Open File Report 91-1

Identification and Remediation of a Mine Flooding Problem in Rico, Dolores County, Colorado with a Discussion on the Use of Tracer Dyes

By Mark W. Davis

Colorado Geological Survey
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ABSTRACT

Residents of Rico, Colorado, became concerned when water from Silver Creek and from an abandoned mine threatened several dwellings located on the Dolores River flood plain. Personnel of the Department of Natural Resources investigated and determined that several factors may have contributed to the flooding. A portion of the Atlantic Cable Mine may have caved to the surface immediately under Silver Creek and that water surged into the mine and discharged within a short distance of four residences. These residences located south of the confluence of Silver Creek with the Dolores River experienced minor flooding problems. Also, the water supply system appeared to have a broken pipe and defective valve upgradient from the residences. In addition, the pipeline ditch along Campbell Street may have served as a preferential pathway for groundwater near Silver Creek to access the residences.

The Atlantic Cable Mine owner installed a culvert over the caved portion of Silver Creek once it was identified and constructed several drainage ditches near the residences. Backfill was added to the caved area and recontouring was done in selected areas.

Rico maintenence personnel repaired the broken pipe and defective valve. No work was undertaken as of December 1990, on the Campbell Street waterline ditch pending outcome of the other two remediation activities

INTRODUCTION

Evaluation

In late May, 1989, residents of Rico, Colorado, became concerned when water from Silver Creek and from an abandoned mine threatened several dwellings located on the Dolores River flood plain (Figure 1). The Department of Natural Resources was advised of this flooding and immediately dispatched a team to investigate the severity and causes of the problems and to recommend solutions. The team consisted of Dave Bucknam, Division of Minerals and Geology; Mark Davis, Colorado Geological Survey; Glen Humiston, Division of Water Resources; and Walt Posey, Colorado Water Conservation Board. Several hours were spent on site on June 7, 1989 followed by consultation with the Mayor, Mrs. Lonnie Cole and interested residents.

Determinations from this investigation and interviews with Rico maintenance people suggested that a portion of the Atlantic Cable Mine may have caved to the surface immediately under Silver Creek and that water surged into the mine and drained through a long drainage adit. This adit was situated within a short distance of four residences. These residences located south of the confluence of Silver Creek with the Dolores River experienced problems with leach field septic systems and different degrees of flooding which ranged from wet yards to minor flooding on a garage floor.

The technical evaluation began with review of U.S. Geological Survey Professional Paper 723, "Geology and Ore Deposits of the Rico District, Colorado", a review of the mine inspection reports compiled between 1925 and 1948 for Atlantic Cable and Van Winkle Mines, and microfiche maps on file at the Colorado State Division of Mines. The site evaluation was conducted with this information in hand to determine: 1) the magnitude and severity of the water flooding threat to the four residences down gradient from the Atlantic Cable Mine and located in or nearly in the flood plain of the Dolores River; 2) what immediate action should be undertaken to mitigate the flooding problem; 3) what longer range mitigation activities should be considered. Stream flow rates were measured and tracer dyes were used to identify flow paths for mitigation. Several water quality samples were taken for the identification of the sources to the seeps observed upgradient of the southernmost of the four residences.

Remediation of the flooding entailed the installation of a steel culvert over the caved portion of Silver Creek by the property owner and construction of several drainage ditches near the residences. Backfill was added to the caved area and surface recontouring was done in selected areas.

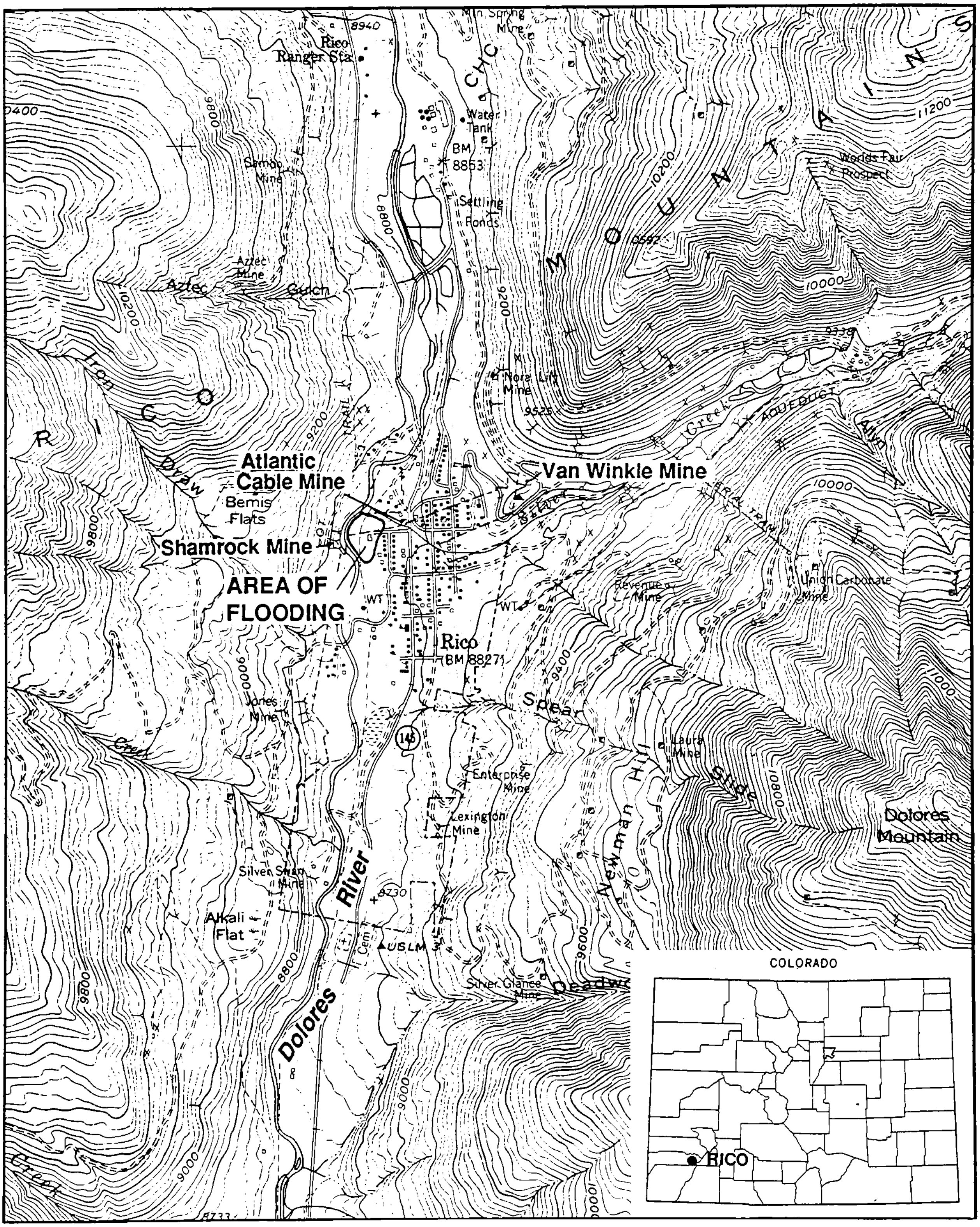

Figure 1. Area of flooding, Rico, Colorado (modified from U.S.G.S. Rico topographic quadrangle, scale 1:24,000).

