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SUMMARY FINAL REPORT— CLAY-BASED GROUTING DEMONSTRATION PROJECT

MINE WASTE TECHNOLOGY PROGRAM ACTIVITY III, PROJECT 2

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ABSTRACT

An innovative Kaolinitic Clay-Based Grouting Demonstration was performed under the Mine Waste Technology Program, which is funded by the U.S. Environmental Protection Agency (EPA) and jointly administered by the EPA and the U.S. Department of Energy. The objective of the technology was to demonstrate the effectiveness of kaolinitic clay-based grouting in reducing and/or eliminating infiltration of surface and shallow groundwater through fractured bedrock into underground mine workings.

In 1993, the Mike Horse Mine was selected as a demonstration site for the field implementation and evaluation of the grouting technology. The mine portal discharge ranged between 114 to 454 liters per minute (30 to 120 gallons per minute) of water containing iron, zinc, manganese, and cadmium at levels exceeding the National Drinking Water Maximum Contaminant Levels.

The grout formulation was designed by the technology developer Morrison Knudsen Corporation/ Spetstamponazhgeologia, in May 1994. Grout injection was performed by Hayward Baker, Inc., under the directive of MSE Technology Applications, Inc., during the fall of 1994. The grout was injected into directionally drilled grout holes to form a grout curtain at the project site. Postgrout observations suggest the grout was successful in reducing the infiltration of the surface and shallow groundwater from entering the underground mine workings. This report describes the demonstration and technology used to form the subsurface barrier in the fracture system.

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FIGURES

1. INTRODUCTION

A significant environmental hazard to surface waterways nationwide and worldwide is acidic, metal-laden water draining from abandoned mines. The State of Montana has identified more than 20,000 abandoned mine sites, on both public and private lands, resulting in more than 1,300 miles (2,092 kilometers) of streams experiencing pollution problems. To address and find technical solutions to the problems created by these sites, the U.S. Environmental Protection Agency (EPA) created the Mine Waste Technology Program (MWTP), which demonstrates field and pilot-scale technologies to treat, reduce, or eliminate the existing hazards.

The MWTP Activity III, Project 2, Clay-Based Grouting Demonstration Project was funded by EPA and jointly administered by EPA and the U.S. Department of Energy (DOE) through an Interagency Agreement. EPA contracted MSE through the MWTP to evaluate and develop the subsurface application of a clay-based grouting technology. The Mike Horse Mine site was selected as the demonstration site (Ref. 1).

The EPA and DOE selected the clay-based grout formulated technology developed by Morrison Knudsen Corporation/Spetstamponazhgeologia (MK/STG) as the demonstration technology. A portion of the workings of the Mike Horse Mine, where water from Mike Horse Creek was determined to flow into the underground mine workings through the subsurface fractures, was designated as the project area to be used for demonstration of the grouting technology. The technology involved formulating and injecting clay-based grout into a fractured bedrock system, thereby reducing the amount of ground and surface water infiltrating underground mine workings. Reducing water inflow into underground mine workings was expected to reduce the volume of impacted water discharging from the 300-level adit portal of the Mike Horse Mine and potentially improve water quality downstream from the mine. Because the technology was developed to eliminate the flow of water into the mine workings, it was considered as a source-control technology.

The Mike Horse Mine site is owned by American Smelting and Refining Company, Inc. (ASARCO) and is located approximately 15 miles (24 kilometers) northeast of Lincoln, Montana. Presently, slightly acidic waters containing elevated levels of heavy metals discharge from the 300-level portal of the mine directly into Mike Horse Creek. The State of Montana recognized this mine discharge as one of the major contributors of metal loading into the Upper Blackfoot River (Ref. 2).

The Clay-Based Grouting Demonstration Project consisted of five major phases: 1) Site Characterization; 2) Grout Formulation; 3) Phase I—Grout Injection; 4) Phase II—Grout Injection; and 5) Verification Monitoring and Technology Evaluation.

2. TECHNOLOGY BACKGROUND

2.1 Site Description

The site selected for the demonstration was the Mike Horse Mine, an inactive underground mine in the Heddleston Mining District in Lewis and Clark County, Montana. The Mike Horse Mine was the largest and most productive mine in the Upper Blackfoot Mining Complex. Silver, lead, and zinc-bearing ores of the Heddleston Mining District were discovered in the late 1800s, and development of the district and the Mike Horse Mine began in 1898 (Ref. 3). ASARCO continued operation of the mine until 1955, when the Mike Horse Mine operation was put out of production due to declining metal prices.

The Mike Horse Mine consisted of 10 underground working levels that were driven along the veins/ faults for distances up to 2,000 feet (610 meters) (see Figure 2-1) . The mine workings extend to approximately 1,000 feet (305 meters) below ground surface. The main haulage drift, at the 300-level, was accessed by a 1,100-foot (335-meter) crosscut tunnel. For this project, the main workings of interest were at the 300-level drift and crosscut tunnel. The elevation at the 300-level portal was the lowest surface expression of the mine. Water entered the mine upgradient of the 300-level through either subsurface fractures or surface flows into the old mine working at other levels. Review of existing mine maps confirmed that mine workings extend beneath the stream bed of Mike Horse Creek; this area corresponded to a losing segment of the creek. This relationship strongly suggested that the water lost from the losing section of the creek was infiltrating the mine workings through fractures and joints in the rock structure underlying the stream and eventually was discharging from the 300-level mine portal back into Mike Horse Creek. MSE Technology Applications, Inc. (MSE), proposed applying clay-based grout under the losing portion of Mike Horse Creek to control water infiltrating the mine workings.

