Sullivan Mine Fatalities Incident: Site Setting, Acid Rock Drainage Management, Land Reclamation and Investigation into the Fatalities

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ABSTRACT
During May 15-17, 2006, four fatalities occurred at a partially reclaimed waste rock dump at the closed Teck Sullivan Mine in Kimberley, B.C. Canada. The deaths took place in an acid rock drainage (ARD) monitoring station at the toe of the No. 1 Shaft Waste Dump (WD1). The station was hydraulically connected via a pipe and toe drain to the covered waste dump. The immediate findings included confirmation that the fatalities were due to oxygen deprivation, yet the monitoring station was safely accessed in the week prior to the incident and for many years earlier. In August, 2006 an extensive program of technical investigations into the fatalities was initiated under the guidance of an expert Technical Panel.

The Sullivan mine, which operated from 1909 to 2001, was one of the world’s largest underground lead-zinc-silver mines. Its metal values were accompanied by an abundance of pyrrhotite, which resulted in prolific acid generation in the mine and its waste materials. ARD management has been a top priority at the mine since the 1970’s and this is reflected in the state of the art reclamation practices applied in mine closure. In fact, the effectiveness of the ARD control measures contributed to the fatalities. This paper will provide a contextual description of the mine’s ARD management and reclamation programs with a specific description of measures applied to the waste dump of issue. It will also describe the commissioning of a technical panel, the scope of the two-year investigation led by the panel, and other responses to the incident.

INTRODUCTION
The safety hazards associated with mining activities are well known and continue to result in serious injuries and fatalities in spite of rigorous regulatory and company safety management systems. However, there appears to be no evidence that hazards have previously been linked to modern mine reclamation practices, particularly those which address ARD management as well as land restoration requirements. Nevertheless, at the closed Sullivan Mine, there were four tragic fatalities during May 15-17, 2006 due to oxygen deprivation in an ARD monitoring station at the toe of a partially reclaimed waste dump. This station was hydraulically connected by a pipe and toe drain to the dump, which had a one metre thick glacial till cover but was not fully reclaimed. While oxygen consumption in sulfidic waste dumps is generally well understood, the hazards posed by conditions in the monitoring station were not recognized, in part due to the fact that it had been safely accessed over several years and in the week prior to the incident. The immediate investigations following the incident by the B.C. Ministry of Energy, Mines and Petroleum Resources (MEMPR) and Teck were effective in establishing the direct causes and circumstances of the fatalities. Moreover, they formed an important basis for an
extensive program of investigations into the underlying technical factors that was initiated in August 2006 under the guidance of an expert Technical Panel.

This is the first in a series of four papers that will disclose the full scope of the technical investigations into the Sullivan Mine fatalities incident, the findings and provide guidance to industry on the avoidance of oxygen deficiency hazards, which are broader than implied by the direct circumstances of the incident. This paper will discuss background information on the historic waste management practices of the Sullivan Mine and the measures subsequently applied to manage ARD releases and achieve mine reclamation in the current era of high expectations by regulators and the public alike. This will provide context for a description of the specific closure measures applied to the waste dump where the fatalities occurred. The immediate investigations and responses to the incident are described and the long-term technical investigations under an expert Technical Panel are outlined.

SULLIVAN MINE BACKGROUND

History of Operations

The closed Sullivan Mine is located in the city of Kimberley in southeastern British Columbia, Canada. It was one of the world’s largest underground mines having produced about 150 million tonnes of ore, which averaged 6.0 % lead, 5.7 % zinc and 24.8 % iron at rates of up to 10,000 tonnes per day. The orebody, a complex sedimentary hosted exhalative deposit, was first discovered in 1892 and acquired by the former Cominco Ltd. (now part of Teck) in. By the time the mine closed in December, 2001, the total combined concentrates production was about 25.9 million tonnes. These yielded about 17 million tonnes of lead and zinc and more than 285 million ounces of silver, which together were worth more than $20 billion.