Purpose and Scope of This Report

This report has been compiled to set forth the findings and the mitigation techniques employed at the site in the event that further flooding is observed and that followup work is needed. The scope of the work involved mitigation of the flooding problem with the least impact on the public utilities, private property and roads, within the budget set forth by the Department of Local Affairs and by the limited funds available in the town of Rico. Ten thousand dollars was approved by Local Affairs to be used for repair of the water system, pumping of septic systems, and correction of the breach in Silver Creek. Funds for testing, evaluation and on-scene coordination amounted to approximately $3,000 and were issued by Division of Disaster Emergency Services.

Geology and Mining

Geology

The geologic environment consists mainly of Paleozoic sedimentary rocks including limestones, shales, sandstones, and arkoses overlain in large part by Quaternary deposits of talus and slope wash, torrential fan deposits, landslide deposits, and alluvial gravel. The sedimentary units dip gently to the south and are cut by many east-west striking faults (Figure 2).

Quaternary alluvial deposits are coarse in texture and confined to the Dolores River valley. Landslide deposits thought to be on the order of several-hundred feet thick and containing many large blocks, encroach onto the alluvial deposits and have forced the river westward against Sandstone Mountain. The torrential debris fans are found at the mouths of Silver Creek, Horse Creek, Aztec Gulch, and Deadwood Gulch. This fan material is shown to cover much of the town of Rico and the area of immediate interest between the Atlantic Cable mine and the Dolores River. Talus and slope wash cover the lower slopes of the mountains surrounding the area and have been measured to be 300- to 400-ft thick in places where mining access was required. Calcareous tufa has been identified on the slopes south of Iron Draw on the west side of the Dolores River and are shown to overlie fan debris in this area. An active hot spring exists approximately 1 mi north of town.

Bedrock in the vicinity of Rico ranges in age from Precambrian to Permian. The Precambrian rocks include greenstone, metadiorite and the Uncompahgre Quartzite. The quartzite is overlain by the Devonian Ouray Limestone which is succeeded by the Mississippian Leadville Limestone. These formations have a combined thickness of 160 ft. The Leadville dips between 23 and 40 degrees to the south near the Atlantic Cable Mine. A thin quartzite thought by McKnight (1974) to be the equivalent of the Molas Formation and identified as Larson Quartzite overlies the older Paleozoic sedimentary units and is shown trending just north of the downtown area and south of the Atlantic Cable Mine. The Pennsylvanian Hermosa Formation is the most widespread in the area and is composed of arkoses, sandstones, shales, and conglomerates. Minor interbedded limestones occur through the 2,800-ft-thick Hermosa Formation, but are for the most part located in the middle of the formation. The limestones of the Hermosa Formation host much of the ore which was mined from this historic district. The conglomeratic units occupy the upper third of the formation. The Pennsylvanian Rico Formation overlies the Hermosa and is composed of approximately 300 ft of sandstones and arkosic conglomerates. The Cutler Formation overlying the Rico consists of 2800 ft of sandstones, conglomerates, shales and thin limestones.

Intrusive rocks in the Rico area include sills and dikes of hornblende latite porphyry, alaskite porphyry, and lamprophyre. A monzonite stock which crops out west of the Dolores River has metamorphosed the adjacent strata for up to 1.7-mi east of the contact. One of the main structural features of the area is a 10-mi-diameter dome centered just east of the monzonite intrusive. Faults are plentiful in the area and generally strike easterly and dip steeply to either the north or south. A large horst block trends easterly from the intrusive. Most of the downtown mining has occurred within this horst.

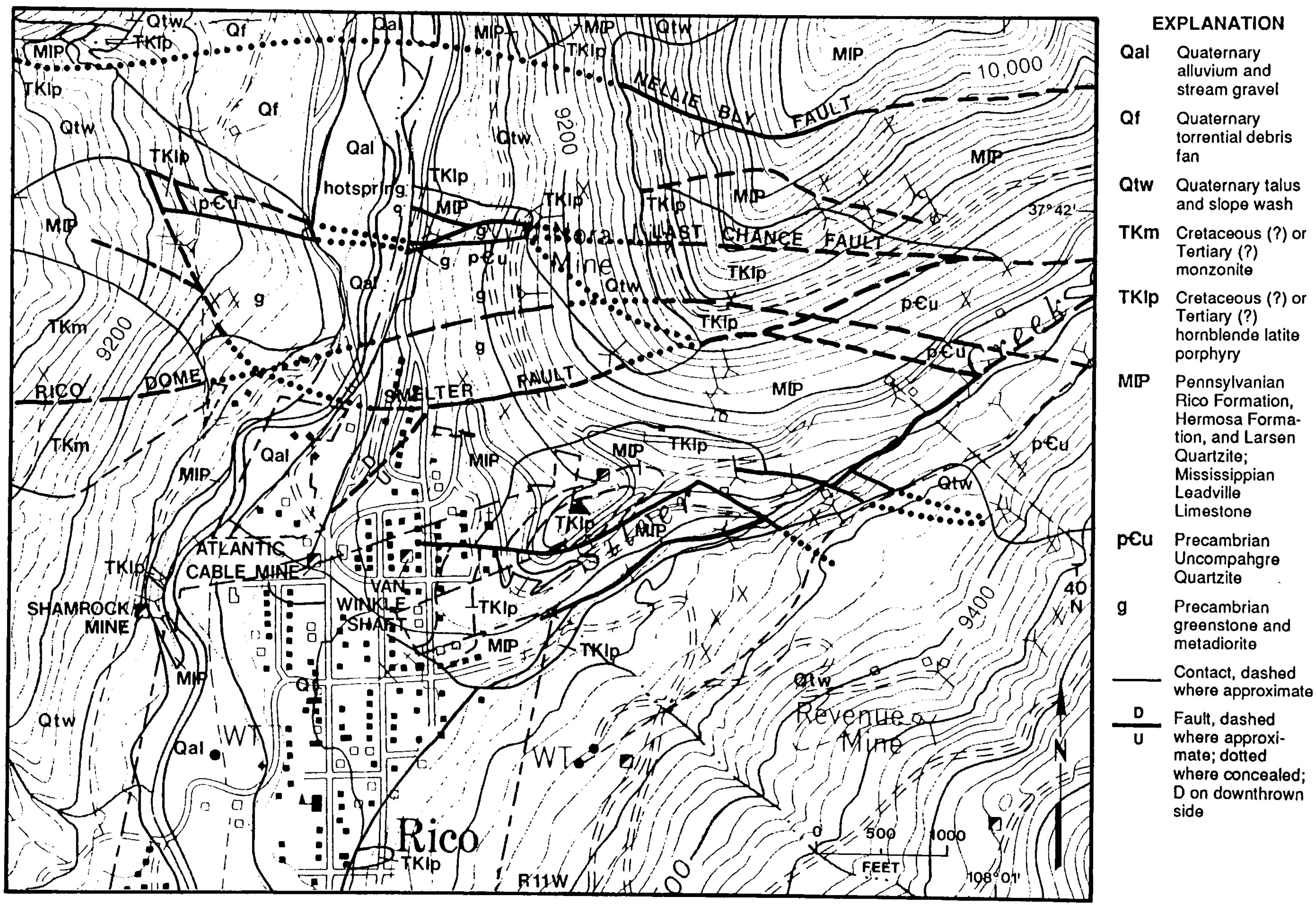

Figure 2. Generalized geology of Rico, Colorado (Modified from McKnight, 1974, Plate 1).

