

**INNOVATIVE DESIGN AND DEEP TRENCH EXCAVATION FOR A GROUNDWATER
COLLECTION IMPROVEMENT PROJECT: PART 2 OF 2 CASE STUDY FROM THE
FORMER SULLIVAN MINE, KIMBERLEY BC**

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ABSTRACT

SNC-Lavalin Inc. conducted detailed hydrogeological investigations and subsequent remedial activities to assess and improve the collection of seepage of acid rock drainage from two large waste rock dumps located in the Mark Creek valley, in what is called the Lower Mine Yard at Teck's former Sullivan Mine Operations in Kimberley, British Columbia.

A remedial options analysis was completed to assess potential long-term solutions, ranging from source removal to in-situ passive treatment. A detailed review of the options included a series of pre-screening questions, evaluation using a project-specific scoring matrix, and a series of technical workshops. The resulting preferred option was an interception trench system with a down gradient physical barrier. The design employed passive gravity flow to a central collection vault followed by pumping into nearby infrastructure for conveyance to an existing treatment facility. SNC-Lavalin developed the design basis and detailed design for installation of a 600-metre long interception trench that consisted of perforated drain pipes and a low permeability liner installed up to approximately six to ten metres below ground surface.

Phase I construction of the system for the South Waste Rock Dump occurred between November 2016 and May 2017. Construction of Phase II commenced in April 2019 and was substantially completed by end of July 2019. Based on the Performance of Phase I, the same design was adapted to upgrade an existing seepage collection system along the toe of the North Waste Rock Dump. Trench stability, especially in areas with higher groundwater elevations and inflows, was a primary concern for both constructability and worker safety. This was addressed by the use of trench box shoring systems, limiting the lengths of open trench, and adapting liner installation methods to different ground conditions encountered. Potential for low oxygen conditions required continuous air monitoring and ventilation to ensure a safe work environment. The potential for worker exposure to low oxygen conditions during system operation and maintenance was mitigated through building and pump system design that eliminated confined space entry for routine inspections.

Results of a performance monitoring program indicate that the system is functioning as designed to collect acid rock drainage affected shallow groundwater. Seepage into Mark Creek has not been observed since upgrades have been completed.

Key Words: Groundwater, Interception, Trench, Remediation, Acid Rock Drainage, Earthworks

PREAMBLE

This paper is Part Two of a two-part case study. Part One was titled *Hydrogeological Assessment for Mitigation of Groundwater Discharge to a Creek in a Confined Valley*. A brief overview is provided below however readers of this Part Two should refer to Part One for a more detail summary of site history and background, mine reclamation activities, geology and hydrogeology.

INTRODUCTION

The former Sullivan underground zinc-lead-silver mine is located near Kimberley British Columbia, Canada, approximately 500 km east of Vancouver, B.C. The mine operated for 92 years from 1909 to 2001 and was once the world's largest producer of zinc and lead, producing 8 million and 9 million tonnes, respectively. Two large waste rock dumps exist on the incised Mark Creek valley, referred to as the North Waste Rock Dump and South Waste Rock Dump, in what is called the Lower Mine Yard. This area underwent remediation in the 1990s, with an engineered and vegetated cover and partial collection of seepage for treatment.

During reclamation activities, shallow groundwater seepage from the dumps to Mark Creek was identified to be a significant issue. In order to isolate the stream from contaminated seepage, a portion of the creek was relocated to a concrete flume upstream of the newly consolidate dump location to a new rip-rap lined channel located further from the toes of the newly regraded dumps. To further control seepage from the North Waste Rock Dump, a 490 m section of a lined flow-through rock drain and collection point seepage collection system, referred to as the North Trench, was installed within portions of the historical Mark Creek channel (i.e., the historical channel was used for the drain location). The drain and collection point were located up to 20 m from the toe of the current North Waste Rock Dump footprint, and except for a 30 m section at the eastern limit and collection point, were buried below the reclaimed dump surface during re contouring and cover placement. For the South Waste Rock Dump, shallow seepage was redirected to the acid rock drainage impacted deeper aquifer in 1999 and 2000 by a series of vertical sand drains at the toe of the dump. Hydraulic interception in the deeper aquifer was achieved by an array of pumping wells which transfer water to the mine's Drainage Water Treatment Plant.

