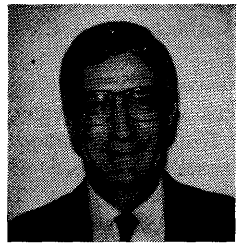
Use of the STG Integrated Grouting Technology for the Prevention of Acid Mine Drainage in the United States



Presented to:

INTERNATIONAL SYMPOSIUM ON MINE DRAINAGE AND ENVIRONMENT PROTECTION FROM WASTE WATER DISPOSAL

KONKOLA COPPER MINE - CHILILABOMBWE, ZAMBIA

SEPTEMBER 1993

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**** ABSTRACT ****

This paper describes the problems involved and the approach taken in analyzing the prevention of acid mine drainage with the use of the STG Integrated Grouting Technology on the National Tunnel, Clear Creek Superfund Site near Denver, Colorado in the U.S.A.

The National Tunnel is approximately 3100 feet long and was constructed at the beginning of the 20th Century to drain the Clay County Mine located in the Central City Mining District of Colorado. The tunnel also connects with and drains the Senator Mine and Horseshoe Mine. These mines all contain sulfide ore (galena, sphalerite, chalcopyrite, and pyrite). The National Tunnel discharges about 45 gallons per minute of contaminated water into North Clear Creek and is the major source of metals loading to the drainage. The metals involved in the contamination include copper, lead and zinc.

The paper describes the conceptual technical solutions for the elimination of acid mine water discharge by the reduction of clean ground-water recharge from the surrounding basin. It also outlines the steps necessary to investigate, analyze, plan and conduct the implementation of the conceptual solution.

The paper also discusses successful applications of the STG Integrated Grouting Technology to facilitate tunneling and drifting at depths in very complicated hydrogeological conditions through fractured rock and fault zones with large water inflows under high static pressure.

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1.0 INTRODUCTION

Since 1985 the United States Environmental Protection Agency (EPA) has been involved in an effort to reduce the discharge of contaminated water from abandoned mines in the western part of the United States. Much of the problem involves the release of acidified water from old mine workings where little is known about the original mining activities. Many historic mining districts have been targeted by the EPA for the reduction of this acid mine drainage and various technologies are being considered to assist in the remediation efforts.

The EPA has identified the method of grouting as one technology which could solve some acid mine drainage problems. If the inflow of uncontaminated water could be stopped before entering old mine workings, the resultant acidification from contact and subsequent oxidation with metal sulfides could be avoided. This control of water before contamination occurs is referred to as source control technology and is the obvious choice in the reduction of any acid mine drainage problem.

1.1 Identification of STG

The EPA's search for technology to accomplish source control lead them to a former Soviet government agency called SPETSTAMPONAZHGEOLOGIA (STG) which had developed a kaolin-based grouting technology for ground-water flow control in deep underground mines. The STG grouting technology had been proven effective in dramatically reducing permeability in fractured rock media. STG has successfully completed over 200 large-scale grouting projects using its technology in the former U.S.S.R. and other Eastern European countries over the past 20 years. Most of these projects were performed to control ground-water inflow into underground mine openings and shafts but STG has also applied this grouting technology to other problem areas such as underground railroad construction, large open pit mines, tunnels, waste isolation and water pollution control projects.

The key elements in the STG grouting technology revolve around grout composition; geologic, geochemical and hydrogeologic characterization and analyses of the host rock; and an integrated design procedure. The grout composition normally contains about 89 percent clay, 10 percent cement and 1 percent special additives which include sodium silicate, calcium chloride and minor amounts of other chemicals which perform various functions. This is a reversal of the typical grout mixture found in the U.S. which is often 94 percent cement, 5 percent clay, and 1 percent other ingredients. The STG grout formulation and its application are customized for each project and the entire process is integrated, based on the nature of the problem, the objective of the application and detailed, site specific information on geology, geochemistry and hydrogeology of the host rock.

The potential economic advantages to the STG technology are obvious, due to the small amount of cement required. The clay portion of the grout can be obtained from nearly any source which is available in the vicinity of the construction site. The grout material is also inert and nontoxic which allows its use in many various applications and makes its use by the EPA particularly attractive in the control of hazardous waste problems.

In June 1992, Region VIII of the EPA commissioned STG to perform an evaluation of their integrated grouting technique for use on an acid mine drainage site in the State of Colorado. The site is referred to as the National Tunnel, Clear Creek Superfund Site and is located just west of Denver. The EPA hopes to identify the STG technology as a viable solution to this problem and subsequently perform a demonstration project to verify the technology in this application.

1.2 Morrison Knudsen Affiliation with STG

Morrison Knudsen Corporation (MK) was first introduced to STG in June 1990 by Professor Roy Williams of the University of Idaho who had been researching the development of the technology for some years. A presentation was made by Dr. Ernest Kipko to the Environmental Services Division of MK where many of the potential applications for the STG technology would be of interest. The dialogue which was started during this meeting continued and lead to discussions of a possible joint venture by 1992.

