

PROTECTION OF GROUNDWATER AND SURFACE WATER AT A BULK EXPLOSIVES FACILITY USING CALCULATED RISK-BASED SOIL GUIDELINES

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ABSTRACT

The Kemess South Mine in northeast British Columbia operated between 1998 and 2011. The former Bulk Explosives Fabrication (BX) facility within the mine area produced ammonium nitrate based explosives to support mining operations. Production and handling caused significant accumulation of ammonia and nitrate (AN) in shallow soils surrounding the BX facility, and groundwater contamination of AN was identified beneath the site.

Given that soil-based environmental quality guidelines/standards for ammonia and nitrate do not exist federally or provincially, site-specific remedial objectives (SSROs) were developed to allow appropriate remediation, in order to facilitate protection of groundwater for drinking water purposes, and to protect aquatic life in the adjacent Kemess Creek. The SSROs were calculated based on threshold leaching concentrations of ammonia and nitrate in soil below which soil concentrations would not cause future potential risks for humans drinking groundwater beneath the site, or for aquatic life in Kemess Creek. Calculations of SSROs were conservative considering attenuation biological and chemical attenuation will occur in the subsurface.

Targeted areas of AN impacted soil were removed from the site, based on the SSROs, with post-remedial confirmatory sampling. Rather than bulk removal of soil impacted with AN ($>1,200\text{m}^3$), a targeted removal of $<400\text{m}^3$ was completed to meet acceptable site management objectives for groundwater and surface water protection.

Key Words: risk assessment, remediation, ammonia, nitrate, aquatic, drinking water

SITE BACKGROUND

The Kemess South Mine deposit was discovered in the early 1990s, and extraction operations began at the mine in 1998. Under the ownership of Northgate Minerals Corporation, the mine extracted through the mid- to late-2000s an average volume of 300,000 ounces of gold and 75 million pounds of copper per year. The current owner, AuRico Gold, is actively reclaiming portions of the Kemess South Mine area. The mine is largely a remote, fly-in operation. From the ground, the mine is accessible via the Omineca Resource Access Road, and is located approximately 300 km northwest of Mackenzie, BC. The former Bulk Explosives Fabrication (BX) facility is located approximately 1.5 km east of the mine pit in the Kemess Creek Valley (Figure 1).