2.2 Project Objectives and Scope of Work

The primary objective of this project was to demonstrate that the strategic placement of a clay-based grout could control and significantly reduce the inflow of surface water and shallow groundwater to underground mine workings (see Figure 2-2). The primary goal was to control the influx of water into the underground mine workings, thus eliminating water contact with sulfide ore zones and, as a result, decreasing the formation of acid mine drainage. The project was not to be viewed as a direct treatment of mine waste but as a method to control one source of acid mine drainage by managing groundwater flow. The project was designed to test and evaluate the effectiveness of the grouting technology.

2.3 Success Criteria

Criteria for the success of the grouting technology was established to define and measure the degree of success the technology developers were able to achieve. Field tests were performed prior to grouting to establish baseline conditions at the site. Postgrouting tests were performed, and results were compared to baseline conditions to determine the performance of the grout with regard to hydraulic sealing of the fracture system. Testing methods were modified during progression of the project, as required, to properly characterize the grout effectiveness. The primary objectives used to define the success of the project are given below (Ref. 4).

- To show grouting had a probable effect in reducing the hydraulic connection between Mike Horse Creek near the project area (drill pad), the groundwater at a monitoring well (monitor well (MW) -4), and the 300-level portal. (See Figure 2-3, site plan view map showing the monitor wells and grout hole locations with regards to the 300-level adit portal.)

- To verify MK/STG's claim that their clay-based grouting process would reduce in situ hydraulic conductivity within known areas of the grout curtain to <1 x 10^{-8} meters per second (m/sec).

- To determine MK/STG's claim that exposure of the clay-based grout to acidic materials (pH <5.5) would not increase the hydraulic conductivity of the grout by more that 15% at a confidence level of 95% (acid resistiveness).

- To determine whether the clay-based grouting process reduced the hydraulic conductivity to 10^{-8} m/sec in grout holes, angle drill hole ADH -7 and ADH-8, in which permeability values were greater than 1.27 x 10^{-6} m/sec based on pregrout packer injection tests (permeability for grout holes ADH-7 and ADH-8).

Although the main objective was to control point-source influx, the evaluation of the project's success also included the feasibility, cost-effectiveness, and flexibility of the technology to be used in other situations and other applications.

2.4 Demonstration History

The clay-based grouting technology and the Mike Horse Mine site were selected by EPA for the demonstration in the summer of 1993 under the stipulation that the Mike Horse Mine would be accessible, as per ASARCO's claims, and flow stations would be placed at the drifts in the 300-level to determine the flow produced from each drift. In the spring of 1994, ASARCO decided not to open the Mike Horse Mine. Furthermore, ASARCO's future plans for the mine included placing a bulkhead in the 300-level mine workings approximately 150 feet in from the portal entrance. In spite of these changes, EPA decided in July of 1993 to proceed with the demonstration at the Mike Horse Mine.

In September 1993, ASARCO constructed an earthen dam (hereinafter referred to as the ASARCO dam) upgradient from the project site to contain and reroute water through a pipeline from Mike Horse Creek to an area below the 300-level Mike Horse portal. This system was designed to decrease the amount of surface flow entering the underground workings. This dam was not keyed into the bedrock, allowing groundwater to move under the dam through the shallow alluvial material on which the dam was constructed.

From spring 1993 to August 1994, pregrout site characterization was performed to provide the baseline parameters necessary to evaluate grout emplacement and grout formulation. During May 1994, the grout formulation was developed in laboratories in the Ukraine by STG using the kaolinitic clay from Troy, Idaho. On September 15, 1994, Phase I of the grout injection was initiated. During Phase I of the grout injection, approximately 1,600 cubic yards (yd^3) [1,224 cubic meters (m^3) of clay grout were injected into the fracture system to reduce infiltration of water into the underground mine workings. Due to severe weather conditions at the site, Phase I of the grout injection was terminated on November 7, 1994. Once Phase I was completed, the technology developers stated that grout injection was only 40 to 50% complete and proposed a second grout injection phase be performed. Phase II of the grout injection was scheduled for July and August 1995; however, on May 7, 1995, high water due to spring runoff caused the 300-level portal, which initially was almost totally collapsed, to washout from the mine towards Mike Horse Creek. All flow devices monitoring the 300-level discharge filled with sediment and became inoperative. Since this main critical data source (the 300-level discharge) had been eliminated by the high runoff event, EPA canceled Phase II of the grout injection on June 21, 1995.

2.5 Pregrout Site Characterization

Pregrout site characterization was performed at the project site to establish baseline information and to determine the locations at which water was infiltrating into the underground mine workings. With respect to the pregrout site characterization at the Mike Horse Mine site, the following observations and conclusions were established.

- Historic flow and geological data provided surface water flow and fracture information about the Mike Horse Mine drainage system. From this information, the annual averages for the 300-level portal flows were estimated at 0.12 cubic feet per second (cfs) [(3.40 liters per second (l/s)], and the annual average stream flow was estimated to range from 0.03 to 3 cfs (0.85 to 85 l/s). A downgradient seep observed flowing every year was interpreted as a surface expression of the original stream bed of Mike Horse Creek that was changed during historic mining events.

- Stream gauging results illustrated the Mike Horse Creek began to lose water where it flowed directly over the Mike Horse Mine 300-level workings, and the quantity of water lost in this region was less than the quantity of water reentering Mike Horse Creek below the 300-level portal.

