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Long-term post-closure surface water and groundwater risk management and subsequent water quality trends at the former Sullivan Mine, Canada

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Abstract

The former Sullivan Mine was one of the world's largest producers of lead, zinc and silver, officially closing in 2001 after 92 years of active production. The former mine and mill areas contain large impoundments of tailings, waste rock, and other process wastes as a result of historical mining processes. Environmental controls, site assessment and mitigation measures to manage and protect surface water and groundwater quality have been in place since the 1960s. Large-scale characterisation of the surface water and groundwater systems was initiated in the mid 1990s. At the same time, incremental efforts to assess and mitigate mining-related impacts to these resources commenced, including: waste impoundment covers, seepage collection systems, mine de-watering, pumping well networks; and groundwater interception barriers, trenches and sand drains. In addition to these mitigation measures, a comprehensive risk assessment was performed culminating in a site-wide Risk Management Plan with annual surface water and groundwater monitoring programs.

Long-term post-closure monitoring at a number of surface water and groundwater monitoring locations since 2001 have provided indicators of improving surface water and groundwater quality across both the former mine and mill areas. These long-term trends have confirmed predictions made through conceptual hydrogeological and geochemical models developed after closure. Monitoring in the tailings impoundments indicated loading to groundwater from acid rock drainage and metal leaching impacts in source areas has been reduced. Monitoring in downgradient areas suggested groundwater capture has been successful in reducing off-site loading. Surface water quality has improved in receiving creeks and rivers. In addition to mitigation measures implemented at the site, natural attenuation mechanisms originally predicted by geochemical modelling have also been confirmed by long-term trends in groundwater quality.

The phased implementation of mitigation measures combined with targeted site assessment and a carefully defined Risk Management Plan with long-term monitoring have provided a cost-effective and successful solution for post-closure management of surface water and groundwater. Additional site assessment, mitigation measures and improvements to existing environmental controls will continue to be implemented on an as needed basis. Further improvements to groundwater and surface water quality are expected to be observed with planned long-term surface water and groundwater monitoring.

1 Introduction

The Sullivan underground lead-zinc-silver mine is located near Kimberley, British Columbia, Canada (Figure 1). The mine operated for 92 years from 1909 to 2001 and was once the world's largest producer of lead and zinc, producing 8 million and 9 million tonnes, respectively. The orebody is considered to be a classic sedimentary-exhalative massive sulphide deposit, with approximately 150 million tonnes of ore produced over its lifetime.

The former mine and mill areas have significant long-term environmental concerns associated with acid rock drainage (ARD). Initial reclamation and remediation began in the late 1960s, with large-scale characterisation of surface water and groundwater systems initiated in the 1990s that were ultimately used to develop hydrogeological and geochemical models of the site. With much of the data collected prior to mine closure and completion of the reclamation activities, long-term monitoring as part of the Risk Management Plan (RMP) enabled evaluation of mitigation measures and model predictions.

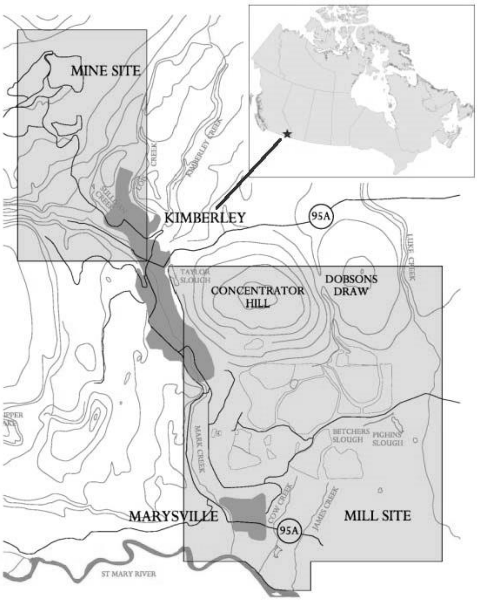

Figure 1 Key map of Sullivan mine site

2 Site history and background

The Sullivan mine was owned and operated by Teck Resources Ltd. (Teck) and its predecessor companies, with the underground mine beginning operations in 1909. A small open pit also operated for a brief period of time. In 1923, a concentrator was constructed remote from the mine site as large, flat surfaces were required for the placement of tailings impoundments. In addition to the concentrator and tailings impoundments, subsidiary industrial processes and buildings operated for a short period of the mine life and included fertiliser, iron and steel plants.

