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CONTROLLING ACID MINE DRAINAGE FROM THE PICHER MINING DISTRICT, OKLAHOMA, UNITED STATES

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ABSTRACT

The Picher Mining District, located principally in north-eastern Oklahoma, was one of the world's largest lead-zinc mining areas during its 55 year life. The field covers an area of approximately 72 square miles (186 km^2); an estimated 1.22 x 10^8 m^3 of material worth in excess of one billion dollars, has been mined.

Mining activities were typified by surface exploratory drilling identifying ore distribution and extension of underground workings to the lead and zinc deposits outlined. Exploration holes were either left unplugged or plugged at the surface with a section of a telephone pole. Low grade ore and waste rock were discarded in mined out portions of drifts. These waste piles containing pyrite and marcasite were left underground and oxidised during the many years of active mining. Upon cessation of mining activities in the mid-1960s, the drifts and shafts of the abandoned workings began to flood as the cone of depression filled in, leading to the dissolution of the oxidised sulfides and the formation of large volumes of acid mine water in the mined out openings. The resulting poor quality water, with high concentrations of cadmium, iron, lead and zinc, began discharging at the surface in 1979. Contamination of the underlying aquifer supplying local residents was first detected on a localised scale in 1980. The present surface water and groundwater contamination have lead to the area being classified as one of the top ten hazardous waste sites in the U.S. by the EPA under the superfund program.

To mitigate the current conditions we have proposed that acid mine water be collected where it currently discharges at identified springs and pumped from widely spaced wells in the workings. The water would then be treated at a 87.4 l/sec lime neutralisation/precipitation facility. Construction costs are estimated to be $3.7 million and $560,000/yr for O & M.

PROBLEM DEFINITION

As with many underground mines, groundwater inflows posed a problem during mining. To maintain unsaturated conditions in the workings large capacity sump pumps were used. Pumpage from the ore bearing Boone formation, a Mississippian cherty limestone, varied with time and depth of mining.

During World War II (WW II), an estimated 1005 l/sec were discharged by various mining operations. As demand for lead and zinc declined after WW II, pumpage declined to about 393 l/sec as deeper workings were abandoned[1].

A conceptual cross section of the area is shown in Figure 1. An indepth description of the local geology and hydrogeology of the area is presented elsewhere[2]. The many years of water removal from the Boone formation resulted in the formation of an extensive cone of depression. Cessation of mining in the mid-1960s, ended more than 50 years of pumpage from the Boone formation, leading to flooding of the abandoned workings as the cone of depression recovered. Mining activities exposed sulphide bearing minerals to moist, oxygen-rich air, which oxidised the iron sulphide minerals present. Waste material (gob) containing pyrite and marcasite were discarded in the mined out

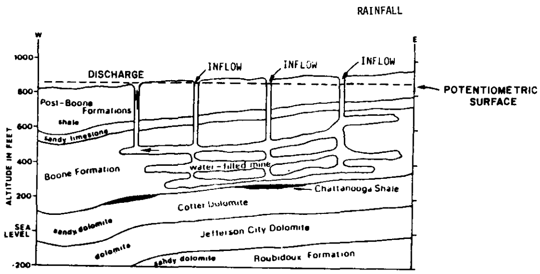

Figure 1. Conceptual cross section of the Picher Mining District

portions of drifts instead of hauling it to the surface. Groundwater that flooded the mine workings came in contact with the oxidation products that had formed earlier and dissolution occurred rapidly. Initially, the acid water containing high concentrations of heavy metals reacted with the carbonate host rock. This reaction neutralised some of the acid water and raised the pH to the 4 to 5 range. Eventually, the calcium carbonate host rock lost its neutralising capacity as precipitates of the reactions formed on the surface area of the carbonate rock[3]. Subsequently, acid neutralisation ceased or was retarded greatly.

Filling of the cone of depression continued with time. Recharge to the cone was occurring radially and from direct surface water inflow to the workings through abandoned exploration holes, shafts and collapse features which penetrate the overlying shaley Krebs Group. Therefore, there was little potential for the highly mineralised water to move laterally, away from the mining district; but an opportunity existed for downward movement along the vertical hydraulic gradient toward the underlying Roubidoux formation, an Ordovician age sandy dolomite. The Roubidoux is the principal source of potable water for northeastern Oklahoma.

As recharge continued the potentiometric surface of the Boone continued to rise until it reached the base of the Krebs Group. The shaley Krebs became a confining layer and the Boone began to behave as a confined aquifer as the potentiometric surface in the Boone rest above the base of the Krebs. By 1979, the potentiometric surface of the Boone exceeded ground surface elevation in several locations. Surface discharge of acid mine water began to occur via abandoned or partially plugged exploration holes and shafts. This lead to the rapid deterioration of Tar Creek which receives the acid mine water. Surface discharge will continue as long as the potentiometric surface of the Boone is higher than the ground surface and hydraulic connections (manmade openings) through the Krebs exist.