- Continuous stream flow measurements included a monitoring plan to provide a water balance for the Mike Horse Mine drainage above the 300-level portal. The data provided baseline stream flow records.
- The 300-level Mike Horse Mine portal discharge data was determined to be critical to the project. Two continuous monitors were placed at the portal. Data from the portal flow monitors supported the conclusion that Mike Horse Creek was hydraulically connected to the Mike Horse Mine in the project area. Direct responses to packer testing performed on August 18 and September 19–20, 1994, were very apparent on the daily flow records provided by MSE's continuous monitoring station. The continuous monitors also provided baseline data used in further interpretations for this project.

- Precipitation data provided useful baseline information for interpretations concerning the 300-level portal discharge and stream flows. The annual precipitation figures show that 1993 was a fairly wet year with respect to long-term averages; however, annual precipitation figures for 1994 and 1995 were below average.

- Groundwater potentiometric elevations contoured for September 9–14, 1994, indicated an anisotropic aquifer system and a significant cone of depression in the vicinity of monitoring well MW-7; MW-7 was located directly over a large stope that was located less than 25 feet (7.6 meters) below ground surface and is directly connected to the 300-level underground mine workings (see Figure 2-4). Additionally, the alluvial system below the project area was on average between l 12 and 20 feet (3.6 and 6.1 meters) deep, suggesting a thin [less than 5-feet-thick (1.5-meter-thick)] bedrock layer between the alluvium and the stope. The bedrock located between the stope and the alluvial layer provided infiltration through the enhanced fractures. The fractures had been enhanced by weathering, subsidence, and historic blasting and mining operations.

- In addition to establishing direct connection between the mine workings and the project area, the packer tests define the variability and magnitude of the hydraulic conductivity of specific intervals of the grout injection holes. These hydraulic conductivity values provide baseline data to calculate and determine the amount of grout that could be injected into the formation.

- A baseline tracer dye study was performed by injecting dye at select points in monitoring wells on September 24, 1994. The dye was detected in a monitoring well located approximately 30 feet (9.1 meters) away from the nearest injection point in just a few hours. Tracer dye was also determined to be present at the 300-level portal on May 4, 1995.

- Geophysical and geologic logging of the core holes was performed to define the geological units and fractures. A borehole video camera was used to view the borehole walls and water table of grout hole ADH-7, which was drilled to a depth of 150 feet (46 meters) (see Figure 2-3). Directional surveys determined hole deviations due to drilling in ADH-7 and ADH-8. Cross sections using this and other surface surveys illustrate that the bottom of ADH-7 is located 3 feet (0.9 meters) from the 300-level mine workings, and the water level in ADH-7 corresponds to the middle of the 300-level mine workings.

- The rock mechanic testing conducted on representative samples from the Mike Horse Mine evaluated the sample density, tensile strength, compressive strength, elastic properties, and hydrofracture pressures required to break the rock. The tensile strength of the rock samples was influenced by the various grades of fracture healing, brecciation, and alteration. Samples with low compressive strengths of <5,000 pounds per square inch (psi) [3,515,500 kilograms per square meter (kg/m^2)] usually failed along preexisting fractures. High-strength specimens >25,000 psi (17.57 million kg/m^2) tended to fail violently. It was apparent the competent rock at the Mike Horse Mine should withstand the forces exerted during grout injection. If maximum grout injection pressures remain below 300 psi (210,900 kg/m^2), hydrofracturing should not occur in competent rock. However, if unhealed fractures existed, then grout could initiate reopening of the fractures. At maximum pressures of 600 to 660 psi (421,800 to 464,000 kgs/m^2), even fractures where metasomatic replacement had occurred could be reopened.

2.6 Grout Injection Procedures

The Phase I field implementation of the grout injection began on September 22, 1994, and was completed on November 7, 1994. A discussion of grout specifications, composition, and procedures is provided in the following sections.

2.7 Grout Hole Specifications

The MK/STG Joint Venture was the technology developer for the Phase I field implementation of the clay-based grouting technology. The concept behind MK/STG's field implementation plan was to inject grout into the 35• (from horizontal) angle grout holes first. Grout injected into these holes would form a cap over the deeper angled, 45• grout holes that would be grouted second. Thus, the cap would force the grout to move deeper rather than shallower in the fracture system. Steeper angled grout injection holes were to be grouted after completing the 35• and 45• grout holes (see Figure 2-2).

2.8 Grout Composition

The grout formulation for the clay-based grout was developed in the Ukraine by STG during May 1994. The overall properties of the clay-based grout depend on the physical and mechanical properties of the clay. The clay used for this demonstration was a kaolinitic clay from near Troy, Idaho. The kaolinitic clay along with water, structure-forming cement, and proprietary chemical additives are formulated into a viscoplastic grout. The grout's properties are such that it retains rheological properties, meaning it retains plasticity and does not crystallize, unlike cement-based grouts. Also, since the water pH at the site ranged from 5 to 7, the grout composition was adjusted to structurally form and remain stable under lower pH conditions.

The composition of the grout used in the project by weight consisted of 30 to 35% kaolinitic clay, 6 to 7% sulfate-resistant cement (Class V), 1 to 1.5% proprietary additive(s), and 56.5 to 63% water; occasionally sawdust was added as a filler material during periods when minimum pressures and large amounts of grout were being injected into extensive voids. The density of the grout was 84.2 to 87.4 pounds per cubic foot (lb/ft^3) [1,350 to 1,400 kilograms per cubic meter (kg/m^3)], with a dynamic shear strength of 0.64 to 0.68 millimeters (mm) if mercury (Hg) (85 to 90 pascals), a structural viscosity of 37 to 40 centipoise (37 to 40 x 10^{-3} pascals per second), and a compressive strength of 1 to 1.5 bars (0.1 to 0.15 megapascals). The kaolinitic clay was transported by truck to a facility having the ability to crush the clay to minus 8-mesh, as specified by the developers.

