires prior authorization of the Mining Supervisor of the Geological Survey. (Author's Note: This requirement was placed in effect in 1967). In some cases, the operators commonly called "gougers" have slabbed or removed the pillars on their leaseholds without authorization and on occasions have been known to stray from their leaseholds and mine pillars on adjoining land.

Many cave-ins have occurred in the District after areas had been mined out without leaving adequate support. Most of those falls have not extended to the surface; however, those that have fallen have inflicted much damage and left the areas unusable.

A number of roads pass over the mined out areas, particularly Highway 69 which traverses the Picher Field. Extensive mining and pillar recovery have been conducted under this highway, and it is the opinion of the writers that subsidence of the highway can occur.

At some small mines, the height of the mine openings and lack of adequate equipment prevent officials and employees from observing, testing, or scaling the high roofs.

The process of mining is followed inevitably by some degree of sinking of overlying strata and consequently to the surface. The subject of mining subsidence is filled with uncertainties, contradictions, and difficulties of interpretation. It is true, regardless of the nature of the underground excavation and method of roof support, that subsidence of the ground above an excavation is very likely to be the final instance of mining. In view of the present mine openings, subsidence is bound to continue, and further mining therein will speed up the subsidence process.

The populated areas and surface structures such as highways and railroads, which require protection from subsidence, constitute only a very small portion of the undermined area in the district. Much of the area where subsidence has or is likely to occur is covered with chat, tailings, and slime ponds and is of relatively little value.

Although backfilling of the entire undermined area would probably be prohibitive from a cost standpoint, such protection might be afforded for the aforementioned critical areas and the remainder purchased for a wildlife refuge. If backfilling is to be done, it should be started before the mine workings are inundated and controlled backfilling is made virtually impossible. Also, if the large expanse of undermined area is to be used for a wildlife refuge, it might be wise to blast out the pillars in these areas to induce caving and subsidence to stabilize the area before it is inundated by flooding once pumping from the mines is discontinued.

Because of the excessive mining under residences, streets, secondary highways, railroads, and drainage areas, an engineering study should be conducted to determine weak areas in which subsidence might occur and to recommend corrective measures for preventing public hazards. The study should include cost estimates of such projects, advising parties involved such as residents, highway departments, etc.; and evaluating the possibility of backfilling in critical areas or other alternatives for the correction of this problem.