The quality of the acid mine water being discharged is significant in that toxic heavy metals such as lead and cadmium are present in average concentrations five times greater than drinking water standards. Iron and zinc are the predominant dissolved metals with average concentrations of approximately 150 mg/l each. The toxic metals concentrations, the enormous estimated volume of acid mine water present within the mines, 4.07 x 10^7 m^3, and the potential for regional contamination of the principal water supply in the area (Roubidoux formation) caused the EPA to designate this area as one of the top ten hazardous waste sites in the United States.

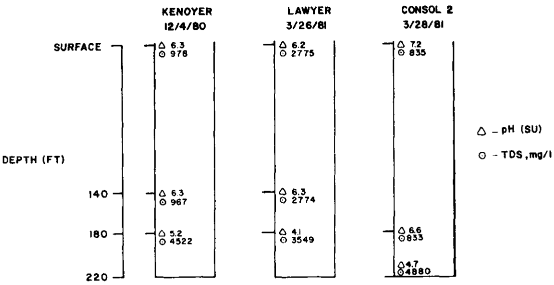

Figure 2. Ph and TDS values at various depths in three abandoned shafts, Picher Mining District.

Figure 2 shows the pH and TDS values of groundwater samples taken from various depths in three representative mine shafts. Inspection of the figure reveals that the majority of moderate pH, high TDS water occurs in the lower section of the shafts. This could be the result of downward migration of acid water of a consequence of the fact that the acid water formed in the lower portions of the mine workings (where the gob is located) and remained there. The authors believe that the principal reason for the acid mine water being present in the deeper levels of the workings is the deposition of the acid-forming waste rock.

MINING HISTORY

Lead-zinc ores, principally galena and sphalerite, were first discovered in the Picher Field in 1901, with output of concentrates beginning in 1904. The main body of the ore deposit was discovered in 1914 and by 1917 the Oklahoma part of the field was well defined by producing mines. Between 1915 and 1920, zinc concentrate production increased from 25,200 to 455,000 tonnes per year. The large increase in production was made possible by the creation of hundreds of small companies operating on 16.2 hectar tracts. At this time there were some 230 mines operating in the field. The Picher Field had its greatest production in 1925 when 679,493 tonnes of zinc concentrates and 117,936 tonnes of lead concentrates were produced.

Following the introduction of the flotation process, the extensive tailings piles produced earlier, when only jigging and tabling had been used, were reworked. This reworking provided approximately 20% of the total zinc production of the field between 1935 and 1945. In the 1930s centralised milling began, leading to the consolidation of mining and milling operations, and the demise of small operators. The centralised milling operations allowed the economic recovery of lower grade deposits from the more depleted mines. After WW II a steady decline in the production rate occurred, partly as a result of reduced exploration and development efforts. By 1957, many operators shut down or cut back operations and the shut down was essentially complete by 1958. Mining was started again in 1960 at a reduced rate and lasted until 1965 when all major operators ceased activities. At this time, pumpes within the mines were removed, leading to complete flooding of the workings. During the early stages of flooding after the major mining companies had pulled out, production from the field continued on a limited scale by "gougers" robbing high grade ore from the pillars. The extent of these operations is unknown, but they undoubtedly facilitated subsidence in the area. One small operator continued working the Old Chicago Mine up to 1976, at which time he was forced out by the rising water.

MINING PRACTICES

Early exploration was accomplished by surface drilling to establish ore location and grade. In heavily mined areas, an excess of 1000 exploration holes (2.6 km^2) can be identified on available mine maps. In actuality, the number of exploration holes is greater than indicated because the mine maps only show more recent exploration work conducted after consolidation of the workings by large operators. Typically, the exploration holes were abandoned or rudimentarily plugged. This was accomplished by either driving a 1.2 to 1.5 meter long section of a telephone pole in the hole or simply by shovelling surface material into the hole until it bridged off. Occasionally, a good show of ore would warrant casing the hole to provide access for air or power to the expanded workings.

Small operators on 16.6 hectare tracts typified early mining operations. This led to an estimated 1600, 1.5 x 2 meter diameter shafts being constructed in the Picher Field. Initial mining was accomplished using the traditional method of hand shovelling ore into steel or wooden cans at the working face. The cans were then transported to the shaft by a tail rope haulage system and finally lifted to the surface. In the late 1930s track mounted shovels provided the first step toward mechanisation of mining. By the mid-1940s, rubber tired diesel trucks were introduced which greatly facilitated the removal of ore.

Extension of the mine workings to lower levels or driving of new drifts involved the handling of a certain amount of waste rock, especially at deeper mining levels where lower grade ore occurred. Instead of removing the waste to the surface much of the material was deposited in lower mined out portions of the workings. These waste piles added greatly to the generation of acid mine water when the workings flooded. Measured values of pH and total dissolved solids at various depths for selected shafts are shown in Figure 2.