2.9 Grout Injection System

Field implementation was performed by Hayward Baker, Inc. (HBI), a ground modification company. HBI injected the grout into the subsurface at the Mike Horse Mine Project site per the direction of MSE and the developer (See Figure 2-5).

The high-clay grout was mixed in two stages. The first stage consisted of making a clay-water slurry. A total of 4 to 5 tons of clay were added to approximately 7 yd^3 (5.4 m^3) of water over 50 to 60 minutes, increasing the density of the slurry from 62.4 to 84.3 lb/ft^3 (1,000 to 1,350 kg/m3); the clay-water slurry was then tested for density. The clay-water slurry mixing was performed using a colloidal mixer. After the batch of slurry was mixed thoroughly, it was transferred to a large storage tank.

The second stage of grout mixing consisted of adding a binder material (cement) into a second (0.56 yd^3 or 43 m^3) shear mixer where it was combined with the clay slurry. Volumes of binder were metered into the second mixer where it was combined with the clay slurry. Then the clay-slurry mix with the added binder was piped to a hopper containing a screw feeder where the proprietary additive(s) and the fillers were mixed into the grout in proper proportions. The entire system enabled the continuous injection of grout into the grout holes at the specified pressure until refusal was reached. Testing ports provided samples for grout density and viscosity. Additionally, instrumentation at the ports provided injection pressure and flow rate.

Initially, grout was pumped from the hopper and down the grout injection holes using a Moyno screw pump; however, gravels, approximately one-quarter of an inch in diameter, clogged and ruined the screw pump. The replacement pump specified was a positive displacement pump that had the ability to pump the gravels and other filler material downhole without binding the pump. The grout was pumped down a 1½-inch [3.8-centimeter (cm)] flexline with a flowmeter/pressure transducer placed at the top of the casing and tremie pipe. The tremie pipe was 1½-inch (3.8-cm), rigid threaded pipe that was connected in 10-inch (25.4-cm) sections.

The grouting was performed in stages with grouted sections being from 20 to 40 feet (6.1 to 12.2 m) long. The injection rate was anticipated to be 15 gallons per minute (gpm) (0.94 l/s), but actually varied between 1 and 20 gpm (0.06 to 1.26 l/s). The upstage method of grouting (from the bottom of the hole upward using an inflatable packer) was used for grout injection.

The anticipated allowable pressure for grouting was 1 to 1.5 psi per vertical foot (703 to 1,054 kg/m^2) of drilled borehole. The Aardvark

Packer used for Phase I of the grout injection was designed to function without slipping up to pressures of 550 to 600 psi (386,650 to 421,800 kg/m^2), usually if the grout hole had not been grouted before. However, the nitrogen (piped through ¼-inch (0.64-cm) tygon tubing) used to inflate the packer would start to compress above pressures of 550 to 600 psi (386,650 to 421,800 kg/m^2), resulting in the packer slipping in the grout hole. The injection pressure was measured at the end of the pump and at the well header. Grouting was continued until refusal was reached or the packer slipped. If refusal was reached and the pressure held for longer than 15 minutes, the packer was kept at the staged interval until the back pressure at the header approached 0 psi.

Approximately 1,600 yd^3 (1224 m^3) of clay-based grout was injected during the period from September 23 to November 7, 1994. It was determine by the developers at the end of the injection period that only 40% of the grout required for the project had been injected.

2.10 Grout Injection Results

During field injection of the grout, the main hydrologic parameters monitored included continuous monitoring of the discharge at the 300-level portal and continuous monitoring of the water level in the monitoring wells at the project site. Results from the 300-level portal did not show a significant reduction in flow during grout injection; however, this may have been due to the large volume of water blocked within the mine workings. During grout injection, however, the monitoring wells did show significant water level changes.

Results of the 1,600 yd^3 (1,223 m^3) of clay-based grout injected were observed in the monitoring wells being continuously monitored. The water level in MW-1 rose approximately 2.5 feet (.76 m) due to grout injected in ADH-14, which closed off a hydraulic connection that had allowed water to infiltrate into the underground mine workings (see Figure 2-2). The elimination of hydraulic connections was also apparent in water level measurements in MW-2. The water level in MW-2 decreased almost 2 feet in response to recharge zones for MW-2 being closed by grout injected in ADH-14.

The initial water level in MW-3 was 111 feet (33.8 m) below ground surface. However, after grouting at ADH-14, the water level in MW-3 rose and is presently between 17 to 14 feet (5.2 to 4.3 m) below ground surface. It was concluded that the previous water levels in MW-3 reflected water infiltrating into the mine. This conclusion was made because DDH-3, an open core hole located approximately 10 feet (3.1 m) east of MW-3, had a static water level of 38 feet (11.6 m) below ground surface. The steep gradient is representative of a dewatering situation. While grouting ADH-14, the fractures hydraulically connecting the mine workings and MW-3 were grouted shut, and the water level in MW-3 rose to at least 17 feet (5.2 m) below ground surface.