The Sullivan lands are divided into two distinct geographic areas (Figure 1): the former mine is immediately north of the City of Kimberley and the concentrator, subsidiary industrial processes and tailings ponds (referred to hereafter as the mill site), are located south of Kimberley, approximately 6 km from the mine.

2.1 Environmental concerns associated with historical operations

The main environmental concern associated with the former Sullivan mine and historical operations is ARD resulting from oxidation of sulphide minerals in the former mine workings, waste rock piles and tailings impoundments. The orebody averaged 6% lead, 5.7% zinc, and 24.8% iron and consisted mainly of pyrrhotite and pyrite (7:3 ratio) as the most abundant sulphide minerals with galena and sphalerite as the principal ore minerals.

Water impacted by ARD has been found in both surface water and groundwater near the former industrial areas. Constituents of concern include cadmium, zinc, arsenic, iron and lead. High metal concentrations have also been found in soil and vegetation in the land surrounding the mine and concentrator areas. The main historical areas of environmental concern are discussed below.

2.1.1 Mine site

Waste rock from underground mining consisting mainly of pyrrhotite and pyrite was deposited in three waste dumps: the North and South Waste Dumps on either side of Mark Creek in the Lower Mine Yard (LMY) and the No. 1 Shaft Waste Dump. The open pit waste rock, composed of overburden and development rock, was deposited in a large single dump surrounding the open pit. A total of 9.75 million tonnes of waste rock was stockpiled by the end of the mine life. From 2000 to 2005, during closure of the mine, the waste rock was moved back into the open pit.

2.1.2 Mill site

The Sullivan Concentrator produced waste by-products of float rock and tailings. Float rock, a coarse by-product from the ore separation by heavy media production (i.e. flotation process), was generated from 1947 until closure and was stockpiled at the concentrator. The tailings ponds were located immediately adjacent to the southeast side of the concentrator. The tailings are acid generating, with iron and sulphur percentages ranging between 19–47% and 19–30% by weight, respectively, depending on time of deposition. Generally, waste dumps, float piles and tailings ponds were located close to operations. At the time, future adverse impacts on the environment were not anticipated.

In 1952, Teck developed a fertiliser operation which required the Sullivan Concentrator to produce iron concentrate. Phosphogypsum and iron calcine (oxide) were by-products of fertiliser production. Initially the gypsum was discharged into the St. Mary River. This practice ended in 1968 when Teck decided to place gypsum into storage ponds to minimise the impact on the receiving waters. The impoundments for the gypsum were constructed further east of the iron calcine ponds and south of the concentrator tailings ponds (Figure 2). The production of ammonium phosphate fertilizer became uneconomical and ceased in 1987. Waste by-products left in storage include 7.0 million tonnes of phosphogypsum and 3.4 tonnes of iron oxide. The main environmental concern associated with Fertilizer Plant by-products is fluoride and sulphate. The porewater is very acidic, with extremely high levels of fluoride, ammonia, sulphate, phosphorus and metals; particularly aluminium, iron, manganese and zinc.

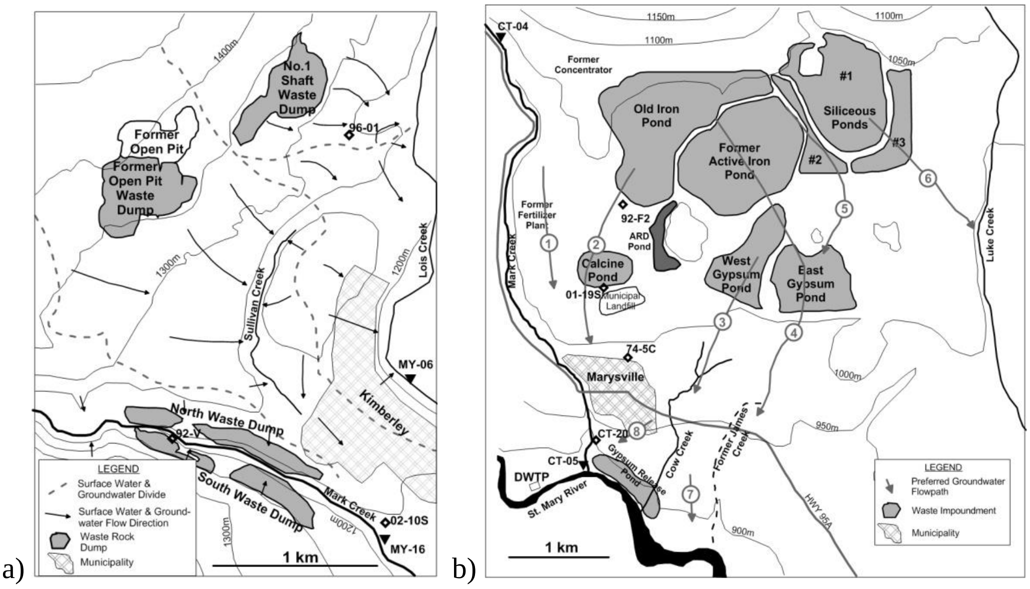

Figure 2 Sullivan plans showing surface topography, waste impoundments, and groundwater flow; a) mine site; b) mill site