To expand their technology into the Western Hemisphere, STG needed to work with a company in the U.S. which was familiar with government contracts, had experience in the construction, mining and environmental fields, had a background of working in foreign countries and with foreign partners and was interested in the development of new technology. MK met all of these criteria and was ideally suited as a partner for STG.

MK collaborated with STG in the National Tunnel feasibility during June and July 1992. In August 1992 MK and STG signed a joint venture agreement in which MK was to facilitate the entrance of the STG technology into the U.S. markets and STG was to assist MK in the pursuit of environmental services projects in the Republics of the former Soviet Union. This joint venture established the guidelines for the transfer of the STG technology to the U.S. and outlined the responsibilities that each party was to fulfil in their long term association.

1.3 Site Description

The National Tunnel is located in the Central City Mining District, Gilpin County, Colorado. Central City itself is 30 miles west of Denver and is accessible year around by traveling west on Interstate 70. Elevations in the district range from 9750 feet in the western part to about 8000 feet in the eastern part.

The National Tunnel is approximately 3100 feet long and was constructed to drain the Clay County Mine, which is located in Lake Gulch (Figure 2). The portal is approximately 3,000 feet southeast of the Town of Black Hawk in Gilpin County, Colorado, on the south side of North Clear Creek. The tunnel also connects to the abandoned Senator Mine, about 850 feet from the portal.

1.4 Feasibility Study Objectives

The objectives of the feasibility study were to:

- Evaluate the potential for eliminating the ground-water flow into and from the National Tunnel using the STG grouting technology.
- Identify data which must be collected to complete this evaluation
- Recommend a program to collect this data and the data collection costs
- Propose preliminary grouting scenarios for the National Tunnel based upon the information available
- Briefly discuss the implementation of a demonstration grouting program

To meet these objectives, MK/STG reviewed reports and mine maps for the Clear Creek

Mining District and reports supplied by the current owner of the Clay County Mine and the National Tunnel, discussed the site with individuals in Central City and Black Hawk who are familiar with the tunnel or the mines connecting to it, and conducted site visits to the Clay County Mine and the National Tunnel portal. MK/STG also collected samples from two clay mines which may be suitable sources of material for the clay-cement grout.

1.5 Demonstration Project Objectives

The objective of the anticipated demonstration project is to evaluate the use of the STG integrated grouting technique for environmental applications. This specific study will evaluate its effectiveness in reducing water inflow to the National Tunnel, thus reducing the volume of acid mine drainage generated and, in turn, discharged to North Clear Creek.

To evaluate the effectiveness of the STG technique, a criteria to measure its success must be established. Prior to initiation of the grouting program, the volume of acid mine drainage discharging from the National Tunnel to North Clear Creek must be determined with relative certainty. This information will then be used to develop the evaluation criteria for demonstrating the success of the STG grouting operation.

2.0 AVAILABLE DATA

The most active period of mining in the Central City/Black Hawk area was around the turn of the 20th Century and then again in the 1930s-1950s. Consequently, much of the available data about the National Tunnel is quite old.

2.1 Geology of the Clay County Mine and National Tunnel

The rock at the Clay County Mine and other mines in the area is schist of the Idaho Springs Formation. Foliation in the schist generally strikes northerly, dipping 10° to 30° to the east. The schist has been cut by at least one monzonite porphyry dike. Near the bottom of the decline at the Clay County Mine the dike is approximately 30 feet wide. The Clay County veins occur mainly in biotite gneiss with a high concentration of pegmatite. Most deposits of importance in the Central City District have been found in veins closely associated with dikes or small bodies of Tertiary porphyry. At the Clay County Mine, such a dike has been found running sub-parallel to the vein group.

Three veins or vein zones were developed in the Clay County Mine; ore was produced mainly from two of the veins. The three veins define a zone approximately 90 feet wide, containing low-grade disseminated mineralization. The veins strike N 21°E, and dip 85°

to the northwest. The known strike length of the vein system is over 2000 feet. Other mines which may be linked with the National Tunnel mined smaller veins running sub-parallel to the Clay County veins.

Three major fault zones appear to intersect the National Tunnel, as shown on Figure 1. These zones could be sources of water to the National Tunnel but no detailed geology of the area is available. During the study MK/STG geologists noted two fracture zones within the first 340 feet of the tunnel. One fracture zone was dry, but the other was oxidized indicating that water entered the tunnel at times along this zone. The tunnel was caved at this point, which prevented further exploration. None of the three major fault zones were observed.

2.2 Surface Water Hydrology

The National Tunnel extends from the sixth level of the Clay County Mine to its portal at North Clear Creek, along a bearing of approximately N 25° E. Both the portal and the Senator Shaft are on slopes which drain directly into North Clear Creek. The National Tunnel discharges between 0.04 and 0.1 cubic feet per second (18 to 45 gallons/minute) to North Clear Creek and is the major source of metals loading to the creek. The discharge does not exhibit significant seasonal variations.

2.3 Ground-Water Hydrology

Limited data are available to assess the ground-water hydrology in the vicinity of the National Tunnel. Further investigations need to be undertaken to evaluate the importance of the saturated alluvium at Lake Gulch (near the Clay County Mine) and the significance of the reported connection between the Running Lode and Senator Mines to the National Tunnel discharge.