In April 2012, seepage thought to be from the shallow aquifer was observed in Mark Creek downgradient of the North Waste Rock Dump (i.e. North Trench) and the South Waste Rock Dump. The identification of seepage in 2012 prompted additional investigation and implementation of a series of temporary mitigation measures. Mitigation measures for the North Trench included construction of a new pump station (PS963) and replacement of plugged drain rock to improve the hydraulic connection near the trench terminus at PS963. Mitigation measures for the South Waste Rock Dump included a series of temporary pumping wells in the shallow aquifer. Based on follow-up monitoring results, it was inferred that improving the hydraulic connection at the terminus of the North Trench was effective, and a plan to continue monitoring was put in place. Monitoring results indicated that temporary pumping wells in the shallow aquifer proved to be effective, however, permanent control measures were required to control seepage for the long-term.

REMEDIAL OPTIONS REVIEW

A remedial options analysis was completed to assess potential long-term solutions to preventing acid rock drainage originating from the South Waste Rock Dump from entering Mark Creek. Twelve options were separated into four groups: institutional control, source control, in-situ remediation, and hydraulic control and treatment. Conceptual engineering design was defined for each option. Each option was evaluated against a series of pre-screening questions and a review was conducted in a workshop setting with Teck.

During the pre-screening review, five of the conceptual options were not considered to warrant further evaluation. The rationale for those options ranged from a case where an identified option did not address overall objectives (no physical action – risk management); to options where there was an unacceptable uncertainty for construction and performance (i.e. stabilize material in south waste dump) and these options were removed from further consideration.

The remaining options were evaluated using a project-specific scoring matrix to highlight the significant strengths and weaknesses of the potential technologies during the implementation and operations, and for use in a scoring process. The parameters were then scored and then multiplied by a weighting factor that was jointly developed by the Teck/SNC-Lavalin team for each parameter.

REGULATORY PROCESS AND STAKEHOLDER COMMUNICATION

Remedial and reclamation work at the Sullivan mine is regulated by the Ministry of Energy, Mines and Petroleum Resource (EMPR) and BC Ministry of Environment and Climate Change Strategy (ENV). EMPR Reclamation permit M-74 exists for the Sullivan mine and contains requirements for environmental actions, some of which are guided by ENV requirements and expectations. Additionally, the ENV is involved with the Sullivan mine closure and risk management through review of site investigation and risk assessment activities conducted in general accordance with requirements outlined in the *Contaminated Sites Regulation*¹ (CSR), and through administration of a discharge permit PE-189 for Teck’s seepage collection system and drainage water treatment plant.

EMPR and ENV (Land Remediation Section and/or Environmental Protection) were consulted on the regulatory process in 2014, on remediation options in 2015, and on the detailed design and technical specifications for preventing acid rock drainage originating from the South Waste Rock Dump from entering Mark Creek. EMPR and ENV were further consulted in 2018 and 2019 regarding a major design change (described below), and regarding further upgrades to the North Trench. The ENV and EMPR permit amendment process was administered separately for each trench project and ranged in duration from four to six months. For stakeholder communication, Teck communicated directly with First Nations and City of Kimberley on the project through a series of meetings, emails and/or phone calls and issued project notifications in local newspapers.

GROUNDWATER COLLECTION SYSTEM DESIGN

Based on the options analysis, the preferred option identified for the South Waste Rock Dump was an interception trench system with downgradient barrier, which employed passive gravity flow to a central collection vault (South Trench) followed by pumping into nearby infrastructure for conveyance to an existing treatment facility. In 2015 and 2016, SNC-Lavalin developed a detailed design for the South Trench. In April 2017, further acidic groundwater discharge from the North Trench was identified near where discharge occurred in April 2012. Based on performance of the South Trench to mitigate a similar issue and the configuration of Teck’s existing seepage collection network, the concept of upgrading a section of interception trench and collection point was selected to resolve further discharge for the North Trench. Due to the similarity in South Trench and North Trench upgrade designs, we present a combined description of both designs below.