3 Site characterisation

Site characterisation work, focusing on surficial geology and groundwater flow, began in 1974 with investigation into seepage from the calcine and gypsum ponds. Large scale site characterisation commenced in the early 1990s, and has continued to the present day. Over the years, the site characterisation has employed the following: review of mineral exploration records; test pitting; borehole drilling; installation of monitoring wells and water wells; electromagnetic surveys; seismic surveys; flow measurement in springs, creeks and the St. Mary River; and chemical analysis of soil, groundwater and surface water samples.

3.1 Geology and hydrogeology

In simplified terms, the surficial geology in the area consists of glacial drift that rests upon the bedrock surface. The drift consists of a very dense silty gravel basal till unit, which is overlain by glacial outwash and ablation till consisting of clay, silt, sand and gravel. Both surface water and groundwater flow patterns in the area have been shaped by the bedrock topography due to large permeability differences between till/bedrock and other, more permeable surficial deposits. The majority of groundwater flow occurs through sand and gravel deposits present within and on top of the till, and generally follows buried sub-basins defined by the combined structure of the bedrock and till.

3.1.2 Mine site

In the LMY, the steep-sided Mark Creek valley has been incised approximately 70 m into bedrock. Valley floor fluvial and glaciofluvial deposits consist of interbedded sands and gravels with fine sand and silt units. There are two aquifers beneath the creek, shallow and deep, separated by a finer-grained sand and silt unit.

Groundwater flow in the mine area is divided into four discrete drainages that discharge into three different creeks (Figure 2). Groundwater downgradient of the No. 1 Shaft Waste Dump and former open pit waste dumps discharges from springs into Lois Creek and Sullivan Creek, respectively. Groundwater in the LMY flows laterally under the north and south waste dumps into shallow and deep sand and gravel aquifers under Mark Creek. A groundwater discharge area from the deep aquifer is present at the east end of the LMY due to a dipping interbedded silt unit.

3.1.3 Mill site

Extensive characterisation and delineation of the bedrock/till topography identified eight distinct groundwater flowpaths (Figure 2). Six flowpaths drain the tailings and gypsum pond source areas; flowpaths 1 through 5 ultimately discharge into the St. Mary River and Mark Creek via flowpaths 7 and 8.

4 Geochemical modelling at the mill site

Interpreted groundwater travel times to receiving water bodies at the mill site were relatively long and as such geochemical modelling was undertaken to predict geochemical evolution of ARD-impacted groundwater along certain flowpaths. A number of computer simulations were completed to assess mineral phases that may limit the solubility of major ions and metals in groundwater and to evaluate the future buffering capacity of downgradient aquifers. Results from the modelling were used to predict future concentrations of parameters of concern that may affect aquatic receptors in support of a human health and ecological risk assessment (HH/EcoRA), as well as to provide a broad timeframe for the prioritisation and implementation of mitigation measures.

4.1 Model calibration and buffering capacity prediction

Flowpaths 2, 4 and 6 were chosen for the simulations as they differed relatively significantly in source and seepage chemistry. Geochemical speciation modelling with 1-D coupled contaminant transport was performed in PHREEQC; the model was calibrated with water chemistry data in order to match the observed migration of iron and sulphate and limited migration of metals and fluoride in the respective flowpaths.

The model indicated that the observed migration of iron and sulphate and dramatic declines in a number of metals and fluoride along each groundwater flowpath can be simulated by the dissolution of carbonate minerals (i.e. calcite) and precipitation of a number of secondary minerals in the aquifer. Using total inorganic carbon values from representative downgradient aquifer material, the model predicted it will take over 480 years (from 2004) to consume the carbonate aquifer buffering capacity between the waste impoundments and the main downgradient aquatic receptor i.e. St. Mary River. Additional conservatism was applied to the model using the lowest carbonate content and maximum groundwater velocity which resulted in travel times of 150 to 480 years (from 2004) for the acid front to reach the receiving environment.