Since the National Tunnel discharge is apparently not supplied by surface water, its most likely source is near-surface ground-water flows into shafts, adits, and shallow stopes and fracture flow into mine workings. The location of the caved Clay County Pump Shaft only 20 feet above Lake Gulch suggests that this shaft can draw upon saturated alluvium of Lake Gulch, and so probably contributes some water to the National Tunnel discharge.

Two monitoring wells were drilled below the tunnel's level upstream of the National Tunnel portal during the Clear Creek Phase II Remedial Investigation (RI) conducted in 1990. One monitoring well, MW-B03, was installed to monitor the bedrock aquifer. It was placed adjacent to the existing alluvial/waste rock well, NT-03, installed in 1985 as part of the initial RI conducted in 1985. The purpose of bedrock well MW-B03 was to evaluate the water quality of the bedrock system subjacent to well NT-03 and the interaction of the bedrock and alluvial ground-water system, as samples of the alluvial ground-water had shown high concentrations of zinc and aluminum (see Table 1).

Water level information collected from wells MW-B03 and NT-03 are presented in Table 2. For both wells, confined conditions are evident. Water elevation differences between the two wells also indicate an upward vertical hydraulic gradient of 0.05 ft/ft. There are no other ground-water level data available for the area adjacent to the tunnel.

Analysis of the available information allows us to make the following observations:

- Mine inflows and the National Tunnel drainage are being dictated by both bedrock and alluvial water-bearing zones. The flow paths contributing water into underground excavations and the interrelationship of bedrock and alluvial waters has not been determined.

- Northeasterly and northwesterly faulting (Dory Hill Fault, Black Hawk Fault, etc.) generated the block structure of the regional geology. Ground-water flows, in similar environments, are deflected by fault zones, and thus the drainage conditions and ground-water levels of these blocks may differ dramatically.

2.4 Water Quality

Both bedrock and alluvial waters can be classified as a calcium-magnesium/sulfate type; however, their characteristics are notably different. As shown on Table 3, bedrock well MW-B03 has significantly higher concentrations of several parameters than alluvial well NT-03; examples include total dissolved solids (1,100 vs. 360 mg/L), iron (54,000 vs. 113 μg/L), manganese (26,900 vs. 6,230 μg/L) and zinc (7,400 vs. 3,170 μg/L). Field pH of the bedrock well is also higher at 5.9 versus 3.7 units. Due to the presence of an upward vertical hydraulic gradient, these bedrock geochemical conditions may be fairly representative of bedrock ground-water conditions that have been influenced by mining-related activities in this area.

2.5 Mining Activities

As has been indicated above, the National Tunnel is known to connect to two mines, the Senator and the Clay County. Connection to a third mine, the Horseshoe, has also been referenced. A list of known and expected openings connected to the National Tunnel follows:

OPENINGS:	ELEVATION (FEET):
National Tunnel Portal	8,050 (approx)
Senator Shaft	8,350 (approx)
Horseshoe Shaft	(Unknown)
Clay County Pump Shaft	8,500 (approx)
Gold Ridge Tunnel	8,560 (approx)
Clay County Main Shaft	8,564
Gold Ridge Shaft	8,600
Raise Shaft	8,650 (approx)
Orion Shaft	8,670 (approx)
Unknown Shafts (discovered during exploration of tunnel)	(Unknown)

The National Tunnel itself was not thought to be driven on a vein, however, during the exploration of the tunnel conducted during this investigation, the MK/STG geologists were able to enter the tunnel to a distance of approximately 340 feet. The tunnel turned to the right after about 217 feet; from here it appeared that the tunnel did follow a vein. The tunnel opening decreased from about eight feet in diameter to about five feet in diameter after the turn. Historical data indicate that the National Tunnel is approximately 3,130 feet long driven on a trend of S25°W.

2.6 Conclusions Regarding Available Data

Based on analysis of the available geological and mining data, and site inspections undertaken by MK/STG specialists, the following items are known about the National Tunnel and vicinity:

- General geological and structural features of the site, position of ore veins and major faults, mineralization, locations of surface streams
- Alluvial and bedrock water-bearing zones appear to be principal sources of mine inflows and the tunnel drainage
- The area of the National Tunnel site has a block structure generated by faulting. The faults deflect ground-water flows and cause the ground-water levels in adjacent blocks to differ
- Data related to bedrock ground-water within the vicinity of the tunnel are extremely limited

- The exact projection of the National Tunnel may be assessed only to a distance of 1950 feet from the portal

3.0 ADDITIONAL DATA REQUIRED

A great deal of additional information and data will be required to enable a demonstration project to be designed for the National Tunnel Superfund Site. The scarcity of current information and verifiable data dictate that a data collection program be conducted which will provide answers to the many questions that still exist relative to the source, cause and extent of the contamination. The following sections outline a program to obtain data which will assist in any remediation effort which may be attempted.