¹ *Contaminated Sites Regulation (CSR), B.C. Reg. 375/96, including amendments up to B.C. Reg. 13/2019, January 24, 2019.*

Trench Design

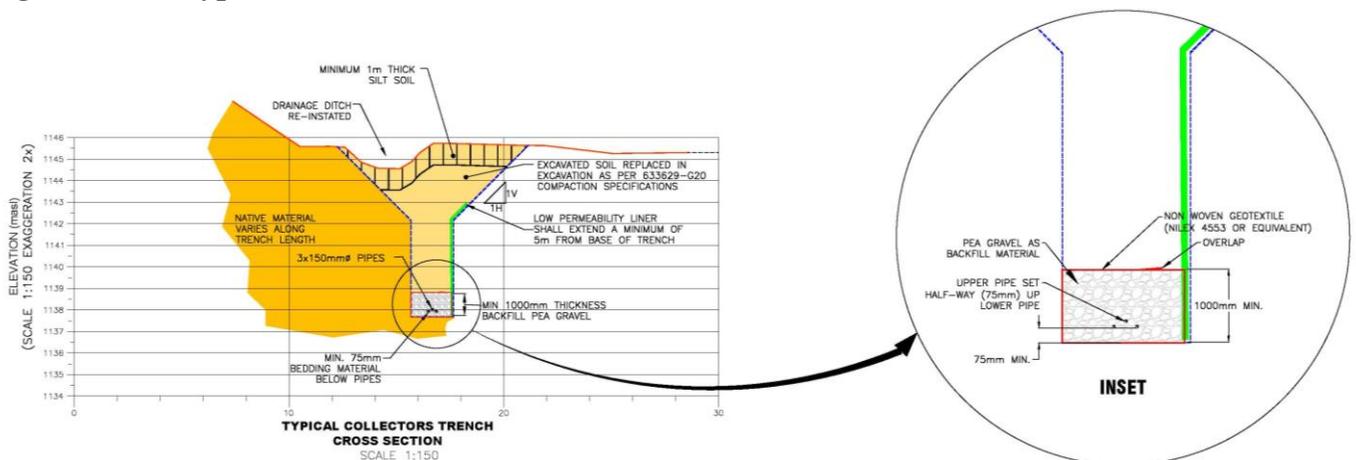
The trench design was developed to meet pre-established design and performance objectives, as well as to consider operational requirements (monitoring and sampling, pump control alarms), outage and reliability requirements (connection of discharge to existing drainage water treatment plant, power failure) and maintenance requirements to increase life expectancy.

The design basis for trench inflow was calculated using hydraulic conductivities of the different hydrostratigraphic units identified along the length of each trench. Using aquifer thicknesses, assumed sections of the trench, estimated hydraulic conductivities and calculated horizontal hydraulic gradients, the groundwater flux and volumetric discharge were calculated, following principles of Darcy's Law. To address the flow that may develop from the creek back toward the interceptor trench and from the seasonal peaks in seepage input to the trench from snowmelt and/or heavy precipitation, a safety factor of five was applied to the maximum flow estimates for design sizing.

After a review of various barrier options (high-density polyethylene [HDPE], composite sheet pile wall, excavated slurry wall, continuous soil mixing barrier, bituminous geomembrane), a double scrim HDPE with low-density polyethylene (LDPE) coating liner was selected for vertical installation on the downgradient trench wall extending 5 m up from the trench floor to direct water above trench bottom to collector pipes. The trench design included installation of three 150 mm nominal diameter polyvinyl chloride (PVC) gasketed sewer pipes, each with two rows of 3/8 inch and 1/4 inch diameter perforations at approximately 90 degrees offset on the pipe (collector pipes) installed at approximately 3% uniform longitudinal gradient with pipe perforations positioned down. The design included the collector pipes to be surrounded by a 1,000 mm thick layer of 12.5 mm diameter pea gravel, and non-woven geotextile filter cloth, which is considered to be acid-resistant.

