Overview of a Full-Scale Trial for Removal of Nitrate and Selenium from Mine-Influenced Water Using Saturated Rock Fill Technology

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Abstract

Teck Resources Ltd (Teck) and its research partners have developed and tested the applicability of saturated rock fill (SRF) technology to treat mine-influenced water. In 2018, Teck conducted the first documented full-scale trial of removal of nitrate and selenium from mine water using SRF technology in the saturated zone of a large backfilled open pit in the Elk Valley, British Columbia, Canada. Naturally present microbes in the SRF were leveraged to remove selenium and nitrate from mine-influenced water at flow rates of up to 10,000 m^3/d. Carbon (methanol) and nutrients (phosphorous) were added to source water that was then pumped through a well field in the SRF; this promoted the denitrification of nitrate and bio-reduction of selenium to less soluble forms (e.g., selenite, elemental selenium or selenium sulfide). Over 605 days of testing, 93% (65,000 kg) of injected nitrate and 92% (350 kg) of injected selenium were removed. The trial demonstrated the feasibility of using SRF technology for *in situ* treatment of water at a mine scale, at one third of the capital cost of comparable tank-based systems. The trial confirmed that biogeochemical mechanisms could be predicted; it also highlighted the importance of the SRF hydrogeological and biogeochemical characteristics during the design stage and demonstrated that a flexible design was needed to allow responsiveness to changing or unexpected conditions. This paper provides an overview of the design, operation and results of the full-scale SRF trial.

Introduction

Concentrations of nitrate and selenium in the Elk River watershed, located in southeast British Columbia, Canada, are elevated above background concentrations at some locations as a result of historical and current coal mining (Villeneuve et al., 2017). Teck Resources Limited, owner and operator of the major coal mines in this region since 2003, has committed substantial resources to improve the effectiveness of water treatment technologies and to investigate long-term solutions for managing water quality at the source.

Through its extensive research and development (R&D) into new technologies over the last decade, Teck, with the support of its research partners, has been a leader in the development of saturated rock fill (SRF) technology for the treatment of nitrate and selenium in mine water. Results from studies at different scales, ranging from laboratory- to small-scale pilot tests, supported the potential for significant removal of nitrate and selenium from mine-influenced water in a SRF bioreactor, leading to the development of a full-scale SRF trial using a flooded and backfilled open pit. Expanding a controlled plant-scale process to a full mine-scale test represents a novel application of known principles that allows for the treatment of large volumes of water and chemical loads in a practical and cost-effective approach.

The SRF Full-Scale trial was designed to evaluate technical uncertainties and feasibility of treatment at a scale applicable to mine-scale flow rates as well as to provide key inputs for the design and operation of the technology at other locations. The trial successfully removed nitrate and selenium from mine water at flow rates and concentrations comparable to the West Line Creek conventional tank-based water treatment plant, also located in the Elk Valley. This paper provides an overview of the design and operation of the full-scale SRF trial at Teck's Elkview Operation, based on detailed multidisciplinary studies (e.g., hydrogeology, chemical transport, geochemistry, microbiology, engineering). Detailed results of the research and full-scale trial were submitted as annual performance reports to regulatory authorities and stakeholders, as a presentation at the 2019 BC/MEND Metal Leaching/Acid Rock Drainage Conference in Vancouver, BC, and will be presented in subsequent publications.

All work was conducted within existing or project-specific permits with Provincial regulatory ministries.

Background

Teck Resources Limited operates four metallurgical coal open-pit operations in the Elk Valley of British Columbia (Figure 1).

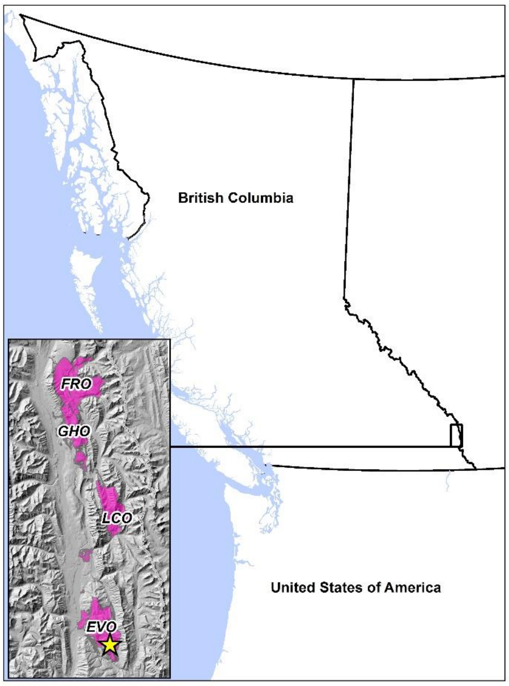


Figure 1: Teck Elk Valley Coal Mines and Project Location in the Elk Valley British Columbia, Canada

These operations produce large quantities of mine rock that are placed in piles within and adjacent to the excavated open pits. In the Elk Valley, as elsewhere, infiltration of precipitation can carry oxidation products of sulfides (such as selenium and sulfate (Hendry et al., 2015)) and leached nitrate residues from blasting (Mahmood et al., 2017; Hendry et al., 2018) into the local watershed, resulting in increased concentrations of these solutes in the receiving environment.