3.1 Geological and Hydrological Data

For formulation of grout and design of a grouting program, the following geological and hydrogeological data will be required:

- Description of the National Tunnel and adjacent mine workings and shafts
- Geological and hydrogeological characteristics of the site
- Rock characterization and description
- Amount of water entering existing mines
- Flow paths discharging water to the various underground openings and the National Tunnel itself
- Flow rate and chemistry of the discharge from the National Tunnel Portal
- Hydraulic properties and hydrodynamic characteristics of bedrock traversed by the tunnel
- Fracture networks and permeable zones intersected by the tunnel and mine shafts
- For each particular fracture zone the number of fracture systems, average aperture, and maximum opening of fractures
- Hydraulic properties and hydrodynamic characteristics of each water-bearing zone

- Ground-water chemistry and corrosiveness

The optimal grout formulation for the program will take into account the hydrogeological environment, degree and content of ground-water mineralization, and the type and quality of grout constituents that will be applied. Grout formulation and testing of the grout characteristics will be conducted at the specialized laboratory of STG in Ukraine in compliance with the recommendations of the design engineers. The primary data required for the formulation of a suitable grout mixture is the composition, physical-mechanical and rheological properties of a locally available clay material.

3.2 Preliminary Investigation of the National Tunnel Site

A Preliminary Investigation will be conducted to collect the additional data which is necessary to complete the evaluation of the National Tunnel site for potential grouting using the STG technology. At present, it appears that a significant portion of water is entering the tunnel through fracture flow into mine workings connected to the tunnel. This scenario supports the applicability of the STG integrated grouting technology, however it is necessary to collect additional data to confirm this hypothesis and evaluate the hydrogeology at the identified openings to the tunnel. A geophysical investigation will be conducted during the Preliminary Investigation to identify other mine workings which connect to the tunnel. The Preliminary Investigation will be conducted in two stages:

- The Stage 1 investigations are focused on obtaining hydrogeologic data at the known openings to the National Tunnel, the Clay County Mine and the Senator Shaft. The measurements of the portal discharge can also be used to establish the performance criteria for the grouting program. Although several measurements of the discharge at the portal have been collected, a more comprehensive program is necessary in order to evaluate the effectiveness of the grouting program once implemented.

- The Stage 2 investigations will locate mine workings connected to the National Tunnel using a combination of geophysical techniques, including surface radar, borehole radar and/or cross-hole seismic.

The data from Stage 1 of the Preliminary Investigation will be used to evaluate the hydrogeology of the Lake Gulch, Running Lode and Senator Shaft areas and estimate the volume of water each may be contributing to the tunnel discharge. The data from Stage 2 will be used to construct a plan of the National Tunnel and associated workings and identify any previously unknown mine workings. Additional investigation may be necessary to characterize the hydrogeology near these newly-identified mine workings and estimate their contribution to the tunnel discharge. Additionally, the geophysical data will be interpreted to provide information regarding fracture locations, apertures, permeability, and water contribution.

3.4 Grouting Program Design Investigation

The first phase of this program is to collect more specific data regarding the geological and hydrogeological parameters. Six boreholes will installed, labeled SNT-1 through SNT-6 as shown on Figure 2. Several of these boreholes may also be used as grout injection holes during implementation of the demonstration grouting. Drilling requirements and specifications for these boreholes are listed in Table 4.

Hydraulic testing of the boreholes will be conducted during drilling and after completion of the boreholes to assess the hydraulic properties of the bedrock, ground-water chemistry, location and permeability of fractures, and the interrelationship of alluvial and bedrock aquifers. Once the testing is completed, the boreholes will be completed as piezometers for monitoring of water levels. The water level data will be used to design the grout curtain thickness.

A program of downhole geophysical logging will be performed at the completion of drilling. This program may include one or more of the following logs: deviation and caliper, electric, temperature and fluid resistivity, natural gamma, gamma-neutron, acoustic televiewer (ATV), and full waveform sonic (FWS). The suite of logs selected will depend on the amount of fracture data obtained by the geophysical investigation conducted as part of the Preliminary Investigation.

Seasonal measurements of the National Tunnel discharge and pH as well as ground-water sampling of the piezometers will be conducted to establish the ground-water recharge regime and study ground-water chemistry.

The Integrated Grouting Method developed by STG uses local clay and loam for grout formulation whenever possible. The most favorable base materials for the STG grout formulation are (in order of decreasing acceptance): kaolinite clay, kaolinite-illite clay, and polymineral clay containing not more than 20% of montmorillonite. Sand content in the clay material must not exceed 8 to 10%. The properties of clay and clay slurries which will be studied in the laboratories of STG are grain size distribution, mineralogy and geochemistry, crystallography, base cations and chemistry of water extracts, plastic strength, static shear strength, moisture content, specific gravity and density, and plasticity index value. The main target of clay testing will be to assess its potential to form stable water suspensions and to accommodate additives that improve the properties of the suspensions. Samples of locally available clays will be studied to determine a source of material for the demonstration grouting program.