The field implementation plan for the demonstration was modified during grout injection. The modification consisted of drilling near-surface grout holes at steeper angles because cross communication occurred between grout injection holes, and grout surfaced frequently when grout was injected into the shallower 35• grout injection holes. As a result of the modification, the steeper grout holes were drilled closer to the 300-level mine workings. ADH-7 was drilled to a point approximately 3 feet (0.9 m) away from the mine workings. When grout was injected at the 122-foot (37.2-m) packer interval, back pressure did not exist (negative pressures). Sawdust filler was added to the grout formulation to fill the void and try to raise the injection pressure. After 168 yd^3 (128 m^3) of grout were injected into ADH-7, sufficient back pressures were not achieved;

therefore, dead plugs were placed at depths of 135 and 128 feet (41 and 39 m). The main quantities of grout (approximately 50%) were placed in two grout injection holes.

A second modification to the field implementation plan was to increase the initial maximum pressures suggested by the developer to a maximum pressure of 600 to 650 psi (421,800 to 456,950 kg/m^2). With this modification, the developer was able to hydrofracture healed fractures in the rock, allowing larger quantities of grout to be injected. Hydrofracturing was performed by decreasing the density of the grout formulation by adding water at a point when high pressures and the grout injection rate had decreased. This allowed grout to penetrate smaller fractures and extend the boundaries of the grout curtain. Unfortunately, the higher pressures caused compression of the nitrogen-inflated packer, allowing the packer to slip up the grout holes. In some instances, the packer was destroyed when it was shredded by sharp fragments or reached a void that allowed the packer to expand until it burst.

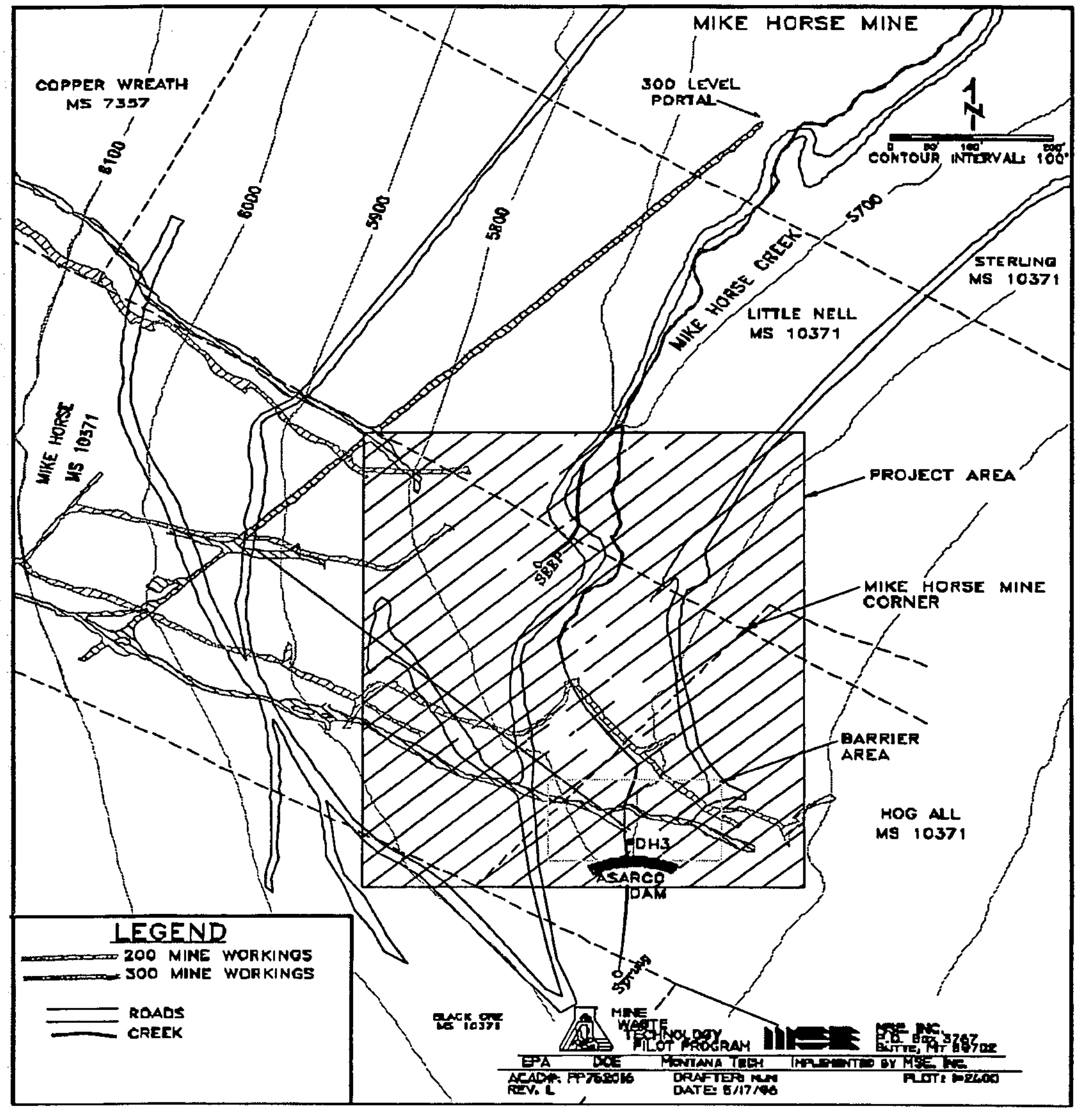

Figure 2-1. Clay-Based Grouting Demonstration site map.