SRFs use the saturated portion of existing backfilled pits as bioreactors to remove selenium and nitrate. The SRF concept, initially published by Bianchin et al. (2013), builds upon known biogeochemical processes (Trudell et al.,1986; Schurmann et al., 2003; Stolz and Oremland, 1999; and Stolz et al., 2006). The concept exploits the sub-oxic conditions of the saturated portion of the SRF to support a microbial community capable of reducing both nitrate and selenium. Similar processes have been used in smaller-scale engineered treatment systems for at least a decade (US EPA, 2009; CH2M Hill, 2013). Reduction occurs through anaerobic respiration, where the microbial community uses nitrate and selenate in the absence of oxygen as electron acceptors and energy from the oxidation of labile carbon. Once reduced, nitrate and selenium are removed from the water: nitrate by denitrification to nitrogen gas, and selenium by precipitation to solid or less soluble forms (e.g., selenite, elemental selenium or selenium sulfide) that remain within the rock matrix. The treated water is subsequently discharged to the receiving environment.

To design and operate a full-scale trial, technical uncertainties such as backfill hydraulic conductivity, reagent requirements and transport characteristics first had to be resolved. Between 2011 and 2016, uncertainties were evaluated through a series of laboratory and field trials, including laboratory batch and column tests, hydraulic testing of backfill material properties, and reactive tracer studies conducted with potassium bromide as the conservative tracer and selenium and nitrate as the reactive constituents. In late 2016, it was concluded that backfill hydraulic conductivity was high enough (between 2×10^{-3} m/s and 8×10^{-3} m/s) to allow desired injection and extraction rates, estimates of reagent requirements could be made and transport characteristics were sufficiently understood to allow system design. Uncertainties had been sufficiently resolved to support the execution of a full-scale trial of the technology.

The full-scale trial was implemented in the saturated zone of the existing backfilled F2 open pit at the Elkview Mine. Background concentrations of nitrate-N were between 0.04 mg/L and 1.3 mg/L, and selenium concentrations were between 1.85 µg/L and 12.2 µg/L. Background concentrations of bromide (the conservative tracer used during the trial) were between 0.24 mg/L and 0.51 mg/L. Source water for the trial was obtained from an adjacent flooded pit that was being dewatered to allow for additional mining activities. The nitrate and selenium source water concentrations (10 to 33 mg/L nitrate-N and 39 and 323 µg/L selenium) and flow rates (≈3,000 to 10,000 m^3/d) during the trial were similar to those being treated at the nearby West Line Creek tank-based water treatment system.

The system was designed and constructed between late 2016 and January 2018, with the trial commencing on January 11, 2018 (day 1 of the test). This paper covers the first 605 days of operation, through to September 8, 2019. The system continues to operate and remove nitrate and selenium as described in this paper.

Materials and Methods

Overview of SRF Design

The SRF trial system included four main components (Figure 2): (1) source water for treatment; (2) a well field within the SRF where water was treated (Figure 3); (3) a reagent addition system; and (4) influent and effluent conveyance infrastructure.

Notes: A. backfilled pit outline; B. wellfield (elevation: 1800 masl); C. influent and effluent conveyance pipelines; D. flooded pit and source water for treatment (elevation 1400 masl); E. discharge to the receiving environment; F. British Columbia Highway 3