During the modelling exercise, other buffering minerals such as aluminosilicates were considered to be important in attenuating the ARD generated by upgradient source areas; however, there were insufficient data for modelling and as such aluminosilicate buffering could not be predicted and was not included in any travel time calculations or risk management decisions. Aluminosilicate buffering is considered to occur where calcite is not present (e.g. bedrock or within the tailings impoundments) and it is anticipated to increase in importance with time once the carbonate buffering capacity becomes depleted.

5 Mitigation measures and long-term water management

Concurrent with site characterisation and modelling efforts, a number of environmental controls and mitigation measures have been implemented at the mine and mill sites since the 1960s. Mitigation measures have been incrementally implemented over this time through proper local and regional site characterisation, resulting in effective long-term surface water and groundwater management. For example, the long timeframe afforded by the buffering capacity of downgradient aquifers at the mill site allowed for a phased approach to water management and the prioritisation and phased implementation of mitigation measures.

The ultimate goal of long-term water management at both the former mine and mill sites is to reduce downgradient loading of contaminants associated with historical activities and comply with applicable regulations. To this end, the following broad categories were used for implementation of mitigation measures and environmental controls:

- Source control and reduction: reduction of geochemical and hydraulic loadings from the source areas to downgradient aquifers and receiving water bodies.
- Surface water and groundwater diversion: diversion of surface water or interception of ARD-impacted groundwater before discharge to the receiving environment.
- Risk assessment: assessment of the risks to downgradient human and ecological health.
- Risk management: incorporation of the above into a long-term surface water and groundwater management strategy.

5.1 Environmental controls and mitigation measures

Beginning in the 1960s, Teck started planning measures to protect the environment. Recycle water systems were developed to minimise the amount of fertilizer plant effluent being discharged to Mark Creek and the amount of tailings ponds effluent discharged to Cow and James Creek. In 1979, Teck commissioned the Drainage Water Treatment Plant (DWTP) to treat acidic waters from the mine, tailings decant water from the concentrator and seepage water collected downgradient of the tailings and gypsum ponds.

In 1991, at the request of the BC Ministry of Energy and Mines, Teck developed a comprehensive Decommissioning and Closure Plan and presented it to a public forum for review. The review and subsequent public meetings continued from 1992 until reclamation was considered complete in 2008. The DWTP, already operating by this time, was the cornerstone of these activities. A major aspect of decommissioning of the waste impoundments and rock dumps was to minimise the amount of water contacting the waste, as it would ultimately have to be treated at the DWTP. As such, site characterisation work focused on identifying the main groundwater flowpaths impacted with ARD, with mitigation measures focused on water interception and collection for treatment at the DWTP.

5.1.1 Source control

As part of the decommissioning, an engineered cover system for the waste impoundments was designed from nearly two decades of research and investigation using locally available materials on sites representative of those to be reclaimed (Gardiner et al., 1997).The cover systems were designed to provide adequate soil to sustain vegetation, reduce water infiltration and oxygen ingress to the tailings, and prevent upward migration of contaminants from contacting the growth media. The growth media and infiltration barrier consist of a 0.6 m thick layer of compacted till overlying a 0.6–1.4 m layer of float rock which creates a capillary barrier to reduce upward movement of contaminants. The soil covers on tailings and gypsum ponds were completed by 2005.

A simpler soil cover was implemented on waste dumps and plant sites, which included re-sloping and capping with up to one metre of till. The reclaimed impoundments and waste dumps were revegetated with grasses and legumes (Przeczek, 2004).

5.1.2 Water diversion

Numerous mitigation measures have been undertaken to reduce the migration of impacted groundwater and prevent its discharge into watercourses, these included, but are not limited to:

- Toe drain around the No. 1 Shaft Waste Dump keyed into till to intercept ARD-impacted water.
- A groundwater funnel system and collection system in Sullivan Creek, which receives ARD-impacted water from groundwater from the open pit waste dump.
- A section of Mark Creek was moved to a lined flume in the LMY to protect it from seepage from waste dumps. The former channel was backfilled with coarse rock, and operates as a drain to intercept impacted groundwater.
- Vertical drains were installed between the shallow and deep aquifers in the LMY to facilitate groundwater capture. A network of water wells intercepts groundwater before discharge into the creek and water quality at key sites is monitored continuously to determine when interception pumping rates need to be changed.
- A network of ditches, sumps and pumps installed to intercept groundwater around the tailings ponds.
- Interception ditches were keyed into the till/bedrock surface immediately downgradient of the gypsum ponds. The interception ditches were completed as the impacted groundwater was shallow enough to collect across flowpaths 3, 4, 5 and 6.
- A mine dewatering system to maintain the underground workings as a groundwater sink.