4.0 RECOMMENDATIONS FOR GROUTING THE NATIONAL TUNNEL

Based on an analysis of the available information about geological and hydrogeological conditions of the National Tunnel site, an assessment of data on the interconnection of the tunnel with old abandoned workings and mine shafts, and the extensive experience STG has in isolating and eliminating old flooded or dry subsurface excavations and mine openings, STG offers the following preliminary concept for controlling acid mine drainage from the National Tunnel:

Phase I - Grouting of fault zone A, shown on Figure 1, and adjoining fractures in proximity to Unknown Shaft 1, through boreholes 160 to 200 feet deep, (Figure 3).

Phase II - Grouting of fault zone and adjoining fractures in proximity to Unknown Shaft 2, at a distance of 370 feet from the tunnel's portal, through boreholes 100 to 120 feet deep, (Figure 3).

Phase III - Grouting of permeable bedrock around the caved Pump Shaft at Clay County Mine, filling the shaft voids and a small portion of the adjacent mine workings at the 135-foot and 195.5-foot levels with grout, through boreholes 150 to 160 feet deep, (Figure 3).

Phase IV - Grouting of the Senator Shaft lateral and encountered rock around the lateral, through boreholes up to 350 feet deep, (Figure 3).

Phase V - Emplacement of grouting barriers within the portal section, if required, (Figure 4).

Accurate monitoring of the tunnel's acid water discharge and its chemistry are planned to be executed on the completion of each grouting phase. The specifics of the grout injection treatment will be revised based on data from the Grouting Program Design Investigation.

4.2 Monitoring Program

Developing a method for verification of the effectiveness of a grouting program is a crucial issue in evaluating grouting as a tool for controlling acid mine drainage. Two methods will be used to evaluate the success of the National Tunnel fracture grouting program.

- Observation wells will be installed at the lowest elevation in the area of the National Tunnel to monitor the recovery of ground-water levels to that which probably existed before the mining operations in the area. As the mining in this area began over 100 years ago, this static ground-water level is unknown. Rising of the water levels in the observation wells above that measured prior to the grouting will indicate that less water is draining into the National Tunnel.

- Measurement of the volume and pH of any residual discharge from the National Tunnel. Reduction in discharge volume and acidic characteristics of the discharge are relative indications of the success of the grouting program.

In addition to the above two methods, identification of any new springs at the surface in the general area of the tunnel portal would point to diminished drainage from the tunnel and thus the success of the grouting program.

5.0 CONCLUSIONS

A program of further investigations has been planned with the objective of collecting the additional data required for the design of a demonstration grouting program. The further investigations are divided into the Preliminary Investigation, which is designed to assess the hydrogeologic conditions at known openings to the National Tunnel, identifying other mine workings which connect to the tunnel, and assessing the nature of the fracturing in the bedrock; and the Grouting Program Design Investigation which will provide the detailed hydrogeological and fracture data necessary to implement the grouting program, as well as collect data regarding the rheological properties of the local clay for grout mixture formulation. Both investigation programs are proposed to be executed in several stages. This will provide for consecutive data assessment and the possibility to re-site the investigation boreholes if required. Some of the investigation boreholes may be later used as grout injection holes within the demonstration grouting program.

6.0 APPLICATION OF THE STG TECHNOLOGY AT THE KONKOLA MINE

The STG integrated grouting technology has been considered for use at the Zambia Consolidated Copper Mines (ZCCM) Limited, Konkola Division to reduce the extremely high degree of ground water inflow which is being experienced. A demonstration project has been proposed which would verify the applicability of the technology within the Konkola Mine. The MK/STG joint venture intends to work with ZCCM to establish and perform a successful demonstration which will allow the use of the STG grouting technology on many of the problems which are currently being encountered at Konkola as well as other mines within Zambia and the vast mining regions of central and southern Africa. The MK/STG joint venture is committed to this purpose and feels that the advantages gained from the grouting of these mines will enable the operations to function much more safely and at a substantial savings in pumping costs. The technology should allow the expansion of operations into more productive areas and enhance the extraction of ore to make the region even more competitive in the world market.

The MK/STG joint venture will be glad to address problems being experienced by any member of the International Mine Water Association and to render an opinion on the application of the STG integrated grouting technology for the solution. Please address correspondence to:

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TABLE 1

Ground-Water Quality Near the National Tunnel			
	Minimum	**Maximum**	**Average**
FIELD PARAMETERS			
Specific Conductivity (μmhos/km @25°C)	445	1,675	898.1
Temperature (°C)	4.2	11.0	6.8
pH (Units)	3.7	5.65	4.49
LAB PARAMETERS			
Total Dissolved Solids (mg/l)	365	1,620	885
Sulfate (mg/l)	201	1,060	553.7
Aluminum (μg/l)	74	9,150	3,899.8
Arsenic (μg/l)	<4.0	<10.0	<8.0
Cadmium (μg/l)	10.6	97.0	36.0
Copper (μg/l)	21	1,410	473.0
Iron (μg/l)	10	1,460	267.2
Lead (μg/l)	<3.0	76.0	<21.9
Manganese (μg/l)	14.4	47,200	10,727.6
Zinc (μg/l)	2,800	19,800	8,574.4