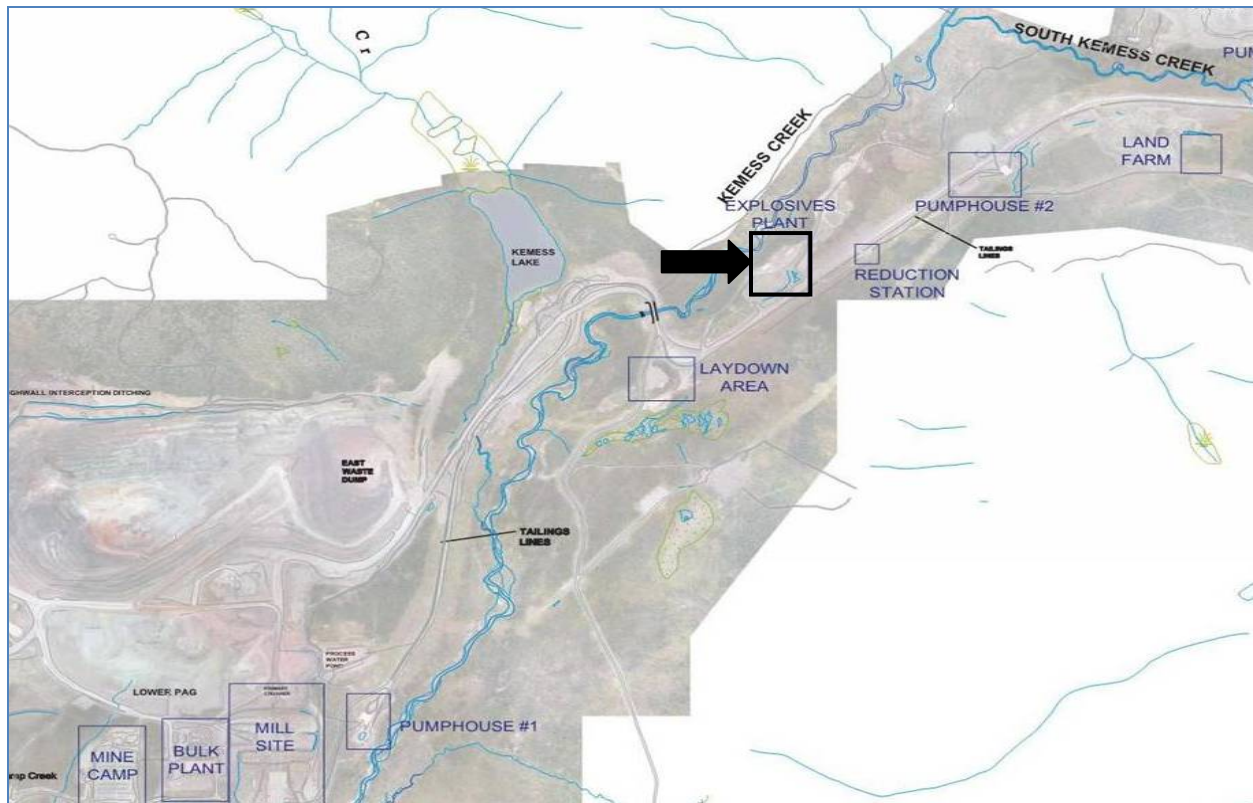


Figure 1. Location of BX Facility at the Kemess South Mine

Orica Canada Inc. operated the BX facility to fabricate ammonium-nitrate based explosive material to support extraction activities throughout the Kemess South Mine. The BX facility included two primary building structures; an ammonium nitrate storage building and a mixing plant (Figure 2). The BX facility site is generally flat with a gentle slope to the east. The site is bordered by treed areas to the east, west, and south and by a steep cliff face to the north at the base of which flows Kemess Creek.

NATURE OF CONTAMINATION

The main ingredients of the ANFO (Ammonium Nitrate/Fuel Oil) explosives are granular ammonium nitrate and diesel, which were stored in separate areas. Ammonium nitrate can be accidentally released to soil from storage facilities during operations as a result of tracking by or spillage from heavy equipment handling, losses through any large cracks in the foundation of the storage shed (Figure 3), or creation of dust followed by dustfall in the surrounding areas.

The resulting releases to exposed ground can decompose and remain in soil as ammonia and nitrate (AN) for a period of time after deposition, depending on site-specific environmental hydrological, hydrogeological, and biogeochemical processes. As a result, the AN released from the soil into groundwater and surface water, can potentially affect the quality of groundwater used for human consumption and/or affect aquatic life in nearby water bodies such as the adjacent Kemess Creek.