PROPOSED SOLUTION

The proposed solution to the acid mine water contamination in the Picher Field involves the collection of naturally occurring acid discharges, pumpage from wells in the lower portions of the drifts and treatment of the water collected. Natural spring discharges of acid mine water vary from about 10.0 l/sec to 43.7 l/sec depending upon the level of the potentiometric surface of the Boone as recharge and discharge oscillate. These natural discharges would be collected in lined spring boxes and transported to the treatment facility via a PVC pipeline.

To arrive at a possible withdrawal rate from the flooded mine working, an estimate of the recharge to the system was calculated using a rough flow net analysis. A recharge value of 80.8 l/sec was calculated; however, it is based upon very little site specific data. Using this value, it was decided that a reasonably combined rate of removal would be 87.4 l/sec. There are two reasons for not wanting to cause excessive dewatering in the Boone: (1) dewatering of the workings would cause oxidation to occur again, producing additional acid mine water, and (2) lowering of the potentiometric surface would likely result in an increased incidence of subsidence.

A well field design was developed and input into a handheld programmable calculator model to simulate the resultant drawdown[4]. A viable withdrawal rate per well was determined to be 100 gpm (6.3 l/sec) for a 12 well production system, excluding back up wells. The well system would be tied into the spring collection system and the withdrawn water transported to the treatment facility.

TREATMENT

Lime neutralisation and precipitation of acid mine water has been demonstrated to be the best available technology (BAT) and the most cost effective alternative for treating acid mine water[3]. Various candidate treatment technologies were analysed in detail with the technical feasibility of the candidate technologies based on criteria such as process fundamentals, control effectiveness, non-water quality impacts, reliability, secondary waste streams, and preliminary cost and economic considerations. The following technologies were evaluated for technical feasibility: carbon adsorption, ion exchange, reverse osmosis, electrodialysis and ozonation. All five alternative technologies were found not to qualify as best available technology (BAT) options based on the above criteria.

A preliminary design and cost analysis was completed for a proposed 87.4 l/sec treatment facility. Based on the water quality data from Tar Creek and various abandoned mine shafts, a level of treatment technology was selected. The proposed treatment plant is a mechanical system incorporating state-of-the-art unit processes used in acid mine water pollution abatement. The flow diagram and unit processes for the proposed treatment plant are illustrated in Figure 3. Sludge handling and removal will involve the recycling of some of the sludge to reduce chemical costs and to increase the solids percentage of the sludge. A sludge lagoon will be sized to store the sludge produced during five years of operation of the treatment plant, while the possibility of metal recovery or a permanent disposal plan is finalised. Effluent quality is expected to be sufficient to help Tar Creek recover to its pre-acid mine drainage condition, but the effluent will not be a potable water source without additional treatment.

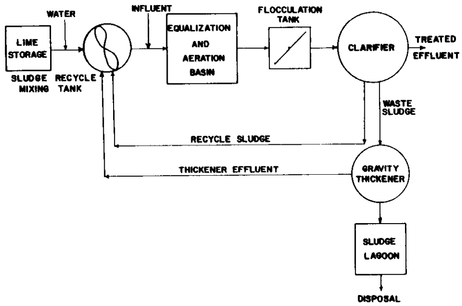

Figure 3. Proposed acid mine drainage treatment plant - unit processes.

COSTS

Preliminary construction costs and annual operation and maintenance costs have been calculated based on second quarter 1981 dollars. A detailed summary of capital and annual operating costs is presented in the Draft Final Report[5], under the heading of Alternative 2. Construction of the collection and piping system is expected to cost $1.25 million. Capital costs for the 87.4 l/sec treatment plant are expected to be $2.42 million. Total construction costs for the alternative are $3.7 million. Annual operation and maintenance costs for the 87.4 l/sec treatment system plant, $470,400/yr, for a total O & M cost of $558,400/yr. Treatment plant O & M costs are based on power, chemicals, labour and maintenance. The collection system O & M costs are based on power, labour and pump replacement.

The 87.4 l/sec treatment plant is designed to treat surface discharges as well as the acid mine water located in the mined-out Boone formation. The construction time of the facility is expected to be between eighteen and twenty-four months with a plant life of twenty-three years. The level of technology proposed in treating the acid mine water is based on the removal of toxic heavy metals, a minimum sludge volume, an acceptable effluent quality, a maximum system reliability and acceptable capital and operating costs. The treatment facility will serve as part of a viable solution to the acid mine discharge problem.

SUMMARY

The Picher Mining District is a major source of toxic metals in the surface water and groundwater systems in north-eastern Oklahoma. The magnitude of the current problem is such that the EPA has designated the area as one of the top ten hazardous waste sites in the United States under the superfund program. It is believed that past mining practices (disposal of iron sulphide bearing material underground and improper plugging of exploration holes) have resulted in the formation of acid mine water. The acid mine water discharges have contaminated the local surface drainage and may potentially contaminate the region's potable ground water supply. A means of mitigating the problem has been proposed. It includes a spring water and well water collection system, with treatment at a 87.4 l/sec lime neutralisation/ precipitation facility.

ACKNOWLEDGEMENTS

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