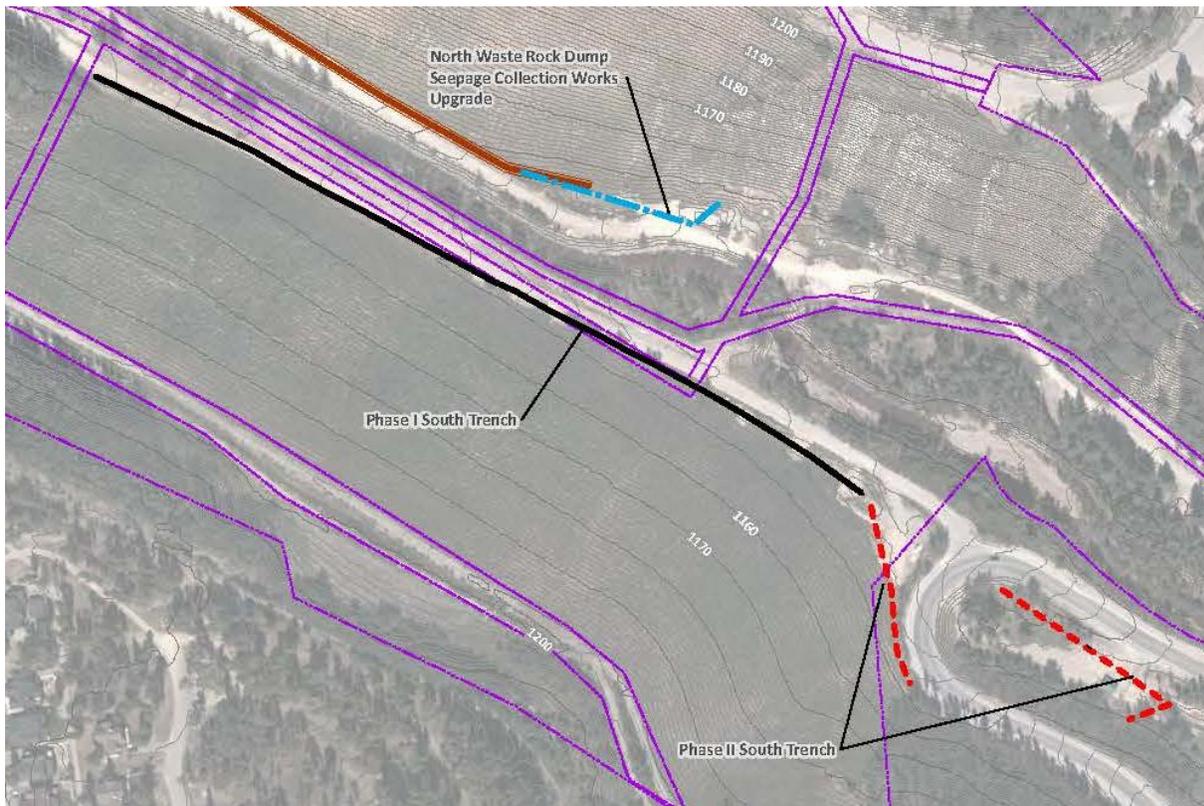
While the anticipated volume of water could be conveyed with only one 150 mm PVC perforated pipe, installation of three collector pipes provided a cost effective redundancy to convey seepage water to the central collection vaults. Clean-outs for the collector pipes were specified at regular spacing (approximately 100 m to 150 m) to provide access for a high-pressure water jetting system to scour the walls of the three collector pipes (jet-rod cleaning) to remove the build-up of precipitates and scaling in the piping. Clean-outs were changed to a bi-directional configuration to improve maintenance access to collector pipe infrastructure. Figure 2 below illustrates some of the key design features of the trench.