The water collected from all collection systems is stored in the ARD Pond, which has the capacity to allow the DWTP to operate on a biannual campaign basis.

5.1.3 Remediation and risk assessment

Independent environmental studies were conducted as a requirement of the BC Ministry of Environment's Contaminated Sites Regulation. As a result, contaminants around the plant operating areas were assessed, excavated, and consolidated within permitted impoundments; this includes soils contaminated with metals or process reagents and any hydrocarbon contamination. Any remaining contaminants have been assessed under the HH/EcoRA and included in the long-term monitoring plan for the site (Higgins et al., 2004).

5.2 Risk management plan (RMP)

The risk management plan (RMP) is the primary tool that is used to guide the long-term environmental management of the site. The purpose of the RMP is twofold: 1) to ensure that future activities do not pose unacceptable risks to persons spending time at the site or to the environment; and 2) to monitor and manage environmental conditions at the site.

The first purpose was achieved by establishing a framework for action that will be taken should certain "trigger levels" for surface water quality, groundwater quality, vegetation performance and receiving environment testing is exceeded. The surface and groundwater quality "trigger levels" are based on exceedances, maximum concentrations within 5 years, and/or rising trends over 3 years which would trigger additional investigation or corrective action. The second purpose was achieved by linking the RMP to the requirements of the Sullivan's reclamation permit issued under the British Columbia Mines Act.

6 Results and long-term trends

Teck operates a water monitoring program at Sullivan that includes 105 groundwater sites and 18 surface water sites as part of the RMP. As can be expected on a site with a number of sizable sources spread over a large mountainous area with complex geology and hydrogeology, trends at these monitoring stations were variable due to preferential groundwater flowpaths; however, water quality improvements from mitigation measures are observed at a number of locations and are consistent with hydrogeological and geochemical conceptual models established during site characterisation work.

Water quality monitoring results from a few representative areas are presented here to provide examples of observed long-term trends. Although there are many parameters that are elevated in the mine and mill areas (i.e. sulphate, acidity and metals, particularly zinc and cadmium), previous work indicates that zinc is an appropriate indicator for loading trends in the mine site, and sulphate as the primary indicator for the mill site. Figures 3 and 4 are cartoon illustrations of the mine and mill sites with concentration and loading trends for indicator parameters zinc and sulphate. It is noted that Figure 3 time series use a logarithmic scale to display order of magnitude changes; this visually reduces seasonal fluctuations and smooth out trendlines.