Figure 2. Components of the SRF Trial System

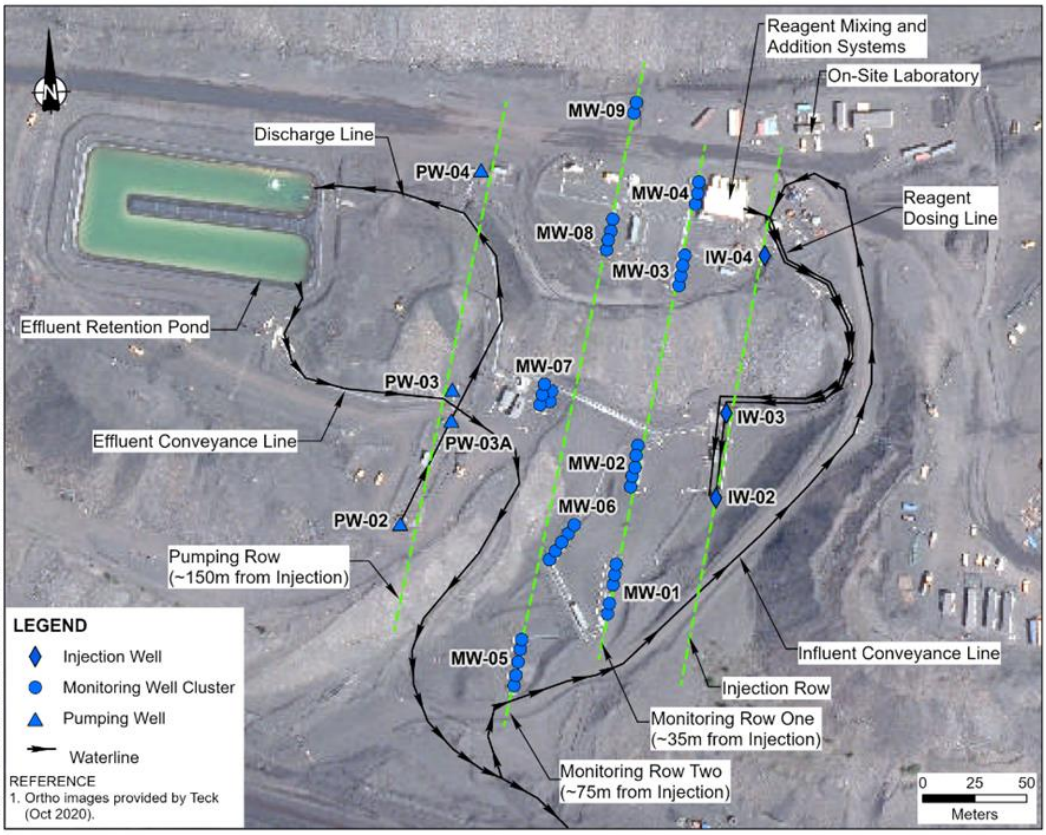


Figure 3. SRF Full-Scale Trial Wellfield

Source Water

Source water for the trial was obtained from a flooded pit with nitrate-N concentrations between 10 and 33 mg/L and selenium concentrations between 39 and 323 µg/L.

Well field

The well field within the backfilled open pit consisted of three injection wells, nine monitoring well clusters for a total of 44 monitoring wells, and four extraction wells (Figure 3). Injection and extraction wells were designed to develop a controlled linear flow field that provided sufficient hydraulic residence time for the necessary reduction reactions to occur. The well field incorporated screen depths to allow water injection, water extraction, and monitoring of water chemistry and microbial characteristics to occur across the full saturated thickness of the SRF.

Reagent Addition System

A reagent dosing system was developed that allowed for the mixing of a carbon source (methanol), nutrients (phosphorus), and tracer (potassium bromide) with influent water.

Conveyance Infrastructure

Influent conveyance included a combination of a floating barge and well-pumping systems that collected intake water from the flooded pit; the source water was conveyed to the SRF via approximately three kilometres of pipeline and three booster stations.

Effluent conveyance included a 10,000 m^3 effluent retention pond with a 24-hour holding capacity and a second approximately three kilometre pipeline that could convey effluent from the effluent retention pond to the receiving environment. In addition, a discharge line was constructed to convey effluent from the retention pond back to the flooded source pit in case SRF-treated effluent concentrations did not meet requirements for discharge to the environment.

Process Flow

The process flow had the following five steps (Figure 4): (1) Source water was pumped from the flooded pit to the SRF. (2) Reagents were added to the source water as follows: (a) potassium bromide (a conservative tracer) was added at a constant concentration for the first 307 days of the trial to track injected water movement through the SRF, to develop constituent breakthrough curves to inform hydrogeology and transport mechanisms, and to allow quantification of influent mass recovery for use in estimating nitrate and selenium removal rates; (b) methanol was added to provide, at a minimum, the stoichiometric carbon requirement for microbial respiration, based on measured oxygen and nitrate concentrations in the source water; (c) phosphorus was added as a nutrient to support microbial growth; (3) source water with reagents was directed into the three injection wells. (4) Injected water migrated through the SRF from the injection wells, past the monitoring wells, and to the extraction wells. (5) Effluent was pumped from extraction wells and discharged into the effluent retention pond where it re-equilibrated with atmospheric conditions. If the pond water quality pond met discharge water quality criteria, it was discharged to the receiving environment (Michel Creek); if not, it was recycled and discharged back to the flooded source pit.

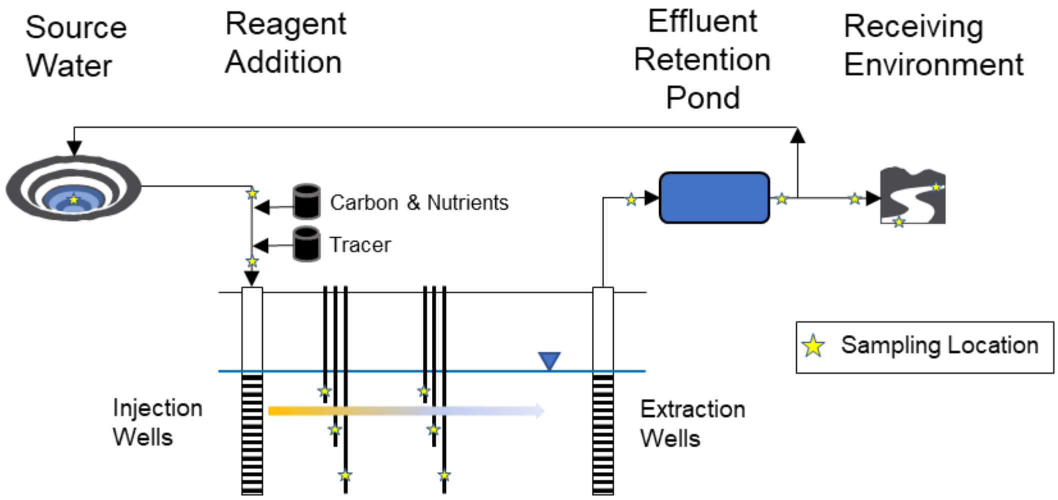


Figure 4. Schematic of SRF Trial Process Flow

Monitoring

Monitoring during the trial was undertaken to evaluate fundamental system processes and overall system performance, and to track responses to changes and disturbances in operating conditions. The trial included a detailed temporal and spatial monitoring program for physical, chemical and biological parameters focused on the injection, monitoring and pumping wells. Routine monitoring included but was not limited to flow rate, water levels, temperature and pipeline pressure at key locations. Water samples were collected for water chemistry analyses including field parameters (dissolved oxygen, Eh, pH, temperature, electrical conductivity), anions, nutrients and carbon, total (unfiltered) and dissolved (filtered, 0.2 μm) metals and total dissolved solids (TDS, gravimetric). With the exception of field parameters, analyses were conducted at external accredited laboratories. In-house analyses of key parameters (e.g., nitrate, nitrite) were also conducted.