Figure 1: Typical Trench Cross Section



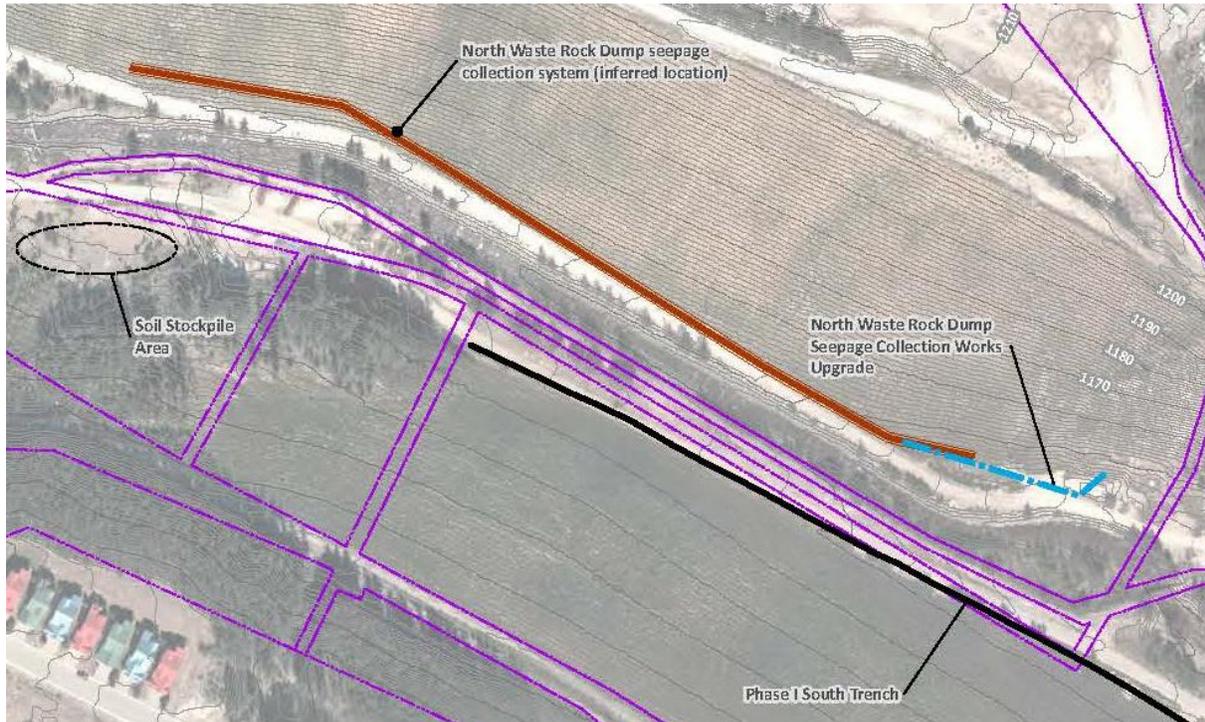
The design for the South Trench was originally a 630 m in length installed parallel to the South Waste Rock Dump and Mark Creek, and ranging in depth from 7 m to 10 m in depth. The trench depth and alignment were established to optimize the collection of seasonally perched acid rock drainage impacted groundwater on top of a low-permeability upper silt till unit and thus interrupt the shallow groundwater flow regime towards Mark Creek. Closure and open cut trench excavation of a segment of the trench through Gerry Sorensen Way (a City roadway) was not permitted by the City, so SNC-Lavalin developed the design basis and detailed design for an alternative design which eliminated a 70 m section of trench through the roadway and replaced it with an approximately 100 m section of trench extending southeast from the existing groundwater collection vault along the edge of the roadway and at the toe of the South Waste Rock Dump. Figure 3 below illustrates the modified South Trench alignment.

Figure 2: South Trench Alignment



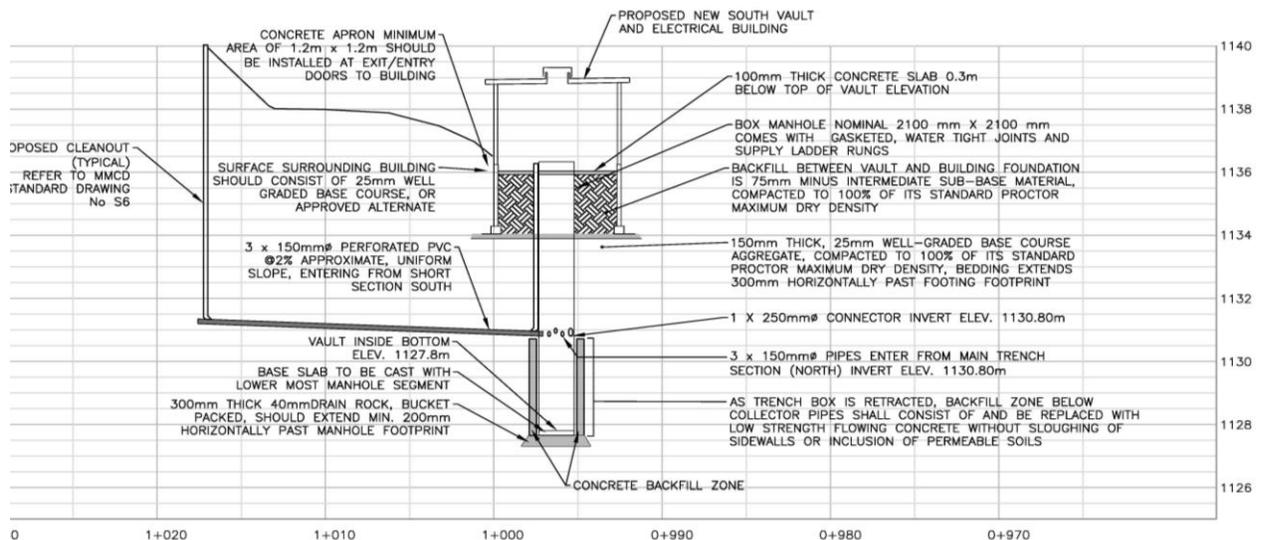
Based on results of a groundwater assessment, seepage from North Trench was limited to the area near the central collection point. Consequently, a design was completed for a new central collection point/groundwater collection vault (north vault), a 100 m section of trench parallel to Mark Creek, and a 15 m arm extending northeast of the north vault. The Trench's configuration was consistent with the South Trench design. The design allows for future extension in the event that groundwater within wells installed downgradient of the existing seepage indicates the existing seepage collection system is not effective. Overall the design provided a low level of complexity for water capture and conveyance, while accommodating a range of flows. Figure 4 below illustrates the North Trench upgrade alignment.