In addition to underground mining, there was a smaller open pit operation from 1952 to 1957. As well, there was a phosphate fertilizer plant which operated from 1953 to 1987. This utilized sulphuric acid derived from the roasting of a pyrrhotite rich iron concentrate produced in the concentrator. The calcine by-product from the roaster was also smelted to produce pig iron and later steel from 1961 to 1971.

Wastes Management

The long history of the Sullivan Mine transcends periods of mining ’by convenience’ to the current era of high environmental performance expectations. This is particularly significant with respect to mine waste management practices and the resultant water quality impact issues because essentially all of the Sullivan’s waste rock and tailings are acid generating. Pyrrhotite in very high concentrations is accompanied by little or no alkaline carbonate mineralization in ore, waste rock and tailings. As an example, the combined tailings from the concentrator in the later years of operation had a net neutralization potential of about -560 tonnes CaCO3/1000 tonnes tailings. Figure 1 illustrates the principal facility and waste disposal locations at the Sullivan Mine and other features that will later be discussed.

At the present time, the main surface waste rock locations are the WD1, where the fatalities occurred, and the Lower Mine Yard Dumps. These contain about 3.0 and 4.3 million tonnes and occupy areas of about 11 and 20 ha, respectively. At the Open Pit location, 4.7 million tonnes of waste rock have been placed in the pit as a part of the mine’s closure program. The three
contiguous tailings ponds contain about 93 million tonnes of tailings (420 ha); total site disturbance is about 1,100.

Figure 1. Sullivan Mine site plan and waste disposal locations, showing historic and current ground and surface water impacts with an overview of the ARD collection system.

Historic Surface Water and Groundwater Impacts
Up until 1979, all ARD contaminated drainages from the mine and waste storage areas were directly discharged to adjacent watercourses or indirectly discharged through groundwater. It is estimated that the maximum loadings of dissolved zinc and iron in mine drainage discharged to Mark Creek were about 1,500 and 4,500 kg/day, respectively. The corresponding peak loadings in tailings drainage discharged to the St Mary River were 2,000 and 30,000 kg/day, respectively. A primary objective in the reclamation practices applied at the mine and, in particular, the waste dump of issue has been receiving water quality protection. By combining current and historic impacts, Figure 1 conceptually illustrates major sources of ARD releases from various mine and waste storage locations and the corresponding watercourse receptors.

ARD Management and Treatment System
In 1979, Cominco Ltd. took the first steps to deal with the complex ARD problem at the Sullivan Mine with the construction of a drainage water treatment plant and the first phase of an ARD
management system (Kuit, 1980). Facilities were built in anticipation that additional ARD sources would have to be accommodated over time.

A major upgrade of tailings pond dykes was undertaken to provide in excess of 300,000 m³ storage capacity for the management of peak drainage flow rates. Mine drainage from the 3900 level (mine levels identified by elevation in feet above msl) discharge was piped in a 7 km line through the city to the now ARD Pond. The ARD was then transported at rates up to 27 m³/min in a 3.6 km pipeline to a high-density sludge treatment plant at the St Mary River (see Figure 1). Chemically stable dense sludge is discharged to an adjacent 17 ha free-draining impoundment, which has about 150 years capacity. The plant was state of the art at the time it was built and it continues to function exceptionally well in a post-closure operating strategy.

**MINE CLOSURE PROGRAMS**

**Reclamation Research**

Research on soil cover systems was initiated at the Sullivan Mine in 1978 with the primary objective of developing a growth medium for self-sustaining vegetation, which was then a key reclamation criterion. However, with growing recognition that ARD treatment at the mine would be a burden in perpetuity, the objective was later expanded to include a significant ARD abatement component. Therefore, in the early 1990’s there were extensive field trials of alternate cover systems that would reduce infiltration to tailings, in particular, from incident precipitation. Studies over a two year period demonstrated that annual precipitation entry below a 55cm glacial till cover (25cm compacted) could be reduced by more than 90 % through a combination of diversion and evapotranspiration (Gardiner et al, 1997) and (O’Kane et al, 1999). The practice subsequently implemented was to apply a one metre thick compacted till cover followed by the scarification of half the thickness before seeding.