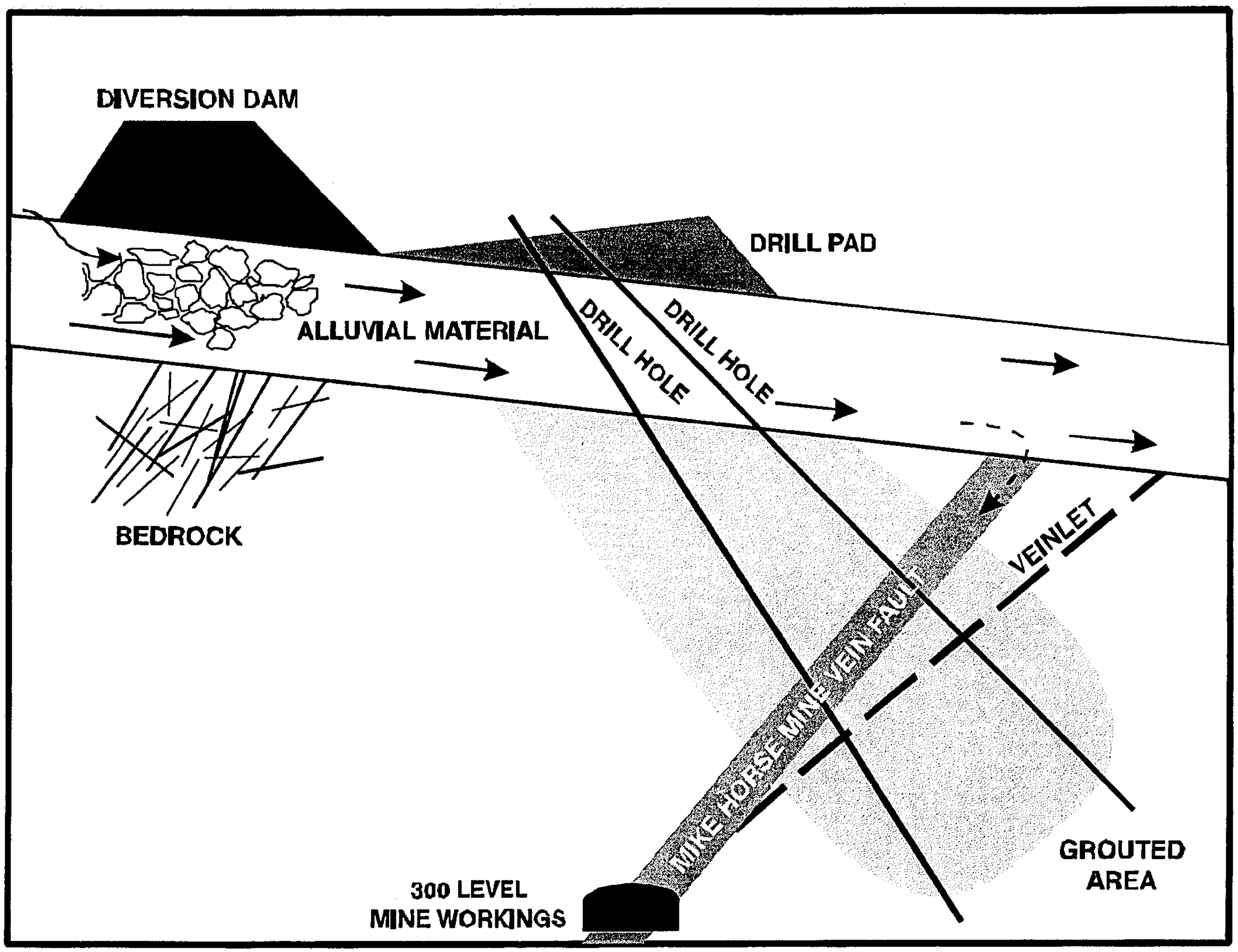

Figure 2-2. Conceptual cross-sectional view of the subsurface grout barrier design.