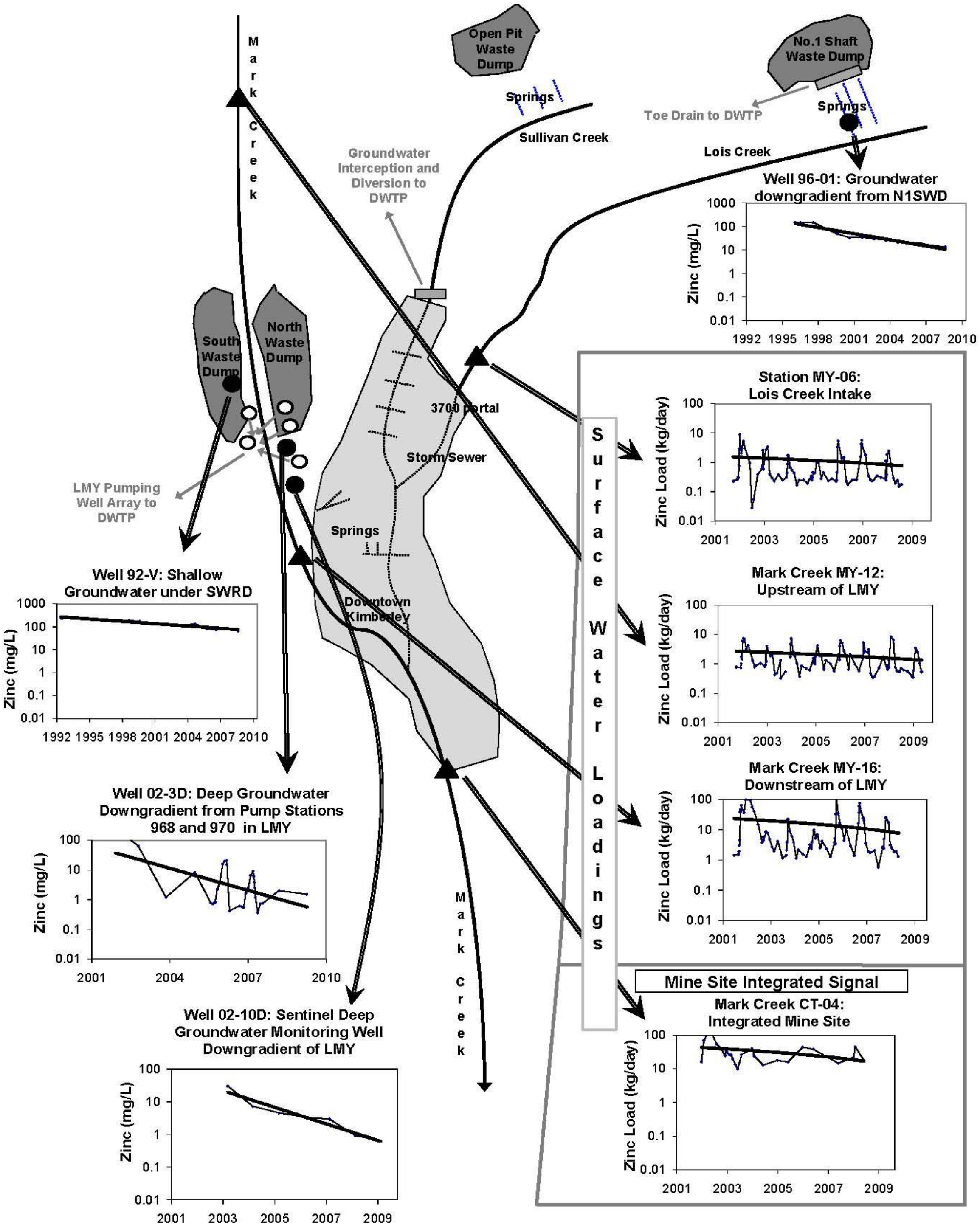

Figure 3 **Time series of zinc concentrations in selected groundwater monitoring wells and zinc surface water loadings in selected receiving water bodies at the former mine site**