Mining Activities

Many of the mountain communities of Colorado and other western states originated as centers of mining activity. Unanticipated problems have occurred in the recent past for people who desire to live in the "tranquillity" which can now be experienced in these locations. Chief among these problems is the residual rock material from which metal values were extracted which is now available for further leaching. Additionally, the mines themselves can alter the the natural groundwater hydrology and may also cause settling and instability of the surface. It behooves the newcomer to these mountain communities to evaluate the local environment, but they rarely know where to turn for information. An understanding of the mining history of an area is usually a good starting point.

Exploration activities in the Rico area began with claim staking in 1869 and were sporadic until 10 years later when rich silver ore was discovered and a small but unsuccessful smelter was built north of town. Another smelter was built south of town and operated into the middle 1880s. Rich silver in a blanket-type ore body was encountered by accident in a prospect shaft on the Enterprise Claim on Newman Hill. These large blanket ore bodies encouraged the Rio Grande Southern Railroad Company to build a narrow gauge line into the area. This line was followed shortly by spur lines up Silver Creek and to the portal of the Enterprise Tunnel. In 1893 the Newman Hill mines produced much of the 2.6 million oz of silver mined in Colorado that year, but production then fell dramatically due to the silver crash and to the decline in grade of the local ores. Base metal ore production increased in the early 1900s and reached a peak just prior to World War I but then again declined rapidly until the flotation process of the early 1920s made zinc recovery profitable.

In 1926 a custom mill was built by International Smelting Company, a subsidiary of Anaconda Mining Company. This custom mill handled much of the ore from the district but closed after two years of operation. Production was only sporadic during the Depression and for several years thereafter but resumed in 1939 when the Rico Argentine Mining Company built and operated a 135 ton per day flotation mill and became the major producer of lead and zinc during World War II. The Rico Argentine Mining Company maintained relatively steady production until the middle 1970s and also produced sulfuric acid for the milling of plateau uranium ores during the first uranium boom and until 1964.

Drilling during the 1970s encountered a large deposit of molybdenum situated approximately 5,100 ft under the base metal deposits to the east of town. Development of this deposit which included a proposed 12-mi haulage tunnel was abandoned in the late 1970s.

The Atlantic Cable Mine

The Atlantic Cable Mine was operated until closure in 1948. The ore deposits are replacement and contact metamorphic deposits of silver, lead, and zinc with minor copper. The 1943 mine-workings map by D.J. Varnes and A.H. Wadsworth of the Atlantic Cable Mine (Plate 1) and investigations conducted by mine inspectors indicate that mining involved shrink stoping and possibly modified room and pillar methods. These stopes could be taken fairly wide and the back held with square set timber.

The Atlantic Cable Mine was serviced by a two compartment shaft for men and equipment and for hoisting ore. There appear to be three levels at the Atlantic Cable Mine served by the shaft. The main stope was developed for approximately 400 ft in a northwest to southeast direction. Plate 1 depicts a drift driven to the west from the sill of the first level at an elevation of 8,738 ft. This westerly drift extends approximately 200 ft from the shaft to what is shown as an incline to the surface on Plate 1. Another heading was driven westward possibly as an extension of this drift for dewatering and haulage. This 500-ft west drift was utilized to dewater the Atlantic Cable to the first level.

Another drift was driven from 60 ft below the collar of the Atlantic Cable shaft to dewater the lower workings of the Van Winkle Mine 1000 ft or so to the northeast and higher in elevation.

Plate 1 does not extend far enough to the west to indicate the presence or absence of stoping below the residences exhibiting the flooding problems. Myron Jones, a local citizen and driller from the mines, reported that attempts to mine to the west were thwarted by of carbon dioxide gas.

Another map in the Dolores County Courthouse files, titled "The Van Winkle and Atlantic Cable Mines, Rico Argentine Mining Company Map 7-104" includes the west adit and shows no mining near this west adit but does show additional development headings driven from the 8600-ft level to the west and from an intermediate level assumed to be at the 8720-ft elevation. The longer of these two exploration drifts is shown on company maps to extend approximately 400 ft west of the Atlantic Cable shaft (Figure 3).

The Van Winkle Mine

The Van Winkle Mine was accessed by a shaft sunk in 1942. This shaft provided access for most of the base-metal production during this period. The mine lies east of and at a higher elevation than the Atlantic Cable Mine. They are connected by the previously mentioned haulage drift which was driven from the 60-ft level of the Atlantic Cable mine on a haulage grade to the Van Winkle Mine. The two properties were mined simultaneously. Sometime after 1981, the Anaconda Copper Company, instituted a district-wide safety program. Anaconda fenced and bulkheaded the shafts of several of the mines including the Van Winkle Mine.

The Shamrock Mine

The Shamrock Mines lies west and slightly south of the Atlantic Cable Mine on the opposite side of the Dolores River. Prior to the study the impact of this mine on the flooding problem was unknown. Furthermore, inhabitants within the immediate vicinity were concerned that a cave-in could occur due to the proximity of this mine.

The location of the Shamrock and its elevation relative to the flooding areas suggest that it has had no affect on the flooding problem. This is due to the fact that the mine is undoubtably flooded, but to the level of the Dolores River. Any possible head of water backed up in workings on the west side of the river would in our opinion equilibrate with the river and not affect the workings on the east side.

It appears from the referenced geologic maps that the Shamrock lies on a geologic trend that includes the Atlantic Cable and Van Winkle Mines. However, attempts to connect the Shamrock Mine to the Atlantic Cable Mine were unsuccessful. The Dolores River water could not be controlled and the connection project was abandoned in 1929 (O. Jahnke, pers. comm., 1989). Mine waste rock from the Shamrock mine was transferred by trestle and dumped on the east side of the river.

Hydrology of Silver Creek

The drainage basin in which many of the larger mines are located lies to the east of town. Flanked on the south by Blackhawk Mountain, the highest peak in the area, it covers approximately 5 sq mi. Many small tributaries drain the steep slopes and flow into Silver Creek which is 3.5-mi long and the principle drainage in the basin. Except for the first mile of very steep headwater length and the last 0.5 mi of gentle gradient slopes approaching the Dolores River Valley, the gradient is uniformly ten horizontal to one vertical (10 percent).

Silver Creek flows westward past the Van Winkle Mine, under State Highway 145 through a concrete box culvert roughly 4-ft high by 6-ft wide, past the Atlantic Cable Mine and then swings northwestward to the Dolores River. Stream velocity is between 5 and 10 ft per second. The channel is about 6-ft deep by 6- to 8-ft wide as it progresses past the concrete wall at the headframe. Bedload consists of cobbles and boulders from 4 to 18 in. in diameter.