Influent and effluent waters were sampled daily for routine water chemistry and for on-site analyses used to guide reagent dosing and discharge-management decisions. Sampling frequency at monitoring wells varied from daily to weekly depending on the path of injected water with respect to the wells. Water levels, temperature, flow rates and pipeline pressures were monitored every minute (referred to as continuous in this paper).

Regular biological monitoring was conducted quarterly via deoxyribonucleic acid (DNA) characterization (through 16SrRNA gene sequencing) of biofilm grown on a substrate housed in biocoupons (small removable cartridges of sterilized backfill material) suspended in the pumping, injection, and monitoring wells. Results were used to assess microbial community structure and diversity over time by documenting relative abundance and diversity indexes. Organisms were identified at the genus level, based on comparison with a curated public database. The identified organisms were used to infer the dominant biogeochemical metabolisms influencing geochemical transformations in the SRF.

Additional monitoring included selenium speciation, nitrogen and oxygen isotopes on nitrate, detailed carbon characterization, gas monitoring in the unsaturated zone, and conductivity-temperature-depth profiling.

Data Management and Analysis

Data collected continuously (e.g., water levels, pump/pipeline flows) were recorded through the supervisory control and data acquisition system and stored in a Historian™ database; all water chemistry data was stored in an EQuIS™ database. The dataset described in this paper consisted of more than 10,000 unique water samples and more than 750,000 analyses. Quality assurance and quality control (QA/QC) protocols included field blanks and field duplicates making up approximately 10% of the samples. Standard QA/QC checks included a comparison of field blanks to method detection limits and field duplicates to paired original samples. Additional checks included ion balance calculations and visual trend analyses.

Data Analysis and Modelling

Processed data were analysed (1) to determine how injected water moved through the system and how these affected variations in chemical loads; (2) to evaluate geochemical mechanisms and their performance; and (3) to identify operational issues in the water treatment process or inconsistencies in results that could inform changes in system operation.

Modelling was completed to understand system dynamics and allow quantification of system processes. Two-dimensional numerical groundwater modelling using FeFlow © included density-dependent flow and conservative transport. Modelling results were used in the interpretation of mechanisms controlling the hydrogeological system which allowed forecasting of future conditions. Thermodynamic equilibrium modelling was used to understand the following parameters: redox conditions (e.g., Pourbaix diagrams of key redox-sensitive species), the effects of alkalinity generated through denitrification on the partial pressure of $CO_{2(g)}$, and the potential for calcite precipitation within the SRF and in effluent discharge infrastructure. Empirically derived zero-order removal rates were coupled with outputs from the hydrogeological models to estimate system performance.

Results

Flow Rates

During the first 8 months of operation, flow rates were gradually increased from approximately 5,000 m^3/d to the design capacity of 10,000 m^3/d. Weekly average injection and extraction flow rates during the trial ranged from 0 m^3/d to 9,995 m^3/d (Figure 5), including 57 days at or above the design flow rate of 10,000 m^3/d. The mean weekly average injection and extraction rates for the entire trial period were very similar: 5,445 m^3/d and 6,013 m^3/d, respectively.

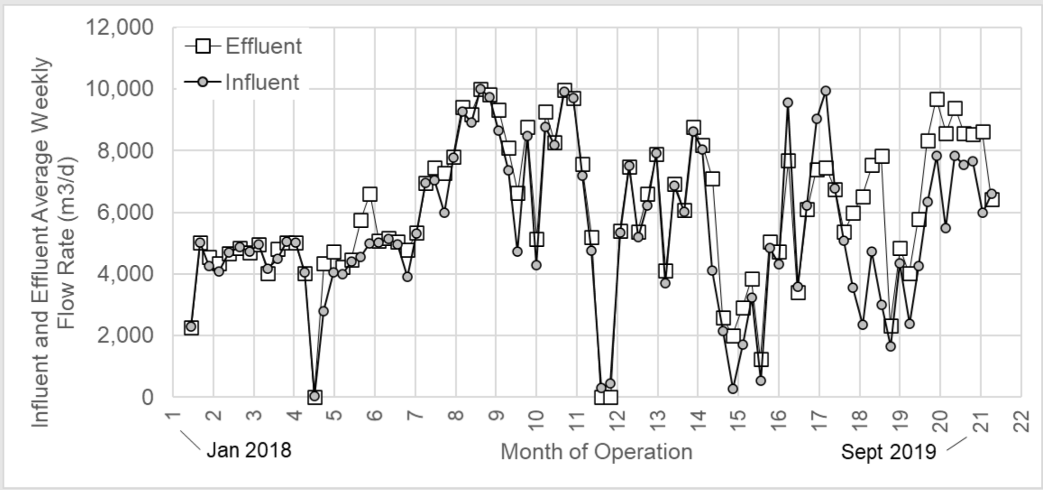


Figure 5. Influent and Effluent Flow Rates

Bromide, Nitrate and Selenium Concentrations

A bromide tracer was added continuously at a target concentration of 35 mg/L from January 13, 2018, through November 14, 2018, a period of 307 days. Monthly average influent bromide concentration from January to November 2018 was 31 mg/L, declining to 5 mg/L or lower within two months after stopping injection (Figure 6). Monthly average effluent bromide concentration increased steadily over 2018, reaching a maximum of 22 mg/L in November 2018. After bromide injection ceased, effluent concentrations decreased to less than 5 mg/L over the following 10 months.