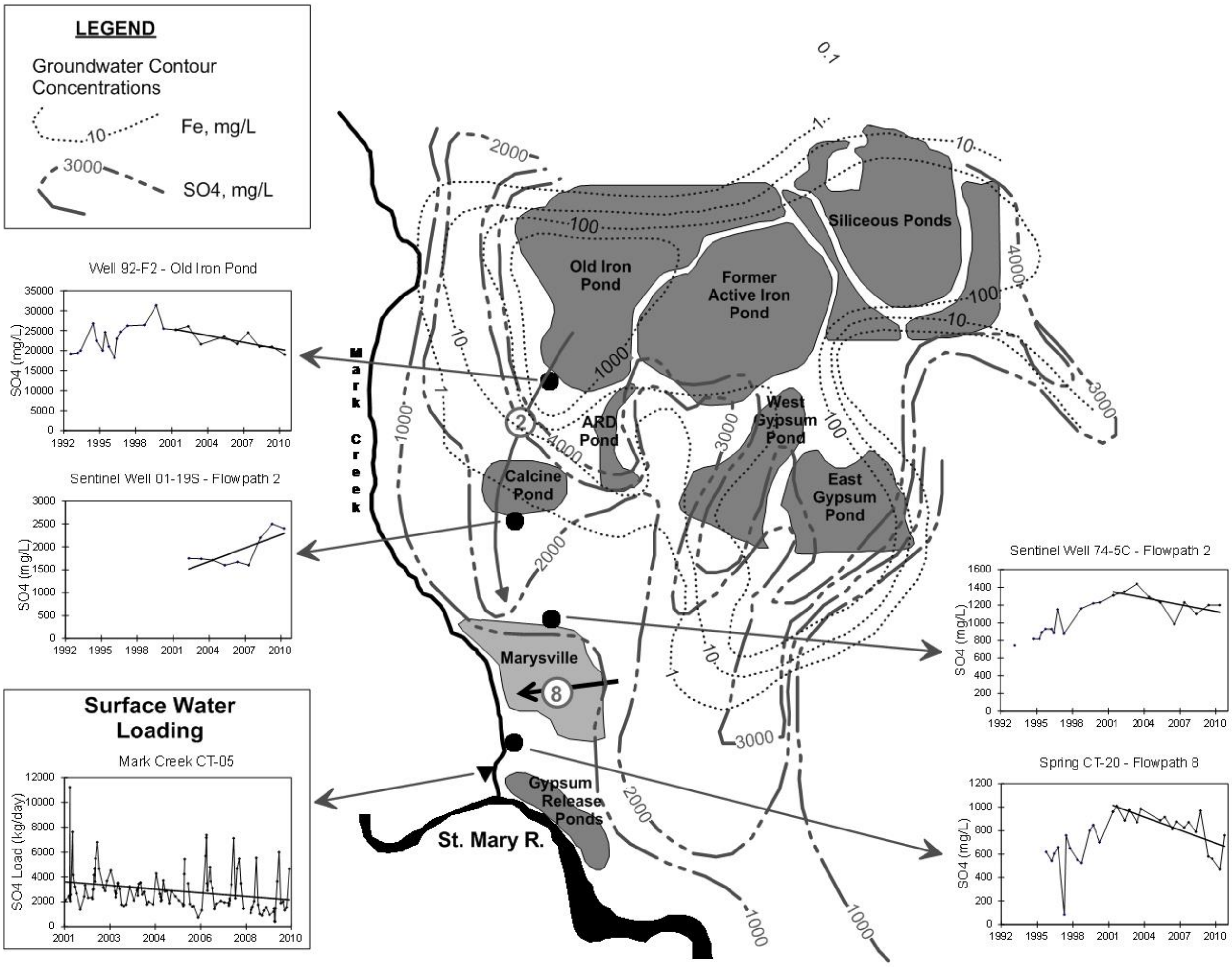

Figure 4 Time series of sulphate concentrations in selected groundwater monitoring wells and sulphate surface water loadings in selected receiving water bodies at the mill site. Contours of iron and sulphate concentrations illustrate large spatial differences

6.1 Mine site

6.1.1 No. 1 shaft waste dump

In 1995, Teck constructed a ditch around the toe of the No. 1 Shaft Waste Dump to intercept ARD emanating from the waste rock. Well 96-01 is one of several monitoring wells sampled annually downgradient of the waste rock, and is completed in a sand and gravel unit that is hydraulically connected to the source area. Groundwater discharges into nearby Lois Creek, which is monitored by location MY-06. The graphs of zinc concentration at 96-01 and zinc loading at MY-06 shown in Figure 3 illustrate the long-term trend of improving water quality that is occurring. The improving concentrations of sulphate and other metals have also been observed. The results observed at the No. 1 Shaft Waste Dump demonstrate the effectiveness of the simple, well-constructed interception ditch.

6.1.2 Lower mine yard

Since the mid 1990s, groundwater and surface water quality in the LMY have been controlled by interception wells that capture groundwater discharge impacted by ARD from the adjacent waste rock dumps. In 2002, breakthrough of ARD into Mark Creek was observed and follow-up site investigations concluded the buffering capacity of the deep aquifer had been exhausted. Additional ARD loading to the deep aquifer from a significant freshet as well as the installation of the vertical sand drains had resulted in the migration of the acid front to a section of the creek. Additional interception wells were installed later that year to capture the impacted groundwater and Teck now operates the groundwater interception system in accordance with the RMP and does not rely on formation buffering of ARD as a control measure.

As shown in Figure 3, the steady reductions of zinc concentrations in monitoring wells 92-V (shallow well adjacent to the south waste rock dump), 02–3D (deep well located within the pumping array) and 02–10D (sentinel deep monitoring well for the valley aquifer) demonstrate the long-term improvement in groundwater quality that has resulted from mitigation measures implemented in the LMY.

In addition to groundwater quality improvement in the LMY, surface water quality and loadings in Mark Creek have improved since post-closure monitoring began in 2001 (Figure 3). The integrated mine site signal indicated by surface water monitoring station CT-04 (located downstream of the LMY and discharge from Lois Creek), has shown consistent improvements in estimated loading of zinc since 2001. The improving concentrations of sulphate and other metals have also been observed.

6.2 Mill site flowpath 2

Since cessation of tailings deposition in 2001 and placement of the engineered covers in the source areas, oxidation of tailings and thus ARD has diminished in the tailings source areas. This is demonstrated by decreasing sulphate concentrations in monitoring well 92-F2, located just downgradient of the Old Iron Pond as shown in Figure 4. Other indicator parameters (e.g. iron, pH) in this well have stabilised and even improved over this time and also suggest a reduction in the ARD load.