Figure 3: North Trench Upgrade Alignment



A square-shaped, pre-cast concrete collection vault with knockouts for collector pipes was designed for the central collection point for seepage water (See Figure 5). Vault installation depths were approximately 2 m deeper than the trench depths to accommodate a range of operating levels for water and accommodate vertical orientation of submersible pumps.

Figure 4: Phase II Vault Design



Vault Pump Control Buildings

To protect pumping, electrical and pump control infrastructure, a permanent building design was prepared for each pumping vault. The building design included a concrete pad surrounding the vault, and was engineered to contain pump infrastructure, a ventilation system to allow outdoor air to enter the building, and a removable roof hatch to allow for pump removal without multiple piping disconnects. The building design provided protection, control for frost and to allows for piping disconnects above grade (i.e., above the vault) which eliminates the need for personnel to enter the vault for routine maintenance and limits the potential for worker exposure to a hazardous atmosphere. The building will be treated as a location that may potentially have an oxygen deficient atmosphere and be subject to administrative controls provided by Teck's Confined Space Policy and Confined Space Entry Procedures.

CONSTRUCTION ACTIVITIES AND METHODOLOGY

Teck retained Marwest Industries Ltd. of Castlegar, BC (the Contractor) to construct the South Trench and North Trench upgrade through a competitive bidding process. The Contractor was responsible for construction work and the implementation of a site safety plan. SNC-Lavalin was retained as the Owner's Engineer during construction. SNC-Lavalin provided a Field Engineer to monitor construction activities on behalf of Teck, to verify the Contractor constructed the South Trench and North Trench upgrades as designed, manage and coordinate design changes and field adjustments, as well as to monitor compliance with health, safety environmental and contract requirements.

Safety Risks and Mitigation Measures

Primary safety risks included working in a congested work site where mobile equipment and personnel were continuously working in close proximity, working in a confined space with a potentially hazardous atmosphere (i.e. low oxygen environment), working at heights above the trench and within deep trenches with continuously changing weather and ground surface conditions, and having restricted access points. Wildlife (bear, deer) entering or denning with in the worksite had to managed on an ongoing basis. Furthermore, construction activities occurred in close proximity to main road access points to the Lower Mine Yard, and so managing access to the work site and maintaining separation of the worksite from non-construction staff was an important safety mitigation measure. Weather conditions ranged from 30 degrees below freezing during Phase I South Trench during winter of 2016 to 30 degrees above freezing during Phase II South Trench construction.

To mitigate for safety risks the Contractor developed and followed a Site-Specific Safety Management Plan that was reviewed daily with the onsite personnel and updated as required. Coordination of equipment (three tracked excavators, two articulated rock trucks, one wheeled loader, and other miscellaneous heavy equipment), and a crew of labourers and pipe fitters in a tight space with restricted access required active and ongoing communication as well as a strong commitment to safety for workers. Photographs (Photos) 1 to 4 below illustrate trench construction activities and examples of some of the access constraints etc.

Photo 1: View of typical daily equipment congestion during Phase II South Trench construction. (May 16, 2019)



Photo 2: View of winter work conditions Phase I South Trench (January 9, 2017)



Photo 3: View of Phase I South Vault Installation (December 2, 2016).