Monthly average concentrations of nitrate-N and selenium were higher in influent waters than in effluent waters for the duration of the trial (Table 1 and Figure 6).

Table 1. Nitrate and Selenium Influent and Effluent Concentrations

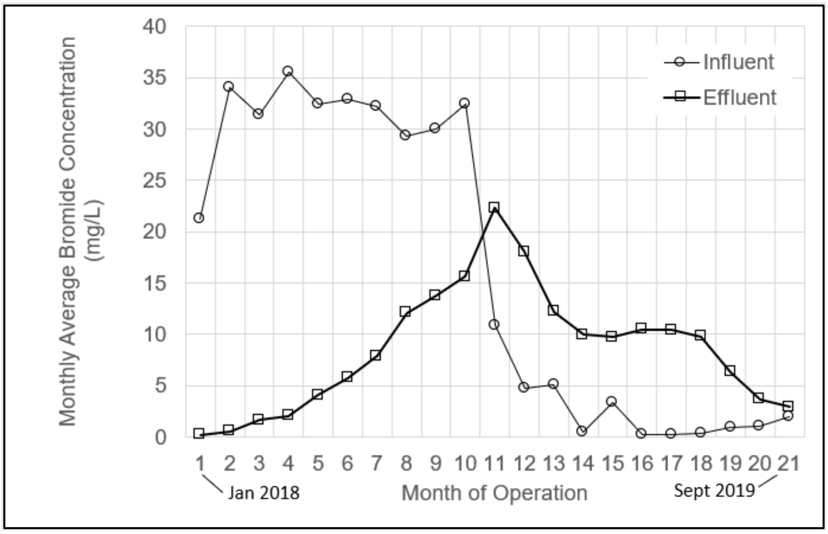
Constituent	Influent Range	Influent Average	Effluent Range	Effluent Average
Nitrate	11 mg/L to 27 mg/L	21 mg/L	0.5 mg/L to 2.8 mg/L	1.5 mg/L
Selenium	46 µg/L to 197 µg/L	118 µg/L	4 µg/L to 14 µg/L	9 µg/L

The amounts of bromide, nitrate and selenium injected, extracted, and considered removed from source water are summarized in Table 2.

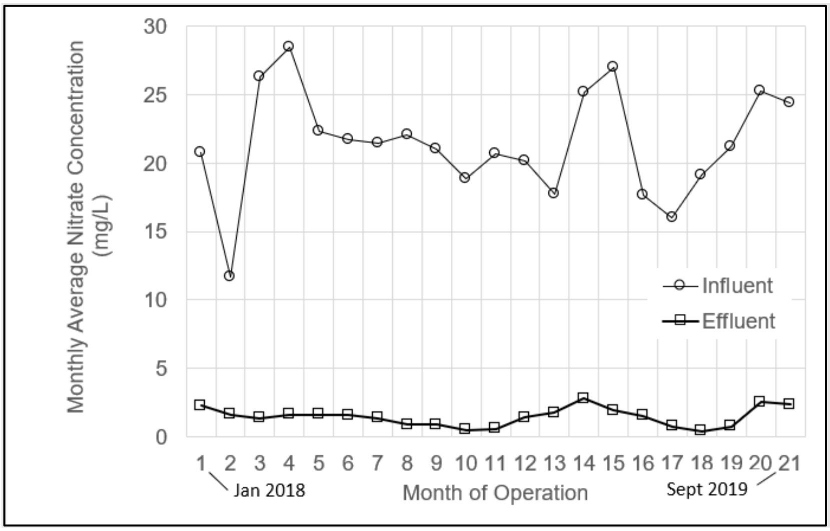
Table 2. Influent and effluent mass, percent recovered, and mass removed for nitrate, selenium, and bromide.

Constituent	Total Mass Injected	Total Mass Recovered	Percent Recovered	Mass Removed
Bromide (tracer)	60,321 kg	33,555 kg	56 %	Not applicable
Nitrate	69,999 kg	4,938 kg	7 %	65,061 kg*1
Selenium	382 kg	31 kg	8 %	351 kg*2