**Regulatory and Public Review Processes**

Mine closure was subject to comprehensive requirements under the Mines Act of British Columbia. These specify conditions for the restoration of mining disturbed lands including waste areas to productive ecological uses, which in the case of the Sullivan were a mix of forest and wildlife habitat. Public safety and long term security of engineered structures were of paramount importance with maximum credible earthquake and maximum probable flood criteria being applied to remedial works for structure’s stability and water management. As well, water quality protection is a key requirement under the Mines Act in addition to legislation under the authority of provincial and federal environmental agencies.

The first version of the Sullivan Mine Decommissioning and Closure Plan was submitted to MEMPR in 1991. This launched an 11 year multi-agency review process that had a large public component through the Sullivan Public Liaison Committee (SPLC). This culminated in the formal approval of a revised plan in September 2004. Meanwhile, substantive closure works that had received conditional approval had already been implemented.

**Water Quality Protection Measures**

The ARD collection and treatment system implemented in 1979 resolved the issue of direct discharge of mine and tailings drainages to streams but subsequently, significant water quality impacts were still apparent due to contaminated groundwater discharges from upgradient waste.
rock dumps, in particular. These waste dumps were the Lower Mine Yard Dumps, the Open Pit Waste Dump and the WD1. The corresponding affected streams as illustrated in Figure 1 were Mark Creek, Sullivan Creek and Lois Creek with the latter two discharging to Mark Creek.

Resolving the first of these three major issues entailed a multiphase program that commenced in 1991. It consisted of Mark Creek’s relocation into a new concrete and rip-rap lined channel and waste dumps consolidation and reclamation. As well, surface drainage collection was upgraded and groundwater investigations led to the permanent installation of a contaminated aquifer pumping system which discharges to the existing mine drainage conveyance line. This project and its effects on zinc loading reductions in Mark Creek are illustrated in Figure 2.

The impacts in Sullivan Creek were due to a combination of natural background contamination and groundwater emanating from the Open Pit Waste Dump. It appeared unlikely that remediation measures could ever improve the water quality in this small stream to aquatic life standards so a decision was made to divert the creek to the mine drainage line built in 1979. Subsequently, the 4.7 million tonnes of reactive open pit waste rock were relocated to the old open pit, covered with one metre of till and revegetated.

Lois Creek is about 1 km downgradient from the WD1 source of impacts. In the early 1990’s it was found that groundwater springs emerging in the creek contained in excess of 100 mg/L zinc and the lower reaches of the creek were highly contaminated but fish were present in a small headwater lake. Following geophysical and intrusive groundwater investigations, in 1995 a
collection ditch was cut into native till and through gravel/cobble lenses at the toe of the WD1 from where the drainage collected was conveyed by pipe to the mine drainage pipeline. Using zinc as an indicator, Figure 3 illustrates the resultant water quality trend in Lois Creek.

![Graph of Lois Creek zinc concentration (or loading) trend](image)

**Figure 3. Lois Creek zinc concentration (or loading) trend**

**Closure ARD Management and Treatment**
The forgoing is a brief summary of some of the major projects aimed at implementing ARD management commitments in the Sullivan Mine’s closure plan. These are built on the original ARD management and treatment system constructed in 1979. However, there are several major changes in the post-closure conditions that now prevail.

Firstly, a former Phosphate Plant cooling pond near the tailings area was converted and upgraded to be an ARD Storage Pond of about 610,000 m³ capacity. A second change was the use of the underground mine as an “in situ” mine drainage reservoir. Finally, overall drainage flows since closure are greatly reduced by simply the cessation of operations but also by the installation of the till covers on waste storage areas. As a result the Drainage Water Treatment Plant is now only required to operate during limited spring and fall campaigns on feed from the ARD Storage Pond. Figure 1 shows a schematic representation of the current ARD management system and is a dramatic contrast with the pathways of environmental contamination that prevailed up until 1979. The majority of impacts to Cow, Mark, Sullivan and Lois Creeks have been eliminated with interceptor systems.