Division of Water Resources personnel analyzed the Silver Creek basin for a flood event with a 10 year return period. They used the computer program HEC-1, and the spillways method to size a culvert for installation in Silver Creek over the caved area. A check of the DWR calculation using the Chezy-Manning equation and assumming 100 cubic feet per second (cfs) flow was conducted by CGS. Using a roughness coefficient of $n = 0.022$ yielded approximately 3 ft as the required diameter. Any pipe of greater diameter would suffice and

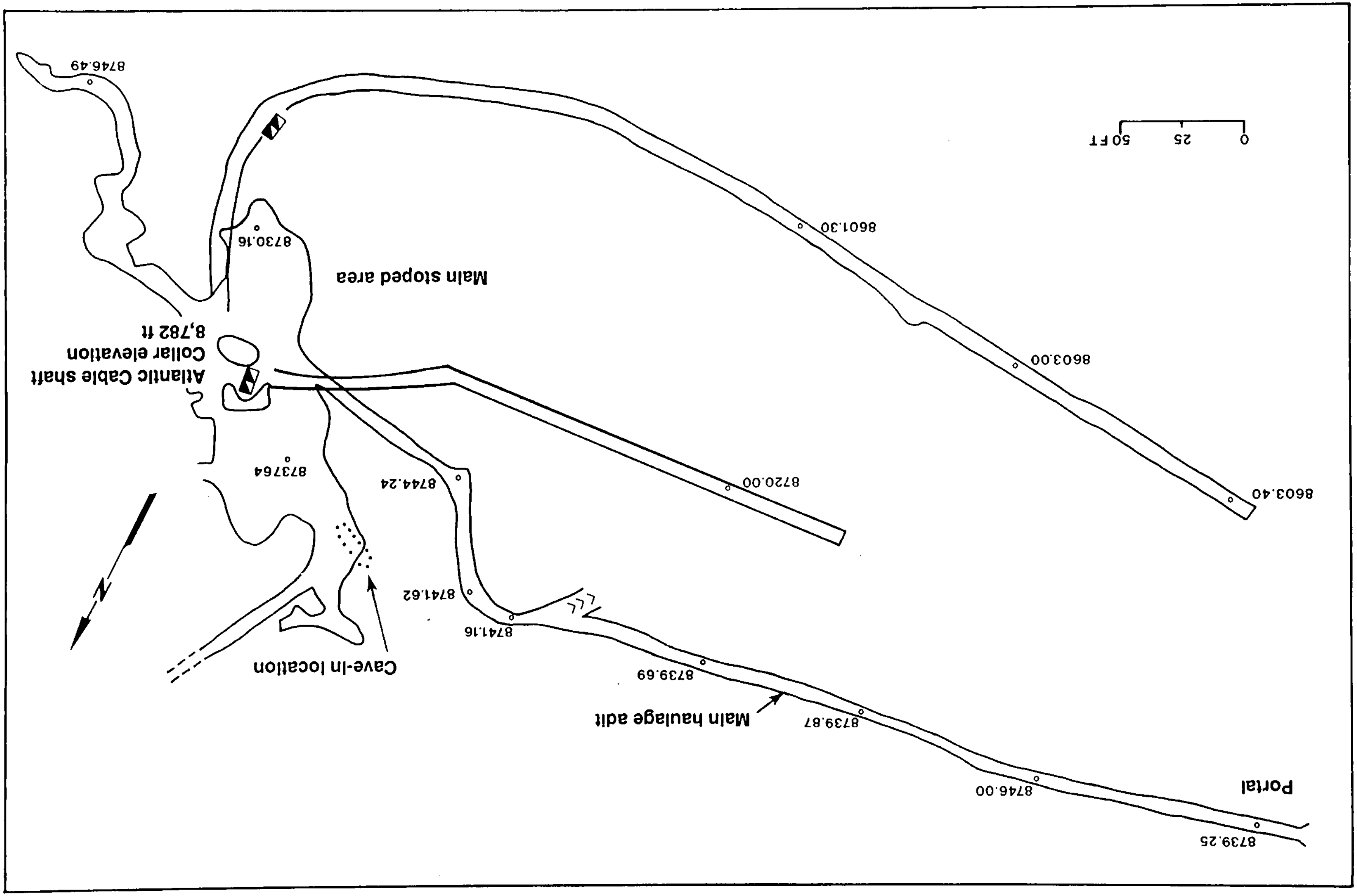

Figure 3. Atlantic Cable Mine, main haulage adit and exploration drifts.

would provide a larger factor of safety, and for the larger volume which would result from a flood event with a longer return period. The final design utilized a 6-ft diameter culvert.

Site Evaluation

Mine Environment

Late in May, residents noticed flooding around certain residences and also noticed a whirlpool west of the Atlantic Cable shaft in Silver Creek (Figure 4). This whirlpool was located approximately N. 60 W., 60 to 75 ft from the shaft and on the south bank. The observers could detect no reduction in stream volume. One observer mentioned that an open hole could be seen in the bedrock and that mine timbers were encountered while he was operating a backhoe in the stream. Rico maintenance people reported that four truck loads (16 yds) of rock and soil were dumped into the whirlpool and much of this material sank into a hole. This whirlpool area overlies the first level stope suggesting that a cave-in could have occurred from the back (roof) of the stope up to the stream bed.

The whirlpool location was several feet lower in elevation than the point in Silver Creek adjacent to the shaft, and the mine is hydraulically connected to the Van Winkle mine at least 100-ft higher in elevation. A large concrete wall was erected on the north side of Silver Creek during the early days of mining to reduce inflow into the Atlantic Cable Shaft. The wall (Figure 5) appeared substantially intact but still might allow entry of creek water to the shaft.

It is likely that the mine discharged a small quantity of water before the cave-in occurred. That mine water could easily be drained by the west drift even though the drift is probably caved along most of its length. Such mine water would then stabilize at the first level sill at approximately the 8,738-ft elevation. Upon breaking through, the mine probably flooded to a level above the drift invert level. This could have caused a surge and additional caving to the surface along the course of the drift. The outflow was reported by earlier observers to contain iron hydroxide bloom.

The location of the whirlpool did not appear to overlie the west drift. However, it may overlie the edge of the large first level stope. The importance of this affects remediation as the use of heavy equipment over a large stope provides a greater safety problem than working over a much smaller timbered drift.

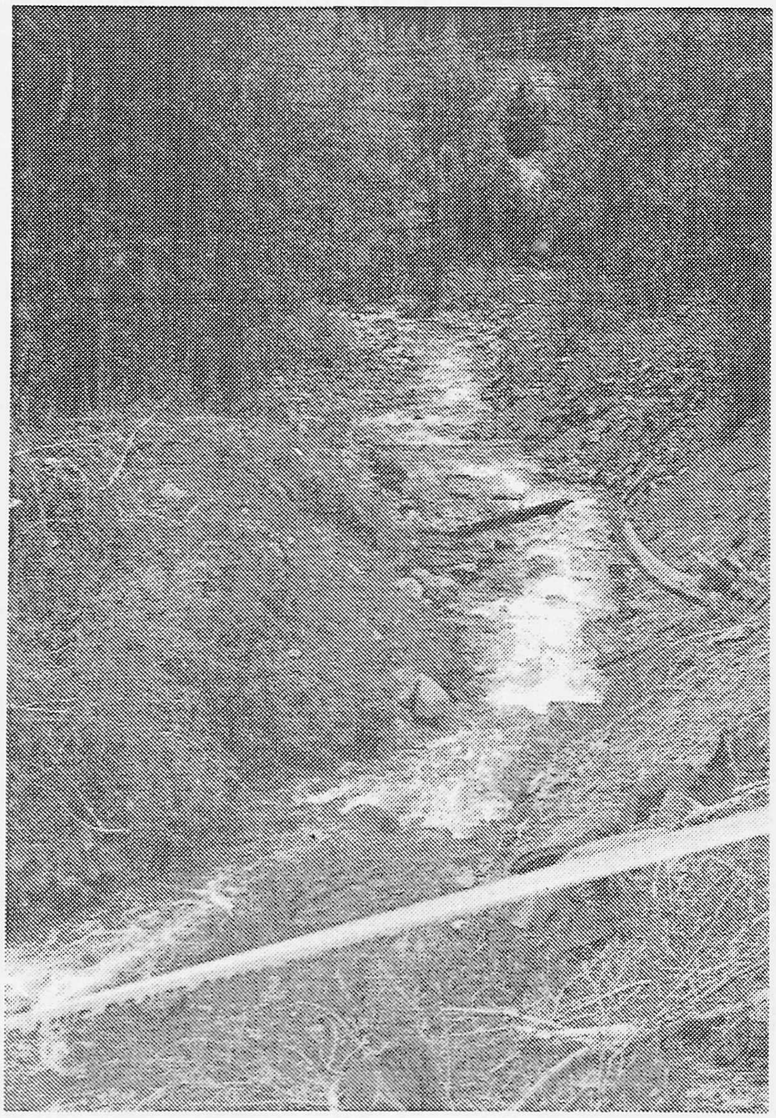

Figure 4. Location of whirlpool and cribbing encountered during re-alignment of Silver Creek channel. The loose fill material on the left side of the Creek in the center of the picture was dumped into the whirlpool.