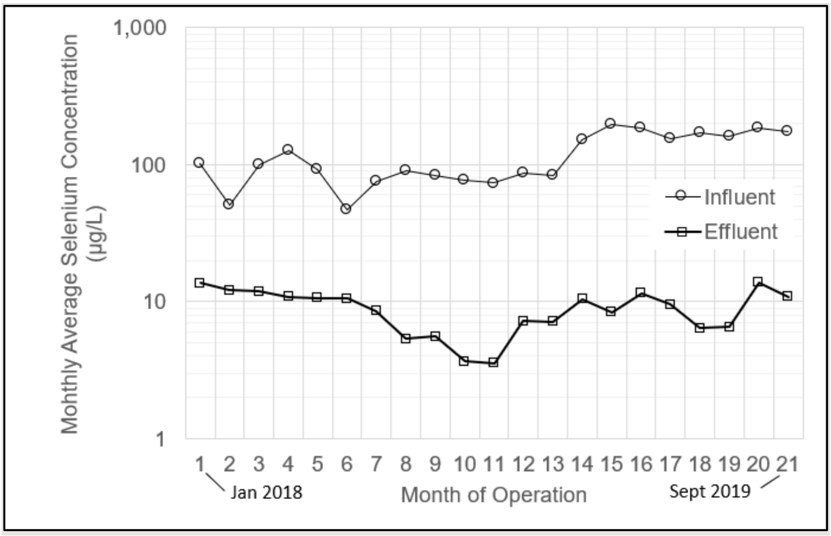
Notes: 1. Nitrate mass removed is nitrate removed from influent water by denitrification. 2. Selenium removed from influent water by bio-reduction within the SRF reactor



6a. Influent and Effluent Bromide Concentrations



6a. Influent and Effluent Bromide Concentrations

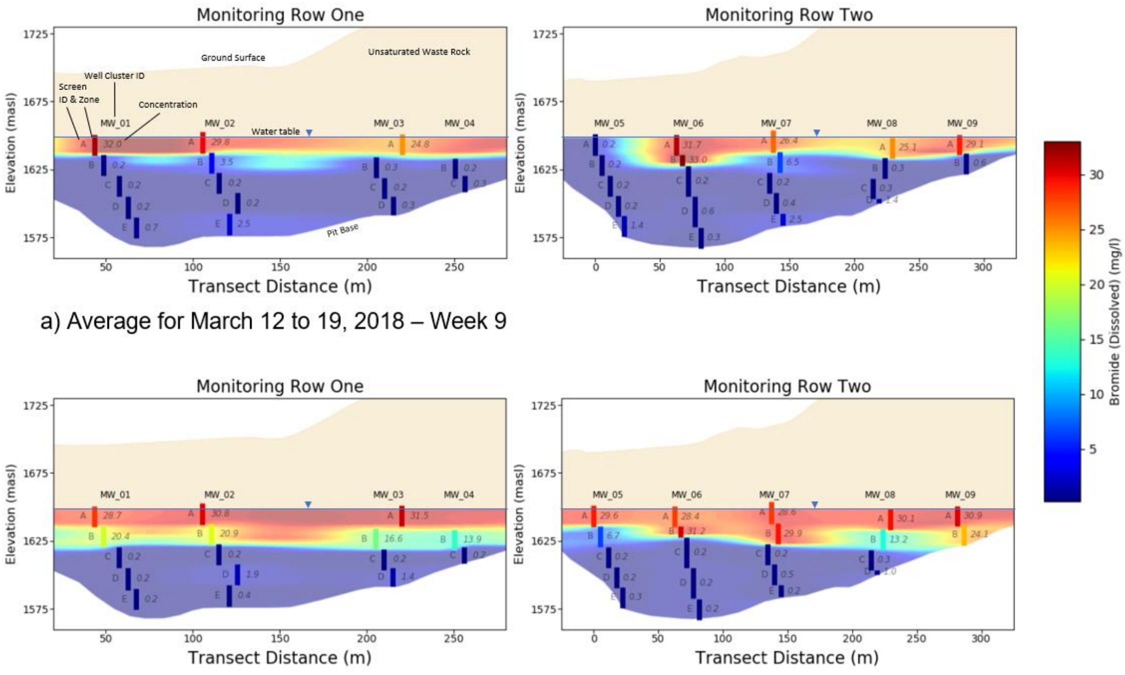


6c. Influent and Effluent Selenium Concentrations

Figure 6. Monthly Average Influent and Effluent Concentrations with time

Tracer monitoring indicated that influent water was generally constrained to the upper 15 to 20 m of saturated thickness; influent water was never observed at greater depths. This response was maintained for the duration of the trial, though the base of this zone of influent water did shift vertically over time by a few meters.

Cross-section plots of weekly average concentrations of bromide tracer in monitoring wells illustrate the vertical location of injected water within the SRF over time (Figure 7). Cross-sections for both monitoring rows (One and Two) for week 9 (early during bromide tracer injection) and week 44 (immediately prior to cessation of bromide injection), show that during week 9, bromide concentrations were near to injection concentrations in all of the uppermost monitoring wells in both monitoring rows, but at background concentrations below 15 m depth in most wells. All wells had background values below 30 m depth. By week 44, bromide concentrations between 15 m and 30 m depth had increased but were still at background concentrations below 30 m depth. This pattern remained consistent throughout the period of tracer injection.



a) Average for March 12 to 19, 2018 – Week 9

b) Average for November 15 to 22, 2018 – Week 44

Notes: Bromide concentrations are average for listed week. Contours generated using Radial Based Functions (Virtanen et al., 2020)

Figure 7. Cross sections of bromide concentrations at monitoring rows a) Week 9, b) Week 44

Microbial Characterization

The analysis of biocoupons from the well field showed a diverse group of denitrifying and selenium-reducing organisms in the SRF. Results showed that denitrifying bacteria in the SRF were dominated by members of the genera *Methylotenera, Sulfurimonas,* and *Dechloromonas.* The dominant selenium bioreducers were identified as members of the genera *Dechloromonas* and *Pseudomonas*. These denitrifiers and selenium bioreducers were present in the SRF prior to the trial.