**No. 1 Shaft Waste Dump Reclamation**
The WD1 was created in the 1940’s and through to mine closure in 2001 mainly by the deposition of waste rock by end-dumping from the adjacent No. 1 Shaft. The 10.7 ha area dump curves along the slope below the shaft in a southwest to northeast direction and has a height from the upper flat portion to the toe of about 55 m. It contains approximately 3.0 Mt of mainly sulfidic waste rock. The estimated dump volume is 1 M m³ with approximately 30% being void space. Figure 4 illustrates the till covered dump and certain features that will be discussed further.
In the earlier years of dump construction, most of the waste rock deposited was less than 15 cm in size due to the nature of older conventional mining methods and haulage limitations imposed by small, narrow gauge rail cars. However, in the 1980’s there was a major conversion to mechanized mining methods that generated larger rock with oversize material being deposited in selected areas of the dump. As well, other waste materials such as steel, wood, domestic refuse and various forms of debris from the mine were also deposited in the dump.

As noted earlier, a collection ditch was constructed below the toe of the dump in 1995 and its discharge to the mine drainage collection system was thereafter monitored for quality and flow using a V-notch weir. However, the open weir was subject to icing and in 1997 it was enclosed in concrete lock blocks and covered by a small building. Subsequently, the Monitoring Station was safely accessed on a routine basis up to and including May 8, 2006, one week before the first of the four fatalities.

In 2004 the toe ditch was substantially upgraded by placing a compacted, low permeability glacial till lining in the ditch, including the downstream slope. It was then filled with coarse rock over topped by fine rock and finally a filter layer. Later in the year, the waste rock dump was reprofiled to address geotechnical stability considerations and waste was moved to partially cover the drainage collection ditch that had been prepared for permanent reliable function. In the fall of 2005, a one metre thick till cover was placed over the entire dump including the toe collection ditch so that surficial uncontaminated water would not enter the drainage collection ditch. In May, 2006 about one week before the fatalities incident, the till cover was scarified in preparation for seeding. Figure 5 (a,b,c) illustrates the toe ditch construction work and a section of the waste rock dump through the Monitoring Station where the fatalities occurred.

**FATALITIES INCIDENT AND IMMEDIATE ACTIONS**

**The Fatalities**

The tragic fatalities in the WD1 Monitoring Station occurred over May 15-17. The first individual to perish was an environmental contractor employee engaged in routine water quality sampling at a large number of locations in the Sullivan Mine area. He had entered the station on
May 15 to obtain a sample of drainage and record its flow. The second death on May 17 was that of a Teck Cominco employee who had entered the station during a search for the first individual. The third and fourth fatalities soon followed and were ambulance service personnel who had been summoned to the scene. Medical findings confirmed that the deaths were due to oxygen deprivation. Full details on the circumstances of the tragic incident and the immediate investigations by the B.C. MEMPR, the B.C. Ambulance Service and Teck Cominco can be found at the web site: http://www.mediaroom.gov.bc.ca/sullivan_mine/sullivan_mine.htm.

Figure 5. The monitoring station prior to reclamation (a). Drain rock being placed in the ditch (b). Cross-section showing drain rock, waste rock and till cover in former ditch with 400 mm pipe conveying seepage to monitoring station (c).

**Incident Investigations and Follow-up**

Investigations into this unprecedented incident were initiated on May 17 and included gas sampling and other measurements in the Monitoring Station using confined space procedures with appropriate personal protective equipment. Hand held instruments indicated very low oxygen concentrations in the station. Gas flows of > 0.5 m/sec emerging from the 400 mm dia pipe connected to the waste dump's toe drain ditch were recorded. Subsequent chromatographic analyses of gas samples indicated concentrations of about 2% O2 and 7% CO2 in the Monitoring Station sump and in the pipe connected to the waste rock dump. No toxic gases such as H2S and CO were found in the gas samples taken. The immediate observations concerning low O2 levels at the Monitoring Station prompted the investigators to examine a number of other locations at the mine including pump stations and ARD stream collection points but no other instances of significantly depressed O2 levels were found.

