CLOSURE OF THE SULLIVAN MINE TAILINGS FACILITY

Rob Marsland, P.Eng. and Rick Rodman, P.Eng.[1]
Bob Newcombe and Bruce Dawson, P.Eng.[2]

[1]Klohn Crippen Consultants, #202, 542 Baker St. Nelson, BC V1L 4H9
[2]Teck Cominco Metals Ltd, Kimberley, BC V1A 3E1

ABSTRACT

This paper reviews the geotechnical and hydrological closure activities undertaken at the tailings facilities of this historic mine. The selection of the appropriate design criteria was based on an assessment of the potential consequence of failure. Design and construction work included: water diversion channels and spillways; and, an ARD storage pond.

This paper summarizes the results from the geotechnical and water management programs for the last 10 years of operations and the first 2 years of closure. Predictions regarding the potential effects of the closure activities on water levels and seepage rates from the tailings facilities were made, indicating that phreatic water levels within the tailings would drop and seepage rates would be reduced. Performance and operation of the new ARD storage pond is discussed. This pond is used to enable campaign operation of the water treatment plant, while accommodating seasonal and continuous collection of ARD water from the former mine site.

INTRODUCTION

This paper reviews the geotechnical and hydrological closure activities undertaken at the tailings facilities of this historic mine.

Historical Background

The Sullivan Mine is located 3.5 km north of the centre of the city of Kimberley, B.C, and about 90 km west of the Alberta/British Columbia boundary. The Sullivan Concentrator is located on the southeast side of Kimberley, north of the community of Marysville, see Figure 1. The Sullivan Tailings Facilities are located immediately to the south of the old Concentrator and mill buildings.

The Sullivan ore-body was discovered in 1892 and is primarily an iron-lead-zinc deposit. Cominco Ltd.[1] acquired the property in 1909 and, since then, mined approximately 148 million tonnes of ore. The mine expanded in several stages to about 9,070 tonnes (10,000 tons)/day while the average production was about 8,000 tonnes/day, 5 days per week, over the decade prior to closure.

In addition to lead and zinc concentrate production, the Sullivan site was also used for production of ammonium phosphate fertilizer between 1953 and 1987, pig iron production between 1961 and 1972, and

[1] Cominco Ltd. is the predecessor company of Teck Cominco Metals Ltd. The change was made July 2001 after the merger of Cominco Ltd. and Teck Corporation.

steel production from 1966 to 1971. The fertilizer production roasted an iron concentrate from the mill to generate sulphuric acid, and produced phosphogypsum tailings and calcine (iron oxide). The iron and steel production used the calcine from the fertilizer operation and left slag and solids, precipitated from the iron furnace scrubber effluent.

After almost a century of operations, the Sullivan Mine was closed at the end of 2001, leaving approximately 94,000,000 tonnes of tailings and 16,900,000 tonnes of mine waste. Reclamation work on the tailings areas has been ongoing since 1990. A Drainage Water Treatment Plant (DWTP), which began operating in 1979, will continue to operate for the foreseeable future as part of the post-closure water management plan for the site, to treat acid rock drainage produced from the underground mine and waste storage facilities.

<u>Site Conditions</u>

The Sullivan Mine Tailings Facilities are situated in the foothills of the Purcell Mountain range on the western edge of the Rocky Mountain Trench. The mountains are composed of thick quartzite, argillaceous quartzite, argillite and limestone beds with large granitic intrusions. Colluvial, fluvial and moraine deposits cover bedrock. The Trench has very thick sedimentary and glacial deposits. The Tailings Facilities are located in the Interior Douglas Fir Biogeoclimatic Zone in Ponderosa Pine sub-zones, in the Montane Cordillera Ecozone at the boundary between the Columbia Mountains and Highlands and the Southern Rocky Mountain Trench Ecoregions, at about elevation 1,040 m above sea level. Undisturbed areas around the Tailings Facilities consist of open stands of coniferous forest, dominated by Ponderosa pine with significant Douglas fir, western larch, and trembling aspen. Ground cover is predominantly grass and shrub species.

The area experiences warm summers with daytime high temperatures in July and August averaging over 25ºC, and occasionally exceeding 35ºC; and cool winters with daily minimum temperatures averaging –11ºC during December and January, and occasionally below –35ºC. The mean annual temperature is 5ºC.