Photo 4: View of shoring cage set up for collector pipe separation repair. (April 6, 2017)



Environmental Management

An Environmental Management Plan was prepared for the construction that documented regulations and best practices applicable to the work and provided plans to ensure that the regulations and procedures were adhered to. SNC-Lavalin's Field Engineer completed environmental monitoring, documented any issues identified, and their resolution. Upgrades to the North Trench had to be completed near a constructed nest platform seasonally occupied by Osprey (*Pandion haliaetus*), which required monitoring to ensure activities were not disrupting nesting Osprey. Overall, construction was completed in compliance with the EMP and no external environmental incident reports were required during the course of the project.

Soil Management

Approximately 37,000 m³ of soil or mine waste with elevated metals concentrations had to be managed during construction to ensure post-construction soil conditions did not pose unacceptable risks to ecological

and human receptors. Due to geotechnical and access constraints, excavation and installation of collection piping and liner infrastructure occurred in ‘segments’ of about 15 to 30 m. To limit soil handling and stockpiling, suitable material excavated from one segment was used to backfill the previous section. As such, backfill materials were obtained directly from excavated materials from the adjoining segment. Excavated silt till cover material and waste rock were separately stockpiled during construction, and disturbed areas within the waste dumps were then reconstructed.

Water Management

Water management included management of groundwater seepage into the excavations, and surface water resulting from precipitation. Seepage was encountered at some depths and locations, and volumes were variable, but generally less than anticipated prior to construction (in part due to low snow pack prior to construction). Groundwater seepage encountered was considered to be contaminated with metals and potentially acidic, and therefore water collected during construction was conveyed to Teck’s seepage collection system for eventual treatment at the Drainage Water Treatment Plant. To minimize the potential to affect other water treatment infrastructure, water had to have similar water characteristics of groundwater in the area, free of hydrocarbons and other contaminants, and low in total suspended solids.

Construction Process Development and Improvements

The construction processes developed for 2016 Phase I South Trench were further refined during construction of the North Trench upgrades and Phase II South Trench. The construction process started with installation of the groundwater collection vault to create a central collection point for management of seepage water during trench construction. Both vault and trench installation employed a pre-excavation of soil to limit the height of the shoring cage system. The vault installations employed a slide rail shore system, while trench installation employed a stackable trench box shoring system.

General trench construction methods were to excavate the trench along the designed alignment to a vertical depth of approximately 8 metres, drape the low permeability liner along the downgradient wall of the excavation with the bottom of the liner on the bottom of the excavation, and suspending the top of the liner by ropes tied to stakes at the top of the excavation. Next, geotextile was placed on the bottom of the excavation and perforated collection pipes were laid down at the design elevation and surveyed to verify their elevation. Once the pipes were installed, pea gravel pipe bedding material was placed around the collection pipes and wrapped in geotextile. At this point, the excavation was advanced ahead of the trench box for the next section of collection pipe, the low permeability liner was unrolled ahead of the trench box using an excavator and lengths of steel pipes fitted with hooks. Finally, the trench box was pulled forward inside the excavation and the next section of collector pipes was prepared. This process was repeated over one hundred times to construct the trench. The low permeability liner suspension and unrolling were challenging tasks, and low temperatures reduced the liner’s flexibility. The roll was heavy and the Contractor had to learn through practice the best ways to execute the combined tasks of managing the liner roll, trench boxes, drain features geotextile, pea gravel and pipes, followed by backfilling above the drain zone and moving to the next segment.

<p>Photograph 5: View of liner installation with prior to pulling shoring cage. (February 28, 2018)</p>	<p>Photograph 6: View of workers installing collector pipe and drainage material. (April 4, 2018)</p>
	
<p>Photograph 7: View of trench box and liner installation configuration with access ramp (February 28, 2017).</p>	<p>Photograph 8: View of congestion backfilling around vault during South Trench South East Arm construction. (April 4, 2018)</p>
	

Site Restoration and Revegetation

After construction, project areas were restored to their approximate original condition. A hydroseed mix was applied at an application rate of 60 kg/ha on disturbed areas using a reclamation seed mix with 21.7% legumes (11.1% Alfalfa; 10.6 Alsike Clover,) and 78.3 % grasses (34.2 % Hard Fescue, 11.2% Intermediate Wheatgrass, 12.6% Pubescent Wheatgrass, 20.3 % Slender Wheatgrass). Surplus soil with low contaminant concentrations was opportunistically used as cover material in an area with residual soil contamination nearby.