TABLE 2

MONITORING WELL COMPLETION AND WATER LEVEL SUMMARY FOR WELLS NEAR THE NATIONAL TUNNEL PORTAL

Well No.	Location	Unit Monitor	Total Depth (ft)[1]	Well ID/ Borehole Diam (in)	Screened Interval (ft)[1]	Base of Bentonite Seal (ft)[1]	Stickup (ft)[2]	Depth to Water (ft)[1]	Date Measure
MWB03	Along NCC above National Tunnel	Bedrock	58	2/5.75	38.0 to 58.0	34.5	0.89	3.78	9/19/89
NT-03	Along NCC above National Tunnel	Alluvium/ Waste Rock	33.8	2/7.25	13.8 to 33.8	6.0	1.75	5.29	9/13/89

[1] Feet below ground surface

[2] Feet above ground surface

NCC = North Clear Creek

TABLE 3

COMPARISON OF BEDROCK, ALLUVIAL, MINE DRAINAGE AND SURFACE WATER QUALITY IN THE VICINITY OF THE NATIONAL TUNNEL

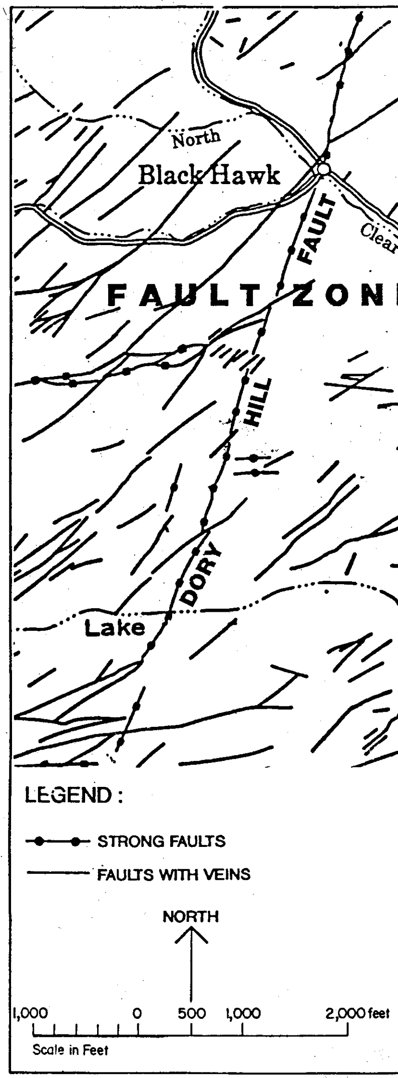
Site Location	NT-03 Alluvium at National Tunnel	MW-B03 Bedrock at National Tunnel	NCC Below National Tunnel	Mine Drainage National Tunnel Portal
Date	09/19/89	09/19/89	09/18/89	not analyzed
Spec Cond (μmhos/cm @ 25°C)	533.00	1,953.00	553.00	not analyzed
Water Temperature (°C)	8.50	7.50	15.30	not analyzed
Field pH (units)	3.70	5.90	6.39	not analyzed
Total Dissolved Solids (mg/l)	360.0	1,100.00	401.48	not analyzed
Sulfate (μg/l)	240.00	840.00	229.00	not analyzed
Aluminum (μg/l)	1,840.00	850.00	130.00	243.00
Arsenic (μg/l)	1.00	3.00	1.00	7.00
Cadmium (μg/l)	6.00	8.00	14.00	7.00
Copper (μg/l)	289.00	169.00	27.00	185.00
Iron (μg/l)	113.00	54,300.00	11,400.00	47,475.00
Lead (μg/l)	68.00	57.00	not analyzed	8.00
Manganese (μg/l)	6,230.00	26,900.00	3,710.00	17,625.00
Zinc (μg/l)	3,170.00	7,400.00	1,500.00	6,303.00
Chromium	not analyzed	not analyzed	not analyzed	6.00
Nickel	not analyzed	not analyzed	not analyzed	212.00
Silver	not analyzed	not analyzed	not analyzed	2.00

NCC - North Clear Creek
SW - Surface Wate

TABLE 4

GROUTING PROGRAM INVESTIGATION DRILLING

WELL NO.	WELL LOCATION	DEPTH (FEET)	WELL DESIGN	WELL PURPOSE	NUMBER OF TEST ZONES
SNT1	In the vicinity of Lake Gulch and Pump Shaft	30-40	Perforated casing to full depth, diameter not less than 4.5"	Studies of alluvial water and its hydraulic interconnection with bedrock water	1
SNT2	In the vicinity of Lake Gulch, between SNT1 and Pump Shaft	140	Casing within alluvium, diameter 8", uncased portion - diameter 4.5"	Studies into hydraulic interconnection of alluvial and bedrock waters	2
SNT3	In the vicinity of Main Shaft, Old Clay County Mine, 30 feet west	540	20-foot long standpipe at surface, uncased portion - diameter 4.5"	Studies into hydraulic properties and jointing of rocks	4
SNT4	1300 feet northeastward from SNT3, at the east side of the tunnel	500	20-foot long standpipe at surface, uncased portion - diameter 4.5"	Studies into hydraulic properties and jointing of rocks	4
SNT5	1000 feet northeastward from SNT4, along the tunnel's trace between the Senator Shaft lateral and Horseshoe Shaft	230	20-foot long standpipe at surface, uncased portion - diameter 4.5"	Studies into hydraulic properties and jointing of rocks	2
SNT6	In the vicinity of Unknown Shaft 1, 300 feet west of the tunnel	130	20-foot long standpipe at surface, uncased portion - diameter 4.5"	Monitoring ground-water levels before and after grouting	1