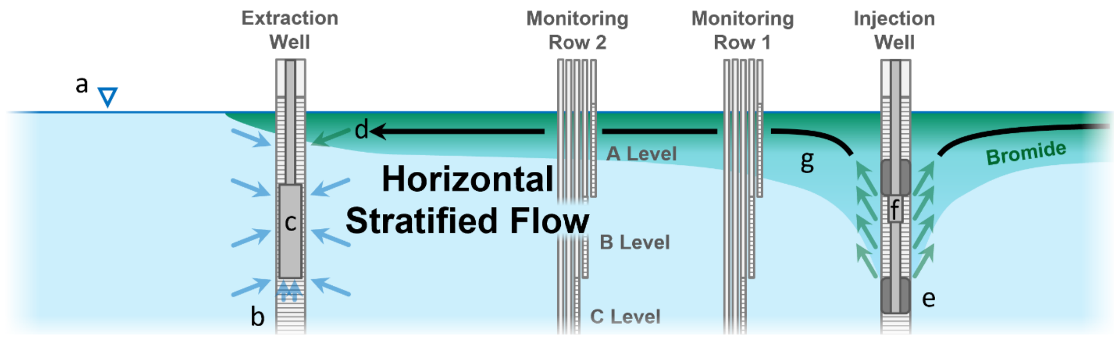
Discussion

Hydrogeology

Groundwater modelling of field trial results led to the following characterization of the backfill hydrogeologic system. The system had very high hydraulic conductivity (*K*) and local heterogeneity did not have a notable effect on the flow system. Prior to the trial, estimates of backfill bulk average *K* from pumping tests and tracer tests ranged between 2×10^{-3} m/s and 8×10^{-3} m/s. Analysis and modelling of the trial data indicated that the bulk average *K* may be greater than 1×10^{-1} m/s, which is at the upper end in published literature (Fetter, 2001). Heterogeneity of the SRF, in the form of coarse-grained vs. fine-grained pockets or layers with varying *K,* was unknown and had the potential to create fast-flow vs. slow-flow pathways, which could lead to variations in effluent water residence times and in rates of constituent removal. Trial results indicated that this heterogeneity had less influence than initially expected, as breakthrough curves for the conservative bromide tracer were relatively consistent at locations in the SRF where injected water was observed: fast-flow pathways were seen to influence results at only two of the 44 monitoring wells (5%). Results from the trial indicated that material (and *K*) heterogeneity was present but did not have a notable effect on trial results.

While heterogeneity did not have a notable effect on trial results, a density-stratified water column existed and remained during the trial that had a significant influence on trial results. Prior to the trial, the saturated backfill water chemistry varied with depth, with TDS strongly influenced by sulfate concentrations (≈700 mg/L SO_4 at shallow depths to ≈1,600 mg/L SO_4 at the pit bottom). Sulfate concentrations in influent water ranged between 600 and 1,000 mg/L. Density-dependent flow in the SRF was not expected during design. Injection zones were set at depths of ≈ 15 m to 30 m below the water table, but bromide tracer presence at monitoring rows 1 and 2 during early weeks of the trial, at concentrations nearing injection concentration in some cases, was only observed the shallow-most monitoring wells, screened at depths of ≈ 0 m to 15 m below the water table (Figure 7). Concentrations of bromide tracer increased at the next deeper set of monitoring screens (≈ 15 m to 30 m) over the course of the trial, but never occurred at greater depths than this. This occurred across almost the entire wellfield. Density-dependent transport modelling of trial results indicated that the stratified flow occurred due to the combination of very high *K* and similarity in fluid density between *in situ* shallow groundwater and injected influent water. Extraction wells PW3 and PW4 were screened at depths greater than 20 m below the water table and were not effective at capturing influent water, which flowed above the screen zones. Extraction well PW3A was constructed in late 2018 with a screen from 0 m to 20 m below the water table and pumping from this well considerably improved the capture of treated influent water.

The combination of influent water of similar density of shallow *in situ* water and high *K* led to influent water rising to shallow depths quickly after injection, then flowing towards extraction wells within this shallow zone of the stratified water column (Figure 8).



Notes: a. water table; b. screen zones; c. extraction pump; d. groundwater flow path; e. injection packer; f. injection zone; g. green shading shows travel of injected bromide tracer

Figure 8. Conceptual Model for Flow in the SRF

High hydraulic conductivity and stratification can have meaningful implications on the design of SRF well fields. For example, while the backfill of the SRF has a sufficiently high K to allow high flow rates, development of relatively thin, stratified flow zones can reduce hydraulic residence time, thus potential treatment rates. Additionally, in a stratified flow system, influent water can bypass extraction wells not designed to capture the target flow zone, resulting in influent water flowing past the well field.

Water Chemistry and Biogeochemistry

Detailed monitoring of the water chemistry and biogeochemistry of the SRF was key to assessing the treatment performance of the system, optimizing reagent dosing and treatment flow rates, and identifying potential risks and upset conditions.