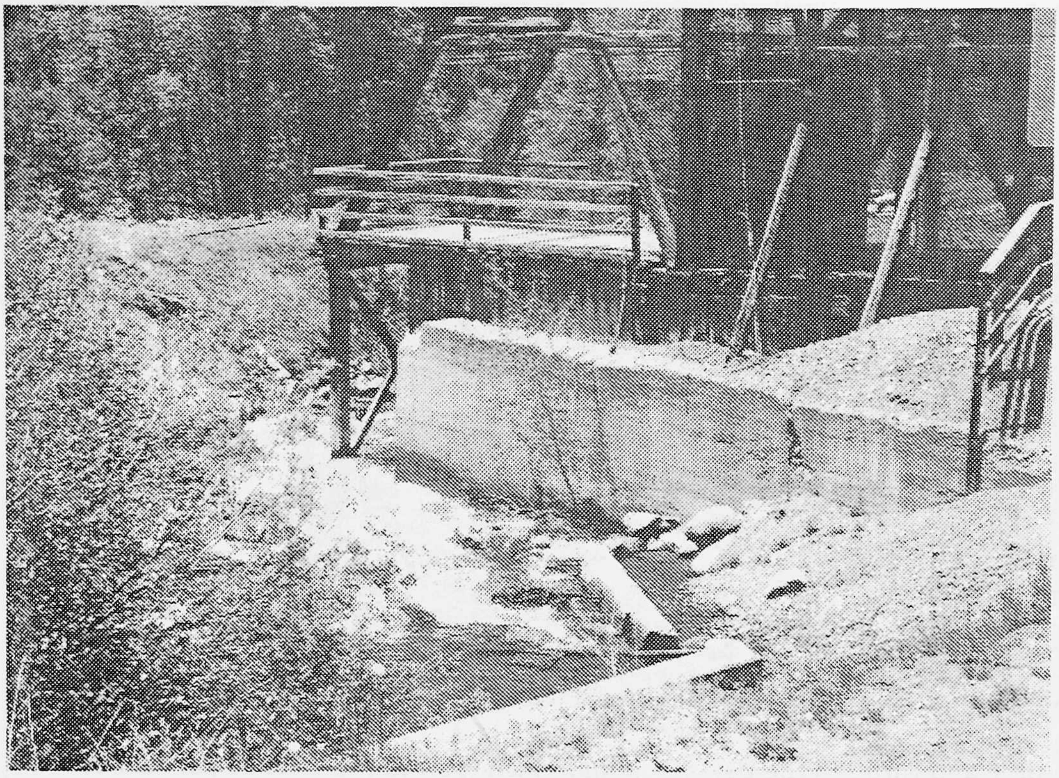

Figure 5. Looking westward at the Atlantic Cable shaft with concrete flood protection wall.

A study of the surface overlying the west drift and overlying the decline indicates that they have caved. These cave-ins have occurred at changes in direction and at what might have been a small stope, as well as randomly along their courses. Two of these cave-ins appeared fresh, suggesting that possible hydraulic changes such as a sudden head change could have occurred in the recent past to perturb the geohydrologic conditions. On June 8, 1989, 0.6 to 0.75 cfs outflow was measured discharging from the caved portal. Additionally, new seeps were identified adjacent to the fresh cave-in and flowing across the surface. All of the seeps observed were south of the alignment of caved ground suggesting geologic controls unrelated to mining except as they may have become preferential pathways following recent cave-ins. There are two major aspects of the geology to consider; east-west trending water course faults and extremely permeable gravels (estimated to be on the order of 10^{-1}, 10^{-2} cm/s hydraulic conductivity).

Seeping and minor piping has occurred immediately west of the west adit and could still be seen in the road, the adjacent front yard and along the bench that extends further to the south (Figures 6 and 7).

Looking north toward the most seriously affected properties,. the main haulage adit is in the trees on the right of the picture.

The flow discharging from the west adit was diverted to the north and temporarily channeled across the road. Some of this flow was thought to be seeping under the road and to the front yard of the southernmost residence in the affected area (Figure 8). The owner indicated that his leach field was located there but no odors or discoloration of the water was observed. However there was a slight discoloration and a septic field odor approximately 80 ft southeast of the residence near the Dolores River.

City Water System

The city of Rico receives water from Silver Creek .75-mi east of the Atlantic Cable Mine and 300-ft upgradient. Water flows by gravity into two 100,000 gallon steel tanks protected with overflows. At a point 150-ft west of the Atlantic Cable shaft just on the north of Soda Street, there exists a double-disk gate valve on a 6 in. main which serves five residences to the north. Water could be heard running through this valve continuously which suggested that the major seep could be caused by city water flow-

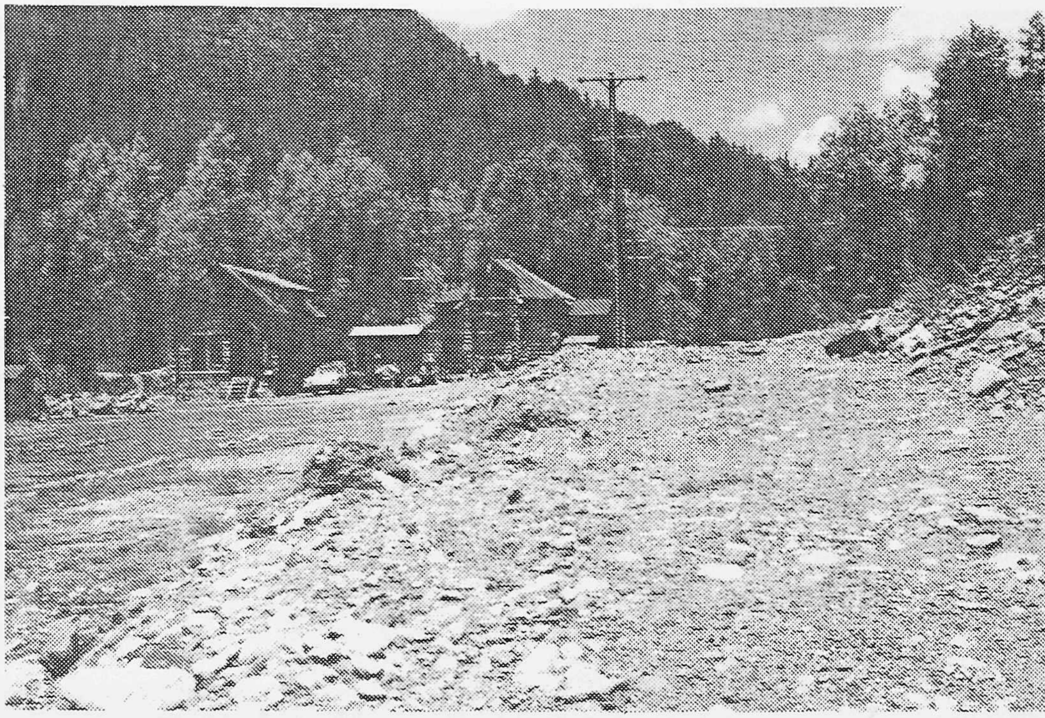

Figure 6. Looking north toward the most seriously affected properties. The main haulage adit is in the trees on the right of the picture.

ing through a broken pipe and through the permeable torrential debris fan material in the area. The valve was determined to be defective when attempts to shut it off failed in late May.