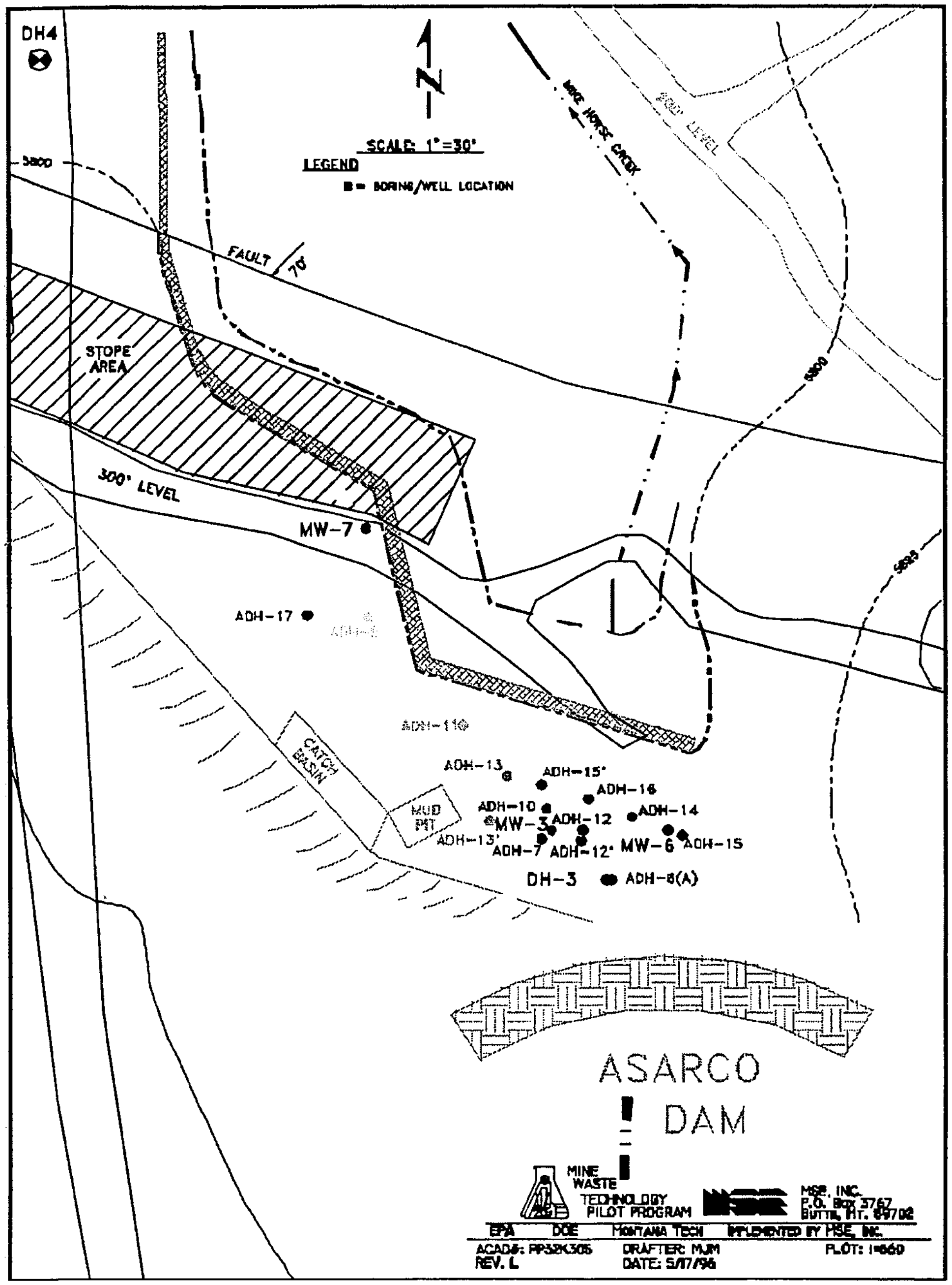

Figure 2-3. Grout project map (plan view).

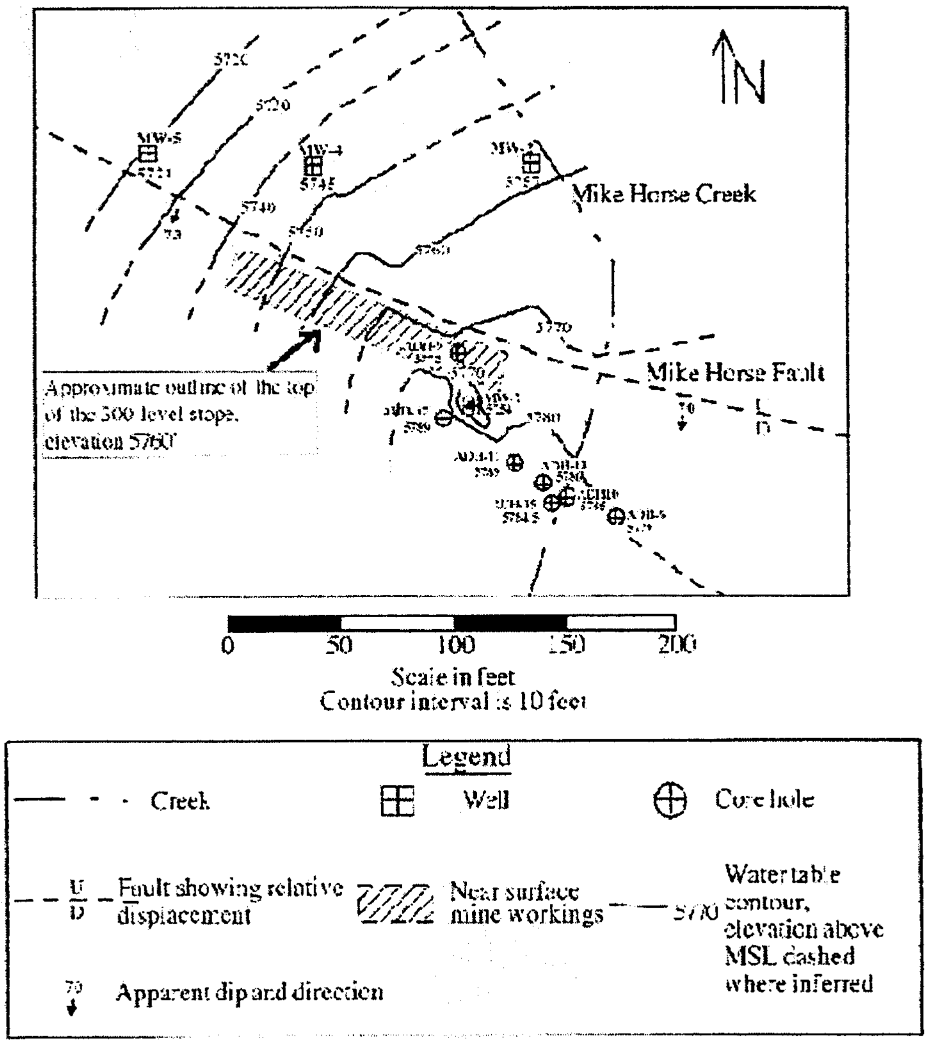

Figure 2-4. Water table elevation at the Mike Horse Mine grouting site (water levels taken during 9/1/94-9/14/94).