Evaluation of STG Grouting Technique
National Tunnel
Clear Creek Superfund Site

Figure 1
Traces of Faults and Veins Near National Tunnel

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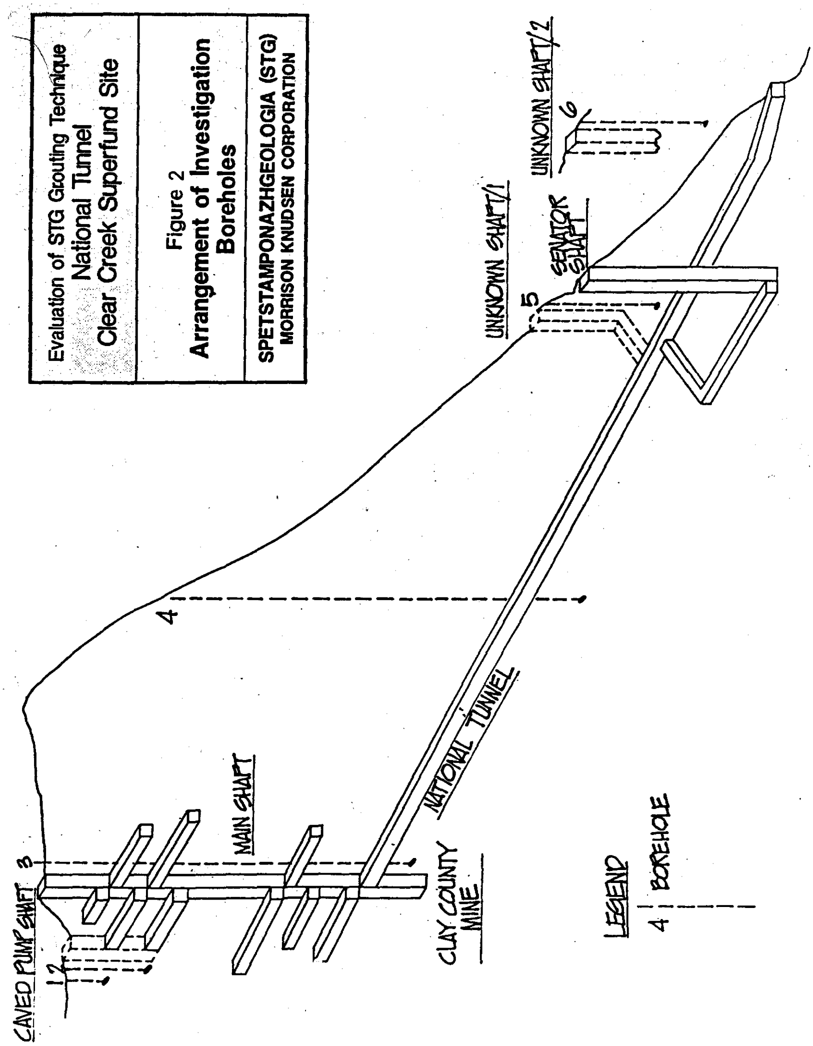
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National Tunnel
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Figure 2
Arrangement of Investigation
Boreholes
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UNKNOWN SHAFT/2
6
UNKNOWN SHAFT/1
5
SENATOR SHAFT
4
NATIONAL TUNNEL
MAIN SHAFT
CAVED PUMP SHAFT
1
2
3
CLAY COUNTY MINE
LEGEND
4
BOREHOLE