May and June are the wettest months, receiving one-third of the annual rainfall. Over the winter, between November and March, most of the precipitation falls as snow, which represents about 42% of the mean annual precipitation of 409 mm (based on site climatic readings). The 1000 year rainfall values are predicted to be: 6 hour - 63 mm; and 24 hour - 92 mm. The Probable Maximum Precipitation (PMP) design values are: 6 hour - 158 mm; 24 hour - 202 mm; and 48 hour - 220 mm (Klohn Crippen, 1995). Lake evaporation for the area has been estimated to be approximately 460 mm, distributed from May through October. A frequency analysis of 16 years (1953 – 1976) of maximum hourly wind data from Kimberley Airport gave a 100-year return period value of 85 km/h and a 1000-year return period value of 100 km/h (Klohn Crippen, 2001).

The Maximum Credible Earthquake (MCE) for the area is a magnitude M6.5 event, with a Peak Ground Acceleration (PGA) of 0.45 g (Klohn Crippen, 2002).

The various tailings types are retained by the following containment dams and dykes as shown on Figure 1:

- Iron Pond;
- Old Iron Pond;
- Siliceous Ponds Nos. 1, 2, and 3;
- West and East Gypsum Ponds;
- Calcine Pond; and
- DWTP Sludge Pond.

The ARD Water Storage Balancing Pond (ARD Storage Pond) retains the acidic drainage from the surface workings and allows it to be fed to the DWTP on a seasonal campaign basis. The DWTP is located on the north bank of the St. Mary River; while the DWTP Sludge Pond is on an alluvial terrace just south of the St. Mary River, see Figure 1.

The tailings deposited in the Old Iron Pond, the Iron Pond and the Siliceous Ponds all contain elevated levels of reactive iron sulphide and heavy metals. These materials present a long term Acid Rock Drainage and metal leachate source. The gypsum tailings are also acidic but are non-reactive. Nevertheless, they contain elevated levels of fluoride and some heavy metals. The calcine is also non-reactive but would be considered a leachable toxic waste due to the presence of extractable lead in the presence of acetic acid.

DESIGN CRITERIA AND PHYSICAL STABILIZATION

The following table summarises the consequence of failure and likelihood categories for the Sullivan tailings dam/dykes. Only those structures with consequence of failure ranking (based on CDA 1999) of Low to High were assigned likelihood rankings.

Table 1 Tailings Dykes and Consequence Classification

IMPOUNDMENT AREA	TAILINGS DYKES	CONTROLLING FAILURE MODE	CONSEQUENCE OF FAILURE	LIKELIHOOD
Iron Pond	Iron Dyke	Emergency Storage Pond pump failure leading to discharge to environment	L	L
Old Iron Pond	Southwest Limb	dam overtops	VL	
	Southeast Limb	dam overtops	VL	
Siliceous Ponds	No. 1 Siliceous Dyke	Rainfall related failure or erosion	VL	
	No. 2 Siliceous Dyke	Rainfall related failure or erosion	VL	
	No. 3 Siliceous Dyke	Rainfall related failure or erosion	VL	
Gypsum Ponds	East Gypsum Dyke	Rainfall related failure or erosion	L-H	L
	West Gypsum Dyke	Rainfall related failure or erosion	L-H	L
	North East Gypsum Pond Dyke	Rainfall related failure or erosion	VL	
	Recycle Pond	Rainfall related failure or erosion	VL	
Calcine Pond	Calcine Dyke	Rainfall related failure or erosion	VL	
Sludge Pond	North Dyke	Capacity exceeded, dam overtops	L	L
	South Dyke	Capacity exceeded, dam overtops	L	L
ARD Storage Pond	North Dam	Seepage causing catastrophic failure	H	L
	South Dam	Seepage causing catastrophic failure	VH	N-L

Consequence Categories based on CDA (1999): VH – Very High; H – High; L – Low; VL – Very Low
Likelihood ratings: N – Negligible (need to exceed PMF or MCE); L – Low/Rare (once per 1000 years); M – Possible (once per 100 years)

Table 2 Summary of Geotechnical Design Criteria

PARAMETER	VALUE
Seismic Design	• M 6.5 PGA 0.45 g o Saturated tailings liquefies at 0.25 g.
Slope Stability • Static Safety Factor • Static Safety Factor Post Liquefaction • Pseudo-static Safety[1] Factor where no liquefaction is predicted	 1.5 1.1 1.15 using M6.5, k=0.1g

1. k is horizontal seismic coefficient.

Klohn Crippen have characterized materials in the Tailings Facilities with at least 24 different sets of material properties, ranging from previously liquefied low density gypsum tailings to native glacial till. Nine different types of tailings, with varying material properties, were identified (Klohn Crippen, 2002).