As shown in Figure 4, groundwater in wells downgradient of source areas exhibited more variable trends for a number of geochemical indicators, indicating complex groundwater flowpaths. Along more permeable flowpaths (e.g. 74–5C and CT-20), concentrations of sulphate and other parameters are decreasing, as a result of the reduced loading from the tailings. Along less permeable pathways (e.g. 01-19S), concentrations of sulphate have been increasing in a number of monitoring wells since 2001, suggesting the relatively non-retarded sulphate plume from ARD impacts is continuing to migrate. Estimated surface water loading in Mark Creek (at CT-05) has been decreasing steadily since cessation of tailings deposition in 2001 and demonstrates the significant role of the high permeability groundwater flowpaths to surface water quality.

6.3 Flowpaths 1–8: natural attenuation

Based on the geochemical modelling results, carbonate buffering was demonstrated to be an important natural attenuation mechanism which would be evidenced by large decreases of iron and secondary mineral formations of siderite and ferrihydrite. Verification that carbonate buffering is occurring in the field are the significant decreases in iron concentrations in each flowpath (Figure 4). By comparison, the relatively conservative sulphate has migrated much further in all of the flowpaths. Indirect evidence of the carbonate buffering is also provided by a relatively strong positive correlation between long-term trends of calcium and sulphate concentrations observed in the majority of wells in groundwater flowpaths 1 to 8 over the monitoring period. Predicted secondary mineral assemblages were not verified in the field, but were inferred by source and downgradient geochemical trends.

The duration of carbonate buffering (e.g. calcite) was estimated by the geochemical model to be between 150 to 480 years. This estimate was considered to be conservative, as the model did not take into account reductions in hydraulic loading from the installation of a cover in the impoundments, surface water and groundwater diversion, or dispersion, dilution and mixing along the groundwater flowpath. The post-closure geochemical evidence displayed by long-term trends confirm that buffering mechanisms exist, and along with reductions in hydraulic and geochemical loading (i.e. the covers will also reduce sulphide oxidation), that the lifespan of this calcite buffering should extend beyond original estimates.

7 Conclusions

The former Sullivan mine and mill areas have significant long-term environmental concerns associated with ARD from oxidation of sulphide minerals in the former mine workings, waste rock piles and tailings impoundments. Extensive characterisation of site geology and hydrogeology identified distinct preferential groundwater flowpaths with discrete seepage areas and discharges to receiving surface water bodies. Geochemical modelling at the mill site was conducted to determine groundwater travel times to predict geochemical evolution of ARD-impacted groundwater along certain flowpaths. Results from modelling were used to predict future concentrations of parameters of concern that may affect aquatic receptors in support a human health and ecological risk assessment (HH/EcoRA), as well as to provide a broad timeframe for the prioritisation and implementation of mitigation measures.

Environmental controls were incrementally implemented to ultimately reduce downgradient loading of contaminants associated with the historical activities. The mitigation measures and environment controls at the mine and mill sites included source control, water diversion, remediation and risk assessment. To ensure that the environmental controls remain effective at the site, a risk management plan has been developed for the long-term environmental management of the site. The main RMP objectives for groundwater and surface water sampling programs are to:

- Detect any unexpected changes in water quality that would need to be assessed and/or mitigated.
- Assess the long-term improvements in groundwater and surface water quality resulting from the mine closure, site reclamation and mitigation programs in order to determine when specific mitigation measures may be discontinued.

The post reclamation monitoring and sampling program conducted demonstrates that the mitigative measures implemented have significantly reduced metal concentrations and ARD loadings from historical levels at both the mine and mill areas. In addition, the natural attenuation mechanisms originally predicted by geochemical modelling have also been confirmed by long-term groundwater trends in groundwater quality. Further improvements to groundwater and surface water are expected to be observed with planned long-term surface water and groundwater monitoring; however, the RMP will identify the need for future site assessment and/or mitigation measures as required.

References

Gardiner, R.T., Dawson, B.B. and Gibson, G.G. (1997) Application of ARD abatement technology in reclamation of tailings ponds at Cominco Ltd., Proceedings 4th International Conference on Acid Rock Drainage, Vancouver, June 1997.

Higgins, C., Wilson, R., Sandstrom, N., Dawson, B., Mann, G., Allard, P. and Baker, R. (2004) Post Closure Human Health and Ecological Risk Assessment at Teck Cominco's Kimberley Operations, BC Overview of Regulatory Process and Findings of the Problem Formulation, Proceedings from 2004 Technical and Research Committee on Reclamation (TRCR) Annual Mine Reclamation Symposium, June 23, Cranbrook, British Columbia, Canada.

Przeczek, J. (2004) Review of the Reclamation Research Program at Teck Cominco's Sullivan Mine at Kimberley, BC, Proceedings 2004 TRCR Annual Mine Reclamation Symposium, June 23, Cranbrook, British Columbia, Canada.