Following an initial three- to four-month microbial growth stage during which the biomass increased and the microbial community shifted towards microbes capable of methanol oxidation and nitrate and selenium reduction, performance monitoring indicated consistent removal of 90 to 95% of nitrate and selenium injected in the SRF.

Nitrate removal was confirmed to occur via denitrification, based on water chemistry results (including field redox and pH measurements) and microbial characterization.

Selenate reduction was hypothesized to occur via microbial dissimilatory energy production or through detoxification pathways resulting in attenuation of more reduced forms of selenium within the SRF (e.g., selenite, elemental selenium and/or selenides). Removal was confirmed to occur based on water chemistry results, including field redox and pH measurements. Removal rates of nitrate and selenium were quantified by comparing concentrations of nitrate-N and selenium at the injection wells, monitoring wells and extraction wells with concentrations of the continuous conservative bromide tracer.

After the initial microbial growth stage, selenium and nitrate were largely removed before reaching the first monitoring row, located 35−40 m away from the injection wells. Zero-order reaction rates for nitrate and selenium were estimated from these observations to be 5.5 mg/L/d and 22 µg/L/d, respectively. These rates were considered as conservatively low, or “minimum” estimates, since the removal actually occurred between the injection wells and the first row of monitoring wells (i.e., the actual removal rate is inferred to be higher).

Throughout the trial, carbon dose adjustments were made to evaluate the optimal dose range and assess the SRF response to these adjustments. When the carbon dose was too low, incomplete denitrification resulted in elevated nitrite (a constituent of concern in discharge water). When the carbon dose was too high, with excess carbon beyond that required for denitrification and selenium reduction, elevated concentrations of dissolved iron were observed; this was attributed to reductive dissolution of ferric iron minerals in the backfilled mine rock. The optimal carbon dose was sufficient for complete nitrate and selenium removal while minimizing the release of iron and related constituents in the pore water.

Nitrite was monitored to detect increases indicating incomplete denitrification caused by lower than optimal carbon dosage. Increases in nitrite were also used as an indicator of a potential upset or change causing stress on the microbial community. Increases in nitrite concentration were observed at start-up after large step changes in flow rates or shifts in influent water quality inferred to affect influent density. Increases in nitrite concentrations were brief (days to weeks) and reflected the relatively rapid adjustment of the microbial community to system changes.

Design and Operating Considerations

The following system performance indicators and mechanisms within SRF systems are some of the aspects that should be monitored and managed: the influence of stratification on the flow system, the potential for nitrite generation, the management of optimal redox conditions, and changes over time in any of these aspects.

Considerable effort was expended prior to the trial in terms of evaluating the uncertainties of the technology and designing a system that had sufficient flexibility to manage those uncertainties. The following features were built into the system to ensure management flexibility: (1) multiple injection and extraction wells; (2) adjustable depths of injection and extraction; (3) full control on amount, rate, and location of introduction of influent water into the system; (4) reagent systems with adjustable control of dosing rate, frequency and placement; (5) integration of a 24-hour effluent retention pond after extraction but prior to discharge; (6) daily water quality checks prior to discharge; (7) the ability to direct effluent to either the receiving environment or recycle back through the system; and, (8) substantial monitoring both within and peripheral to the SRF well field.

Cost Comparison to a Tank-Based Treatment Plant

Costs of the SRF trial system were compared to those from the nearby West Line Creek treatment plant which treats a flow rate of 7,500 m^3/d, at nitrate and selenium concentrations similar to those in the SRF influent. The SRF was constructed at a capital cost of approximately one third of that of the West Line Creek facility and operates at approximately one half the operating cost for a similar flow rate.

Conclusions and Implications

The field trial tested the potential to scale up a known microbial water treatment process in a SRF to a previously untested scale. Results from almost two years of operation demonstrated that biogeochemical mechanisms were removing over 90% of nitrate-N and selenium in influent water. By using an existing a saturated backfilled excavation (SRF) as an *in-situ* water treatment facility, and by enhancing naturally occurring bacterial processes, this trial demonstrated that SRF technology was successful at removing mine-derived nitrate and selenium at flow rates and chemical loads similar to those achieved in traditional tank-based systems, yet at a fraction of the costs and without the need to build additional infrastructure.

This technology could potentially be applied successfully to other mine settings where it could help solve similar water chemistry challenges, with the added benefit of material cost savings compared to tank-based water treatment systems.

Acknowledgments

The success of the SRF trial would not have been possible without the commitment from Teck and its research partners. Specifically, the Teck Applied R&D and Water Operations teams, Jim Hendry and Lee Barbour from the University of Saskatchewan, Lisa Kirk and Seth D'Imperio at Enviromin Inc., Brent Peyton from Montana State University Center for Biofilm Engineering, Silvia Mancini and her team at Geosyntec Consultants, as well as the many staff at SRK Consulting (Canada) Inc. and O'Kane Consultants are acknowledged. Recognition also goes to Wood PLC for leading the detailed engineering design for the trial.   Thank you to Daniele Heon for editorial support.

Declaration of Interest

This research was conducted while providing consulting services to Teck Coal Ltd. The authors received consulting fees for the included work but have no financial interest in Teck Coal Ltd. and will receive no royalties or other financial gain resulting from any licensing or use of the described technology.

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