The "Guidelines for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia", Ministry of Energy and Mines, August 1998, recommend that, at closure, where consequences of failure are high, the minimum design criteria for dams should be the Maximum Credible Earthquake (MCE) and for water management structures should be the Probable Maximum Flood (PMF). For lower consequence structures, such as low consequence dykes and non-critical water conveyance structures, the 1000 year return period event has been used for design.

A minimum freeboard of 0.3 m has been provided for all channels and spillways to allow for standing waves, uncertainties in hydrology and hydraulic modelling, and wave run-up. For the purposes of water storage, in areas where ponding would occur, the volume of the 48 hour PMP (220 mm) was checked in addition to a 1000 year return period snowmelt (643 mm) volume at a maximum expected melt rate (30 mm/day). The ponds are designed to either, retain the PMP with a freeboard of 0.6 m, or safely release it.

REMEDIAL DESIGN AND CONSTRUCTION

Klohn Crippen began providing engineering solutions to the long-term physical stabilization of the tailings facilities in late 1991. A series of stabilization works, consisting primarily of slope flattening and toe berm installation, were constructed between 1992 and 2000, in concert with dam raises and other work required to keep up with operational requirements. The tailings ponds are intended to have dry covers on closure. A new ARD Storage Pond was constructed in 2001. Construction of spillways and drainage channels began in 2001 and is still on-going.

All mine water, and seepage collected from the waste dumps and the Tailings Facilities, are pumped to the ARD Storage Pond and then campaigned through the DWTP and discharged to the St. Mary River outside of the low flow period in the river (December through March). No acidic drainage or other water containing elevated concentrations of heavy metals is intentionally released to the environment. If excess water volumes require temporary storage between operating campaigns of the DWTP, some water storage capacity is available in the Emergency Storage Pond, located within the Iron Pond. This pond will only be used during unusual climatic conditions and will be pumped to a low level during each operating campaign of the DWTP.

<u>Water Management</u>

ARD management at the Kimberley Operations, involves the collection and treatment of mine drainage, contaminated groundwater, and seepage from tailing ponds and waste dumps. Eventually mine water from the underground workings will be pumped as required once the water level in the mine reaches the 3650 ft. level, through a HDPE pipe at the 3700 ft. portal which runs to the ARD Storage Pond. The ARD Storage Pond can be bypassed, with mine water going directly to the DWTP. The water from the waste dumps and the tailings seepage collection sumps is pumped, as required, to the ARD Storage Pond, which serves as a flow equalization basin, to facilitate operating campaigns at the DWTP. Bypass lines allow for temporary discharge of mine water and seepage water to an Emergency Storage Pond, located within the "Active" Iron Tailings Pond.

An emergency spillway has been provided for the ARD Storage Pond. This spillway will discharge to the Emergency Storage Pond and has a design flow value of 1 m^3/s. This is approximately 7 times the maximum expected monthly ARD and precipitation inflow of 8.24 m^3/minute, which was derived from water balance studies for design of the Pond.

To establish the Maximum Operating Level (MOL), in relation to the Dam Crest elevation, the following items were considered:

1. Freeboard allowance of 0.3 m;
2. Surcharge for design flow ("wet" year maximum monthly inflow) passing through the emergency spillway, which was estimated at 0.31 m^3/s, however, a more conservative design flow of 1 m^3/s was assumed. This resulted in a pond rise of 0.3 m with a 4 m wide broad-crested weir spillway;
3. The greater of the PMF plus the wave run-up associated with a 1:100 year wind event (0.3 m) or the wave run-up associated with a 1:1000 year wind event (0.35 m) on top of the MOL. This incorporates a flood storage allowance of 50,000 m^3, which is the expected volume generated by the 48 hour PMP of 220 mm, causing a pond rise of 0.6 m.

These calculations lead to the establishment of a combined allowance of 1.5 m from the MOL to the dam crest, ensuring that no acidic water will accidentally escape into the Emergency Storage Pond during any reasonably foreseeable climatic event.

Geotechnical Stabilization

The primary stabilization effort was expended on the ultimate "active" tailings pond (Iron Pond). This pond will continue to serve as an Emergency Storage Pond and thus must remain capable of being a water retaining structure after the closure cover is in place. To ensure long term physical stability, a toe berm/buttress, constructed of float rock, was installed along approximately 1 km of dyke length, beginning in 1992.

MONITORING

Physical stability monitoring is conducted through quarterly monitoring of over 105 piezometers plus monitoring wells, supplemented with an annual geotechnical inspection of the dams, which includes bi-annual reading of 4 inclinometers and 21 settlement gauges (Klohn Crippen, 2004). As part of the annual inspection, all spillways and drainage channels are checked to ensure they are free from blockages or defects in the riprap lining.