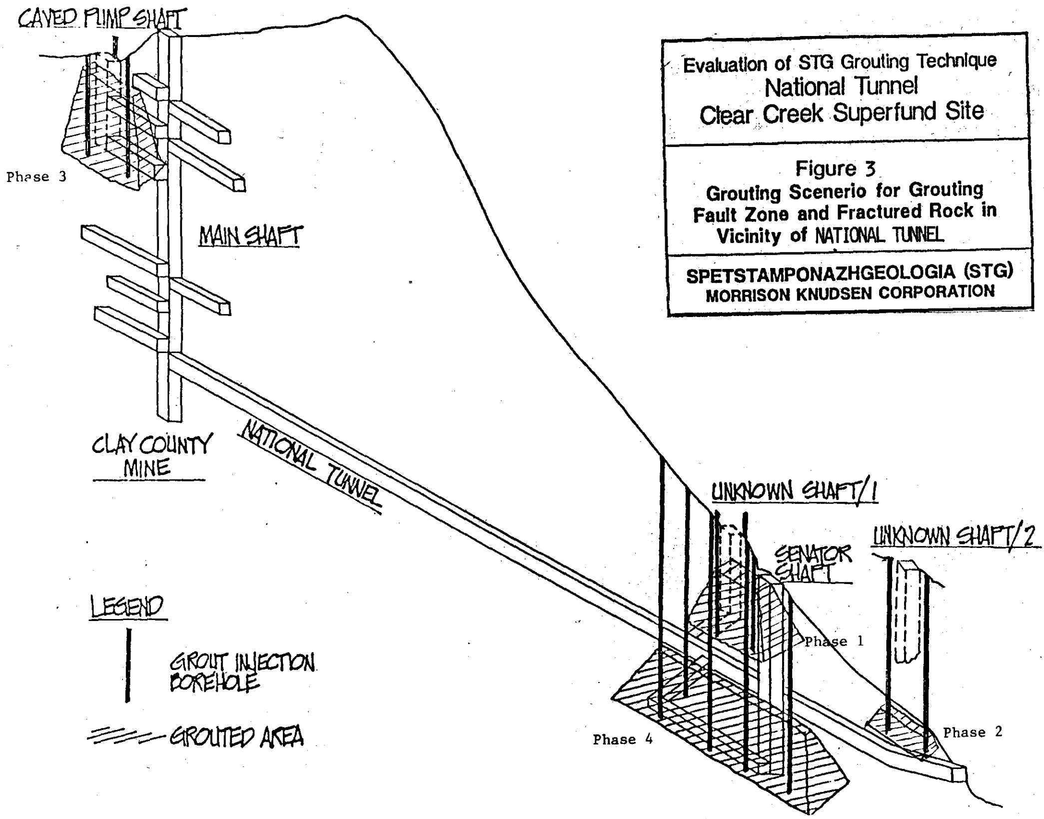
CAVED PUMP SHAFT
Phase 3
MAIN SHAFT
CLAY COUNTY MINE
NATIONAL TUNNEL
UNKNOWN SHAFT/1
SENATOR SHAFT
UNKNOWN SHAFT/2
Phase 1
Phase 2
Phase 4
LEGEND
GROUT INJECTION BOREHOLE
GROUTED AREA
Evaluation of STG Grouting Technique
National Tunnel
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Figure 3
Grouting Scenerio for Grouting Fault Zone and Fractured Rock in Vicinity of NATIONAL TUNNEL
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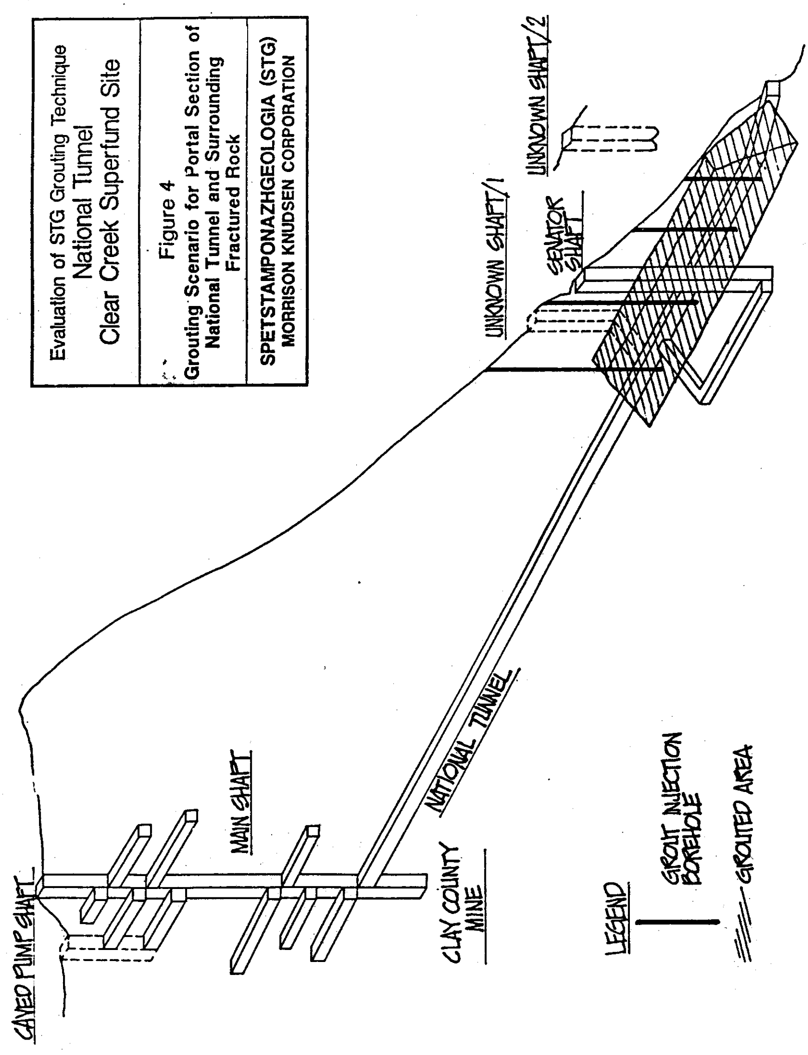

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National Tunnel
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Figure 4
Grouting Scenario for Portal Section of National Tunnel and Surrounding Fractured Rock

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