Because of the elevation difference between the main storage tank and the residences near west Soda Street, the City of Rico required pressure regulators on private taps. This was to reduce the pressure from the 175 pounds per square inch (psi) to the 40 to 60 psi needed. It was assumed that supply to the residences would not necessarily be disrupted by a broken pipe given the high pressure and potential delivery rate.

The major seep is 100-ft west and 10-ft lower in elevation than the watermain which this valve controls. To determine if the seep was caused by a broken watermain, the next

Figure 7. Water line on flooded bench. The riser pipe in the lower foreground and the hydrant are connected to the water line.

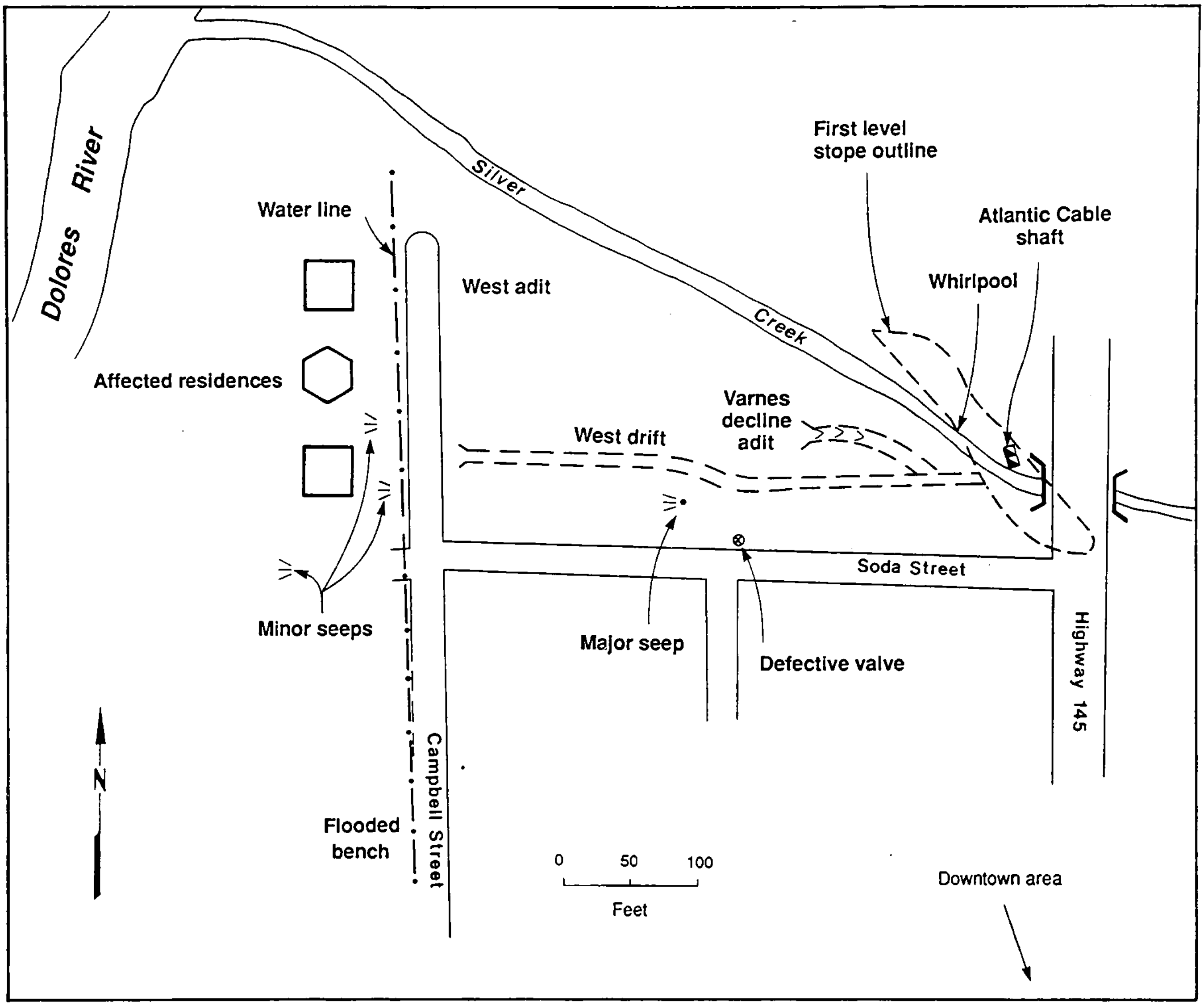

Figure 8. Affected residences and their relationship to Silver Creek and the west adit.

valve higher in the system was turned off and a fire hydrant nearby was opened to bleed off head. No diminution of flow from the seep was observed in the 45 minutes that this valve was shut off, and no bypass was heard in the defective valve. This suggests that the seep below the valve was caused by factors other than the broken pipe. A water line has been extended to serve the residences on Campbell Street and undeveloped lots to the south. The pvc line with riser pipe from the ditch is 6-ft deep. One stand pipe to the north was discharging water and many others were standing partially full. This attests to the shallow groundwater conditions present along the pipeline trench. The location of one seep several-hundred feet south of the subject residences suggests that this line may be distributing ground water preferentially through the backfill material located in the pipeline trench.

Site Testing

Hydrography

Stream flow quantity was determined at two stations, one approximately 300-ft upstream from the highway culvert and the other 100-ft downstream from the Atlantic Cable shaft and downstream from the whirlpool location. These sites were selected to bracket and isolate the mine and any of the known workings so that stream water loss could be determined. The upstream flow was 20.6 cfs and the downstream flow was 17.6 cfs. The three cfs difference between the upstream and downstream measurements is indicative of some type of loss. Measurements on other reaches of Silver Creek downstream from the mine area showed no diminution of flow suggesting that the losses were entering the mine and not simply recharging the debris fan aquifer. The accuracy of this type of instream hydrography is a function of many parameters but in this situation no more than five percent error would be expected with this type of monitoring. Additional stream flow measurements taken on June 14, 1989 were 16.7 cps upstream and 10.5 cps downstream for a net loss of 6.2 cps.

Residents reported that this was a rather dry year. This is important from the standpoint that a wetter year could cause even greater problems especially if the observed flooding was the result of a combination of factors. By the time CGS and the Water Resources Division (WRD) arrived the creek was noticeably down from just a few days earlier indicating that the levels which we observed in all of the specific areas of interest could have been substantially changed and cause and effect relationships obscured.

Chemical Testing

The objective of testing for chemical parameters was to identify the sources of flood water. It was thought that mine water would carry elevated metals whereas water flowing from a broken water main should be much lower in contained metals. Additionally, residents requested information from the Colorado Department of Health with respect to potential water quality problems and it was suggested that CGS sample and analyze for metals where appropriate.

Water samples were collected at the following locations:

1. Seep in the front yard immediately west of the west drift
2. Portal of west drift
3. Major seep down gradient from the broken watermain
4. Stand pipe to water main ditch at the residence located at the confluence of Silver Creek with the Dolores River
5. Silver Creek upstream of highway culvert
6. Pool near cave-in of decline shown on the Plate 1.