Quality Assurance and Quality Control

SNC-Lavalin completed quality assurance monitoring to ensure that pipes, fills and geosynthetic materials were installed in accordance with the design intent, manufacturers' instructions and best practices. Throughout the project, SNC-Lavalin and the Contractor worked on a collaborative basis to complete quality

control and quality assurance. Upon completion of construction, copies of quality control checklists, torqueing records, field piping and equipment test reports for pipe cleaning and final written procedures, along with photographic and video documentation were provided as part of as-built reporting and for future reference.

OPERATIONS AND MAINTENANCE

Operation and maintenance activities for the North Trench and South Trench, and remainder of the Sullivan's seepage collection system, are conducted using a combination of Teck personnel and on site contractors in accordance with Teck's Seepage Collection Manual). Operational monitoring of the North Trench and South Trench includes daily visual inspections of the systems, combined with frequent water level and pump operation monitoring via the programmable logic controller. Preventative maintenance programs include annual inspections of key infrastructure (e.g., pumps, instrumentation), and cleaning or replacement as necessary; periodic inspection of collection piping using down-hole video camera, annual collection pipe cleaning by jet-rodding and flushing the system through the clean-outs. The frequency of collection pipe maintenance is revised based on observations during flushing and camera inspections (e.g., sediment, scaling).

PERFORMANCE MONITORING

SNC-Lavalin developed a plan for performance monitoring of surface and groundwater quality in the Lower Mine Yard to verify South Trench and North Trench performance. Objectives are to monitor for potential discharge of acid rock drainage from the North and South Trench system, evaluate groundwater flow and vertical/horizontal hydraulic gradients up- and down-gradient of the interception trenches and to evaluate the effectiveness of the interception trenches at capturing shallow groundwater, and assess trench flow. Preliminary monitoring results indicate both the South Trench and upgraded North Trench are performing as designed. Seepage into Mark Creek has not been observed since construction has been completed, and groundwater elevations on the upgradient side of the trench have been reduced.

CONCLUSIONS

Collection and treatment of acid rock drainage affected seepage at Sullivan Mine Operations requires a complex network of pipe, pumps, seepage collection systems at surface and in underground mine workings which will continue to require care and maintenance for years to come. The seepage collection system constructed during site closure activities has been maintained and upgraded annually. A detailed surface and groundwater monitoring in and around the seepage collections is in place, which identified seepage of groundwater impacted by acid rock drainage to Mark Creek. After reviewing remedial options, an interception trench system with a downgradient barrier, which employs passive gravity flow to a central collection vault followed by pumping into existing nearby conveyance infrastructure for treatment was designed to managed seepage in shallow groundwater in the Lower Mine Yard.

More complicated groundwater containment systems (composite sheet pile wall, excavated slurry wall, continuous mixing barrier) were considered as there were limited examples of how a low permeable barrier could be installed vertically on a downgradient wall of a trench up to 8 m in depth. However, after thorough review of remedial options and consideration of quality control and project costs, a traditional trench excavation approach was selected to construct over 700 metres of trench and three new central collection vaults in the Lower Mine Yard.

The construction process as well as project health, safety and environmental management required Teck, SNC-Lavalin and the Contractor to engage on a collaborative basis. While there was clear leadership in project roles and responsibilities, success was in a large part attributable to the entire team listening to each other and remaining open to changes in the construction process, regardless of team position and/or role. This level of active and ongoing communication between the entire team, from pipe fitters to the project management team were key to project success.

Preliminary performance monitoring results indicate that the South Trench has been effective at interrupting the shallow groundwater flow regime of seasonally perched acid rock drainage impacted groundwater, and thus interrupting the shallow groundwater flow regime downgradient of the South Waste Rock Dump. A similar design approach was employed to upgrade the terminus of a section of rock drain installed in the former Mark Channel and toe of the North Waste Rock Dump or North Trench. Results of the preliminary performance monitoring have shown an improvement of the hydraulic connection of North Trench to the central collection point near where the historical Mark Creek channel enters the active channel.