CONCLUSIONS

The Sullivan Mine tailings area contains a complex variety of tailings streams produced over a 90year operating life. Physical stabilization works have been implemented to ensure the long term stability of these structures to minimize the likelihood of any catastrophic failure. The dry cover system is designed to provide an end land use compatible with the local environment of grassland with various woody species. The seepage collection and pump back system to the ARD Storage Pond, in conjunction with campaign operations through the DWTP, ensure that contaminant loadings to the environment are minimized and adequately attenuated.

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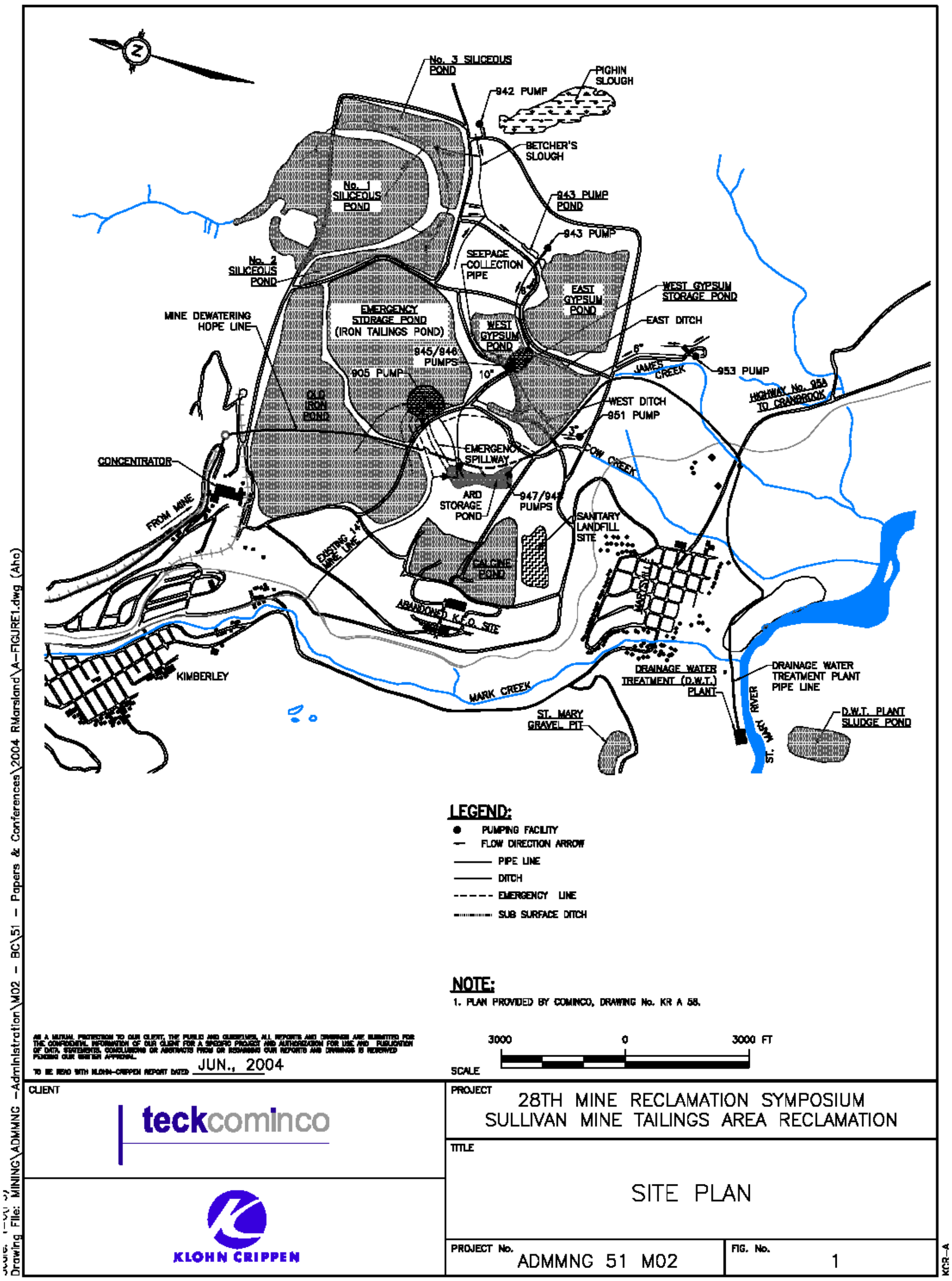

Figure 1 Site Plan