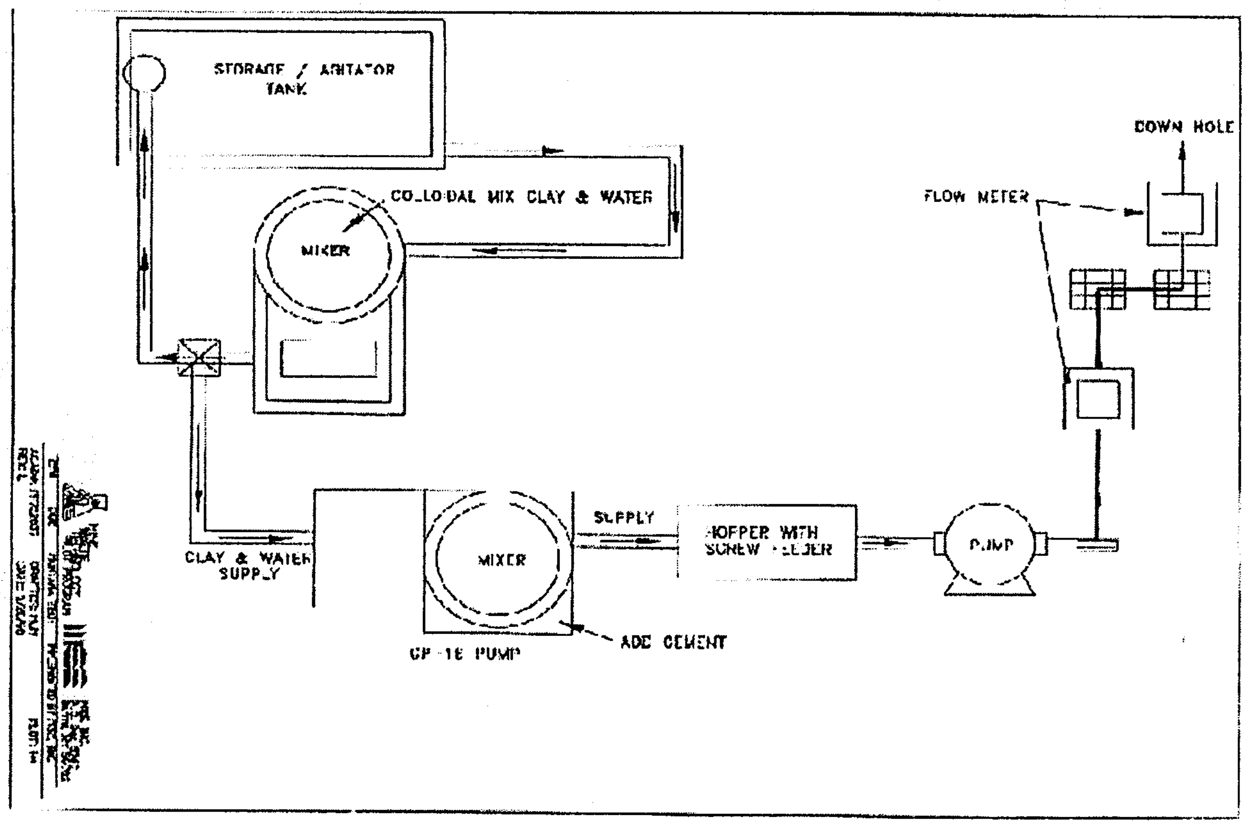

Figure 2-5 Grout injection system.

3. CONCLUSIONS AND RECOMMENDATIONS

Within the *MWTP, Activity III, Project 2, Clay-Based Grouting Demonstration Project, Final Report* (Ref. 1), the ability of the clay-based grout, developed by MK/STG, to reduce and/or eliminate flow into subsurface fracture systems was evaluated against the specified criteria. This specified criteria included grout integrity, ability to inhibit water inflow, grouting method, and potential for future implementation.

In summary, the recommendations and conclusions addressing kaolinitic clay-based grout for reducing the permeability of a fractured bedrock system include:

- Kaolinitic clay can provide a substantial reduction in the permeability of a fracture system. From the hydrograph created between April 1993 and May 1995, portal discharge was shown to have been reduced by up to 29% in March 1995 and up to 42% in May 1995. However, high flow conditions reflect larger reductions in flow compared to small reductions during the low flow conditions. Note, the amount of flow reduced is proportional to the flow conditions of the mine.

- The reduction was also apparent from flow measurements recorded during the first week of April 1996, as measured by ASARCO. This data consistently read 23 gpm (1.45 l/s). This value was approximately 10 gpm (0.63 l/s) lower than base flow conditions on pregrout years.

- Kaolinitic clay-based grout can provide reduced permeability in fracture systems, and it also maintains its rheological properties in saturated/partially saturated conditions. It also maintains its continuity under acidic conditions; this is an advantage when comparing the clay-based grout to other viable grouts.

- However, primary disadvantages of this grout are that it does not provide structural strength for use in civil projects and it should not be used in arid or unsaturated areas because desiccation and cracking of the grout occurs, allowing water to infiltrate through the grouted area. If the grout is specified for implementation in such conditions, special considerations should be taken. Also, if the soil moisture is significant enough in an unsaturated area, then this grout may be feasible for emplacement of a subsurface barrier.

4. REFERENCES

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4. SAIC/SITE Program *Quality Assurance Project Plan (QAPP) for the Clay-Based Grouting Demonstration Project, Revision 1*, September 28, 1995.