Reports at the time of the immediate investigations indicated that there was a significant organic waste (wood, domestic refuse) content in WD1. This led to speculations that the highly elevated CO2 concentrations and by inference, the low O2 levels, in gas emerging from the
dump could be due to the combustion of organic material. Therefore, aerial infra-red thermal imagery analyses were conducted through aircraft surveys flown in the nights of May 30 and 31, 2006. These covered the WD1 and other reclaimed waste locations at the mine for reference. No evidence of “hot spots” in the WD1 was found although some subtle variations with inertial surface heat were apparent. However, temperature differences across the surface of the dump were within about a 2º C range. Also, stable isotope analyses on gas samples were arranged through the University of British Columbia. These confirmed that the CO2 in the gas samples was principally of an inorganic origin.

On May 25, 2006, the Chief Inspector of the B.C. issued a Directive to all mining operations in the Province to immediately examine all sampling structures below waste locations for potential O2 deficiency hazards, to secure these structures and to equip them with signage warning about the potential hazards. Furthermore, within four months these structures were to be equipped with positive ventilation and to have O2 monitoring equipment accessible from the outside (B.C. MEMPR, 2006).

In June 2007, a public inquest into the fatalities was held pursuant to the B.C. Coroners Act. The jury found that the fatalities were accidental and issued a number of recommendations to the B.C. MEMPR, the B.C. Ambulance Service and to Teck. The testimony of an independent expert technical witness at the inquest corroborated the unprecedented nature of the fatalities incident and the unexpected phenomenon of gas outflow at the toe of the waste dump.

**Technical Panel Investigations**

It was apparent to all that the underlying phenomena which caused the incident would require an extensive program of technical investigations. Within days of the fatalities, Teck sought advice from independent experts in the Mining Engineering Dept. at the University of British Columbia (UBC) and from a consulting firm. The UBC experts recommended staged investigations that would initially focus on the apparent “respiration” of the waste dump through the pipe into the Monitoring Station and later address the internal conditions of the waste dump including gas conditions and geochemical properties. Moreover, they strongly recommended that a scientific panel be struck to oversee the technical investigations. The recommendations of the consulting firm were very much aligned with the technical approach suggested by the UBC experts. Moreover, they were accompanied by a hypothesis that barometric pressure was the major driver in the waste dump’s “respiration”. Subsequently, a first phase technical program was implemented in August, 2006. This consisted of instrumentation installed in the Monitoring Station and the 400 mm pipe to monitor gas flow and conditions, till cover moisture monitoring and a meteorological station on the waste dump.

In the fall of 2006, the Technical Panel was formed under direction from the B.C. MEMPR to guide the scientific investigations into the incident. It consists of B.C. MEMPR staff and advisors; Teck staff, technical contractors and advisors and; independent members from the UBC Dept. of Mining Engineering and from an international consulting firm. The Panel has the mandate to fully investigate the technical causes underlying the incident and to provide guidance aimed at preventing similar incidents in the future. In its tenure, the scope of the technical investigation has expanded and evolved to include the research and findings that are fully
described in subsequent papers (Phillip et al., 2009; Lahmira et al., 2009; Hockley et al., 2009). It is expected that the Panel will conclude its work later in 2009.

**CONCLUSION**

In excess of $CAD 88 million has been expended to complete the decommissioning and closure of the Sullivan Mine. Most of the major programs have been specifically aimed at redressing the many ARD management burdens imposed by historic mining practices as well as achieving productive land use objectives. Soil cover systems, contaminated drainage collection and clean water diversion consistent with state of the art practices are key features of the remedial works completed. Unfortunately, the very diligence in the application of these measures was clearly a contributing factor to the tragic fatalities incident. It is believed that this is the first time that deaths have directly resulted in such mine closure circumstances and in a facility intended for environmental monitoring. Clearly, it is incumbent on the mining industry to learn from the incident and apply procedures such that similar incidents will be prevented in the future.

To contribute to this vital need, comprehensive technical studies have been conducted with the findings an ensuing guidance being separately reported in the three subsequent papers.

**REFERENCES**


Kuit, W. J., Mine and tailings effluent treatment at the Kimberley, B.C. operations of Cominco Ltd., *CIM Bulletin, December, 1980*