The results of the chemical testing (Table 1) were inconclusive with respect to absolute identification of the source of floodwater. The elevated zinc contents in samples 1, 2, and 4 suggest that these had time to scavenge metals from the mine environment or the mine waste rock piles which formed a dump around the Atlantic Cable shaft. The lower readings in samples 3, 5, and 6 with respect to zinc suggest limited contact with highly mineralized material. However, a cave-in in the stream channel might cause a watercourse that would act as a short-circuit though mine workings with insufficient residence time to mix or otherwise equilibrate with standing water in the mine.

The Atlantic Cable Mine and other mines in the immediate area have mine drainage with elevated Ph, probably a function of the carbonate-rich host rocks which have a tendency to buffer the conditions caused by oxidation of sulfide ore deposits. This is fortunate in that many of the metals do not readily dissolve in neutral-to-basic water. No appreciable iron hydroxide bloom was observed around the Atlantic Cable Mine although other mines did display this feature which is typically associated with sulfide oxidation.

Tracer Dye Testing

Tracer dye testing was recommended initially by Mined Land Reclamation Division personnel who have conducted similar studies as a common practice in mine drainage identification (Anne Clift, pers. comm., 1990). The use by CGS at this site was generally inconclusive. No pathways were observed which categorically identified the cause of the flooding.

The use of tracers is fairly wide spread in many different environments and an understanding of their reactions and limitations is critical to any specific project. The user should contact the appropriate health department and fish and wildlife department before use.

The State had sulpho-rhodamine B available

Table 1. Results of chemical testing (mg/l).

Parameter	Sample Number 1	2	3	4	5	6
Alkalinity $CaCO_3$	108	107	113	87	70	80
Bicarbonate $CaCO_3$	108	107	113	87	70	80
Carbonate as $CaCO_3$	0	0	0	0	0	0
Carbon dioxide	20	20	3	8	5	4
Hydroxide as $CaCO_3$	0	0	0	0	0	0
Ph (lab)	7.0	7.0	7.8	7.3	7.4	7.6
Sulfate	43	41	45	25	19	8
Solids, total dissolved	163	160	164	120	104	106
Cadmium, dissolved	0.028	0.007	<0.005	0.008	<0.005	<0.005
Copper, dissolved	0.01	0.01	0.01	0.02	0.01	0.01
Iron, dissolved	0.02	0.07	0.23	0.02	0.32	0.13
Lead, dissolved	<0.02	<0.02	<0.02	0.09	<0.02	<0.02
Silver, dissolved	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc, dissolved	4.2	1.17	0.39	1.38	0.25	0.23

so the Rico-Silver Creek testing was limited to its use. Sulpho-Rhodamine B is reddish purple and visible in amounts as dilute as one part per million. Although it is reported to be susceptible to sorption onto clay this was not considered to be detrimental to the study.

Dye was placed in the small ponded area at the mouth of the west adit. Approximately 100 ml of dye was mixed with 2 l of water and this concentrate was added to the pool water. The purpose of this test was to observe the dye movement and strength before applying any larger measures. The secondary purpose was to observe the effects of dye flow for the short distances to the affected front yards. Dye surfaced in neither of these locations indicating that portal flow may not be a major factor in these areas. Since all previous observations by the respective property owners concluded that the cave-in of the old stope and the large slug of portal drainage did cause the flooding, the lack of tracer identification of a pathway was enigmatic.

A larger measure of dye (400 ml in 3 l of water) was added to Silver Creek 40-ft upstream of the whirlpool area. This was done to determine if water was entering the mine and exiting at the portal of the west drift or at any of the observed seeps. A very rough approximation of volume was made of the flooded portions of the Atlantic Cable Mine so that a quantity of dye could be added which would not be diluted to less than the 1 ppm visible range. A factor was used to estimate the path since dilution throughout the entire mine workings was thought to be unlikely in the dynamic areas of primary concern.

The June 14, 1989 flow measurement which showed the 6.2 cps loss suggested that at least one-third of the dye was flowing into the mine. Observers were positioned at the west drift portal, at the south seeps, in the affected yards, at the major seep, at the watermain stand pipe to the south, and at the mouth of Silver Creek. No observation of the north seep area was necessary. These points were observed for 1.5 hours and no dye was seen at any of the locations except for Silver Creek and the Dolores River. The sites were all revisited on an hourly basis until nightfall without observing dye. The dye has a suitably long half-life especially when not in direct sunlight to be observed over this time period.

Rico maintenance personnel were able to insert a pipe into a hole in the bed of Silver Creek to a depth of 3.5 ft on June 21, 1989. This was near the original whirlpool area and thought to be the hole into the mine. With observers stationed as on the previous day dye was injected into this pipe. This was done at a trickle rate of approximately one liter every 10 minutes until 4 l had been injected. No dye was observed at any of the stations.

A large measure of dye was added to Silver Creek in quiet waters just upstream of the Highway 145 culvert. This was to identify any pathway through mine workings including directly down the mine shaft without regard to the exact location for the pathway. No dye was observed in any of the locations. Dye was placed at the major seep below the broken valve to determine if this seep might have another pathway besides the surface flow as there appeared to be a slight diminution of flow away from the seep. No dye flowed into the nearest affected front yard from surface or seep but dye flowed underground for a comparable distance to that of the first day's test when dye was added to the portal flow but did not surface at the adjacent residence. This suggested that the negative observation results were not a function or chemical reaction or absorption with soil. Furthermore, the velocity of the dye in the groundwater system between the points observed was compatible with velocities calculated using Darcy's equation. This suggests that the portal flow at the time of dye testing was not seeping to the adjacent residence.

Dye was added to the waterline ditch near the manhole at the northernmost of the four affected residences to determine if the watermain ditch represented a preferential pathway from Silver Creek to the affected properties. No dye was observed in any of the down gradient locations.

Dye tracer testing was inconclusive with respect to pathways from the mine to the major seep but literature review of the results from similar studies indicates that non-observation of the dye event is not substantial evidence that the pathway does not exist. If further testing is undertaken Rhodamine WT may be more effective. Furthermore, there are detection systems available that can detect concentrations measured in parts per trillion. These are also effective in mine discharge which may contain iron compounds which impart a distinct color to the water and would ordinarily mask the dye.

Site Remediation

Following the chemical and dye testing, Silver Creek flow had dropped off to not much more than a trickle, measured by WCD to be between 1 and 2 cfs. During this low water period, the bed of the stream was investigated and the cave-in area surveyed to the Atlantic Cable shaft. The center of the cave-in lay 63-ft west of the concrete retaining wall on the west side of the shaft. Although cobbles and boulders made identification difficult, the hole in the stream bed was approximately 3-ft wide measured perpendicular to the stream direction by 7-ft long. Timbers were observed running on either side of the hole with eight inch lagging supported on the timbers. At the time of these observations the entire above-bed flow of Silver Creek was flowing into the caved mine workings. It was decided that the most cost effective short-term solution to the flooding problem was the installation of a culvert over the cave-in beneath the creek (Figure 9).

The property owner was experienced in these types of installations and accepted the responsibility for overseeing this work utilizing

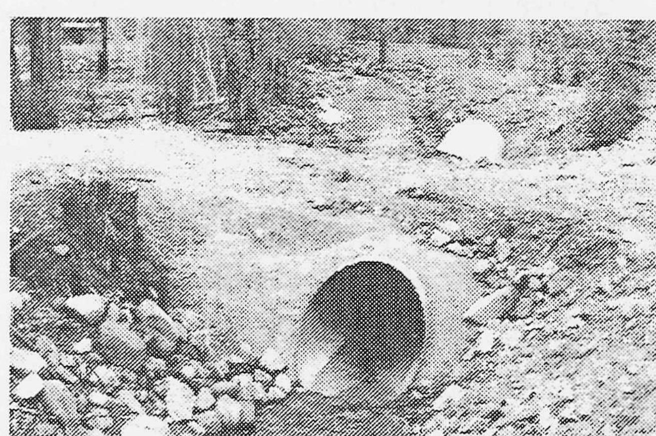

Figure 9. Silver Creek culvert over caved-in area of Atlantic Cable MIne.

Rico maintenance personnel and members of his own staff. The creek was contoured to accept a 6-ft-diameter by 60-ft-long culvert.

Concrete was used to pave the hole and to form a cover over the backfill and bedding material to minimize erosion at the upstream end of the culvert.

Regrading of the portal area of the west drift and the drainage ditches east of the subject residences and of the road was also conducted. Flooding around and in these areas was curtailed. The Soda Street valve was undergoing maintenance at that time.

This short-term maintenance has been successful but it is coupled with the fact that water levels had receded naturally. Spring runoff may raise the levels of the Dolores River and Silver Creek and generally recharge the alluvium and torrential debris fan material such that localized flooding may result. Monitoring wells which could be installed in strategic locations around the confluence of Silver Creek might act as an early warning system for rising groundwater conditions. This was not specifically recommended due to cost and to the fact that wet conditions are fairly obvious and knowledge of their onset would not preclude the leach field pumping that these conditions would necessitate.

REFERENCES

Vanderwilt, J.W., 1947, Mineral resources of Colorado: State of Colorado Mineral Resources Board: Colorado Geological Survey Miscellaneous Information 1, 547 p.

Varnes, D.J., and Wadsworth, A.H., Jr., 1943, Atlantic Cable Mine—geology and transit survey of mine workings: U.S. Geological Survey, Strategic Mineral Investigation Preliminary Map, scale 1:250.

McKnight, E.T., 1974, Geology and ore deposits of the Rico District, Colorado: U.S. Geological Survey Professional Paper 723, 100 p.

Clift, Anne, Groundwater tracers: Division of Minerals and Geology Memorandum, February 15,1990.

Mine Inspection Reports 1923–1948

Colorado Geological Survey
Division of Minerals and Geology
Department of Natural Resources

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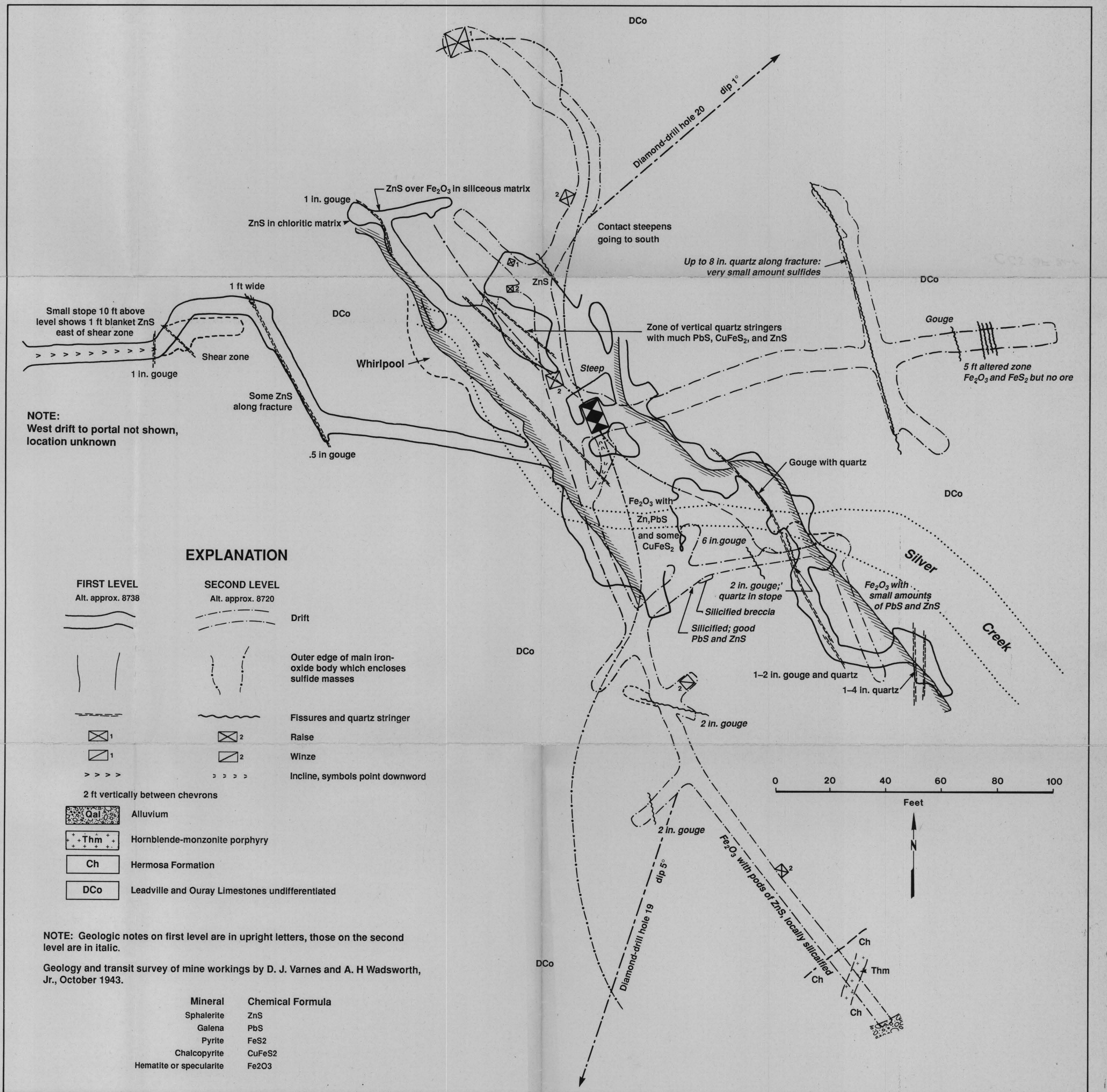
Plate 1

Atlantic Cable Mine, Rico, Colorado

Geology and Transit Survey of Mine Workings

By D. J. Varnes and A. H. Wadsworth, Jr.
1943



EXPLANATION

FIRST LEVEL Alt. approx. 8738	SECOND LEVEL Alt. approx. 8720	
		Drift
		Outer edge of main iron-oxide body which encloses sulfide masses
		Fissures and quartz stringer
1	2	Raise
1	2	Winze
> > > >	> > > >	Incline, symbols point downword

2 ft vertically between chevrons

Qal	Alluvium
Thm	Hornblende-monzonite porphyry
Ch	Hermosa Formation
DCo	Leadville and Ouray Limestones undifferentiated

NOTE: Geologic notes on first level are in upright letters, those on the second level are in italic.

Geology and transit survey of mine workings by D. J. Varnes and A H Wadsworth, Jr., October 1943.

Mineral	Chemical Formula
Sphalerite	ZnS
Galena	PbS
Pyrite	FeS2
Chalcopyrite	CuFeS2
Hematite or specularite	Fe2O3