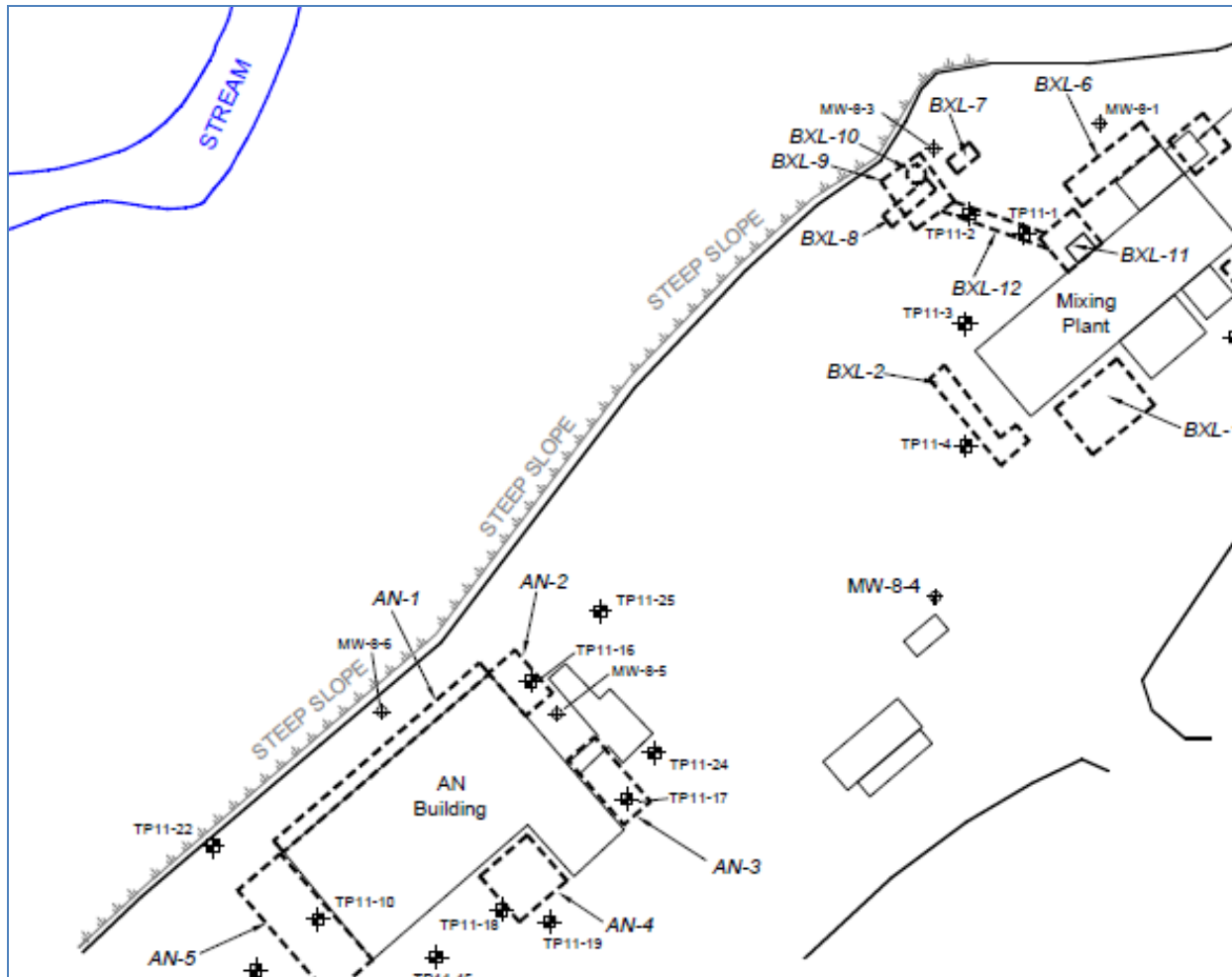


Figure 2. Former BX Facility Infrastructure and Topographic Features

Investigations at the BX facility did identify AN in soil and groundwater samples. Concentrations in soil varied across the site and with depth depending on the investigation location relative to historical storage and mixing operations. The highest soil concentrations measured were 540 $\mu\text{g/g}$ ammonia-N and 700 $\mu\text{g/g}$ total ammonia-N plus nitrate-N. Groundwater samples were collected over several events, and concentrations in several wells exceeded the applicable Contaminated Sites Regulation (CSR) Aquatic Life (AL) and/or Drinking Water (DW) Standards. The highest measured concentrations of ammonia-N and nitrate-N were 33 mg/L and 101 mg/L, respectively. Nitrite-N concentrations in groundwater were low, with concentrations typically much less than 2 mg/L. As outlined below, further management of the risks based on the combined sum of the two anions did not add any value to the overall risk management objectives.



Figure 3. Photograph of ammonium-nitrate storage shed with spills to ground surface.

REGULATORY REVIEW

The Kemess South Mine is currently undergoing closure, as regulated by the Ministry of Energy and Mines (MEM) under the *Mines Act*, which applies to the core areas of a producing mine, (e.g. the Pit). The Ministry of Environment (MOE), under provisions in the British Columbia Environmental Management Act (EMA), also provides regulatory oversight through the Water Stewardship Division (WSD - permitting and dams) and the Environmental Protection Division (EPD - human health and the environment including contaminated sites). The Contaminated Sites Regulation (CSR) and the Hazardous Waste Regulation (HWR) apply to the non-core areas of a producing mine at closure, including the BX facility.

Currently, there are no provincially adopted or federally endorsed generic soil quality guidelines for ammonia, nitrate, or nitrite developed for protection of groundwater or aquatic life. For provincial water quality, the CSR Groundwater Standards (Schedule 6) and the BC Water Quality Guidelines (WQG) define values which can be used to inform the development of leaching-based soil values (Table 1).

Table 1. Summary of Provincial Regulations Applicable to the Site

	Ammonia - N (mg/L)	Nitrate - N (mg/L)	Nitrate - N + Nitrite - N (mg/L)	Nitrite-N (mg/L)
BC CSR AL¹	15.1 ⁴	400 ⁵	400 ⁵	0.20-2.0 ^{5,6}
BC CSR DW²	Not defined	10 ⁵	10 ⁵	3.2 ⁵
BC WQG³	Not defined	30-d average to protect freshwater aquatic life is 3.0 mg/L Maximum is 32.8 mg/L	Not defined	30-d average for freshwater aquatic life is 0.020 mg/L (as N) for low chloride water (i.e. <2 mg/L) Maximum is 0.060 mg/L (as N) for low chloride water

Notes:

- (1) BC CSR Schedule 6, Column II Aquatic Life
- (2) BC CSR Schedule 6, Column V Drinking Water
- (3) BC Water Quality Guidelines for Nitrogen (Nitrate, Nitrite, and Ammonia), 2009
- (4) Ammonia standard varies with pH (1.31mg/L @ pH>8.55 to 18.4 mg/L @pH <7.0). Given groundwater pH at the site was typically less than pH 7.0, the BC CSR Schedule 6 aquatic life standard for total ammonia at pH<7 (i.e. 18.4 mg/L) has been applied. Value has been converted from total ammonia-NH₃ to total ammonia-N by multiplying by 0.822
- (5) CSR Standards for nitrate and nitrite expressed as nitrate-N and nitrite-N, respectively.
- (6) The nitrite (but not nitrate) aquatic life protective standard varies with chloride concentration, from 0.2 mg/L for [Cl⁻] < 2 mg/L to 2.0 mg/L for [Cl⁻] > 10 mg/L.

Note that the BC CSR aquatic life standards are applicable to groundwater prior to entry into waters frequented by aquatic life, while the BC Water Quality Guidelines are intended to be applied to the ambient environment.

As summarized above, since there is no BC CSR Schedule 6 Standard, BC Water Quality Guideline, (or Canadian Drinking Water Quality Guideline) for ammonia for the purpose of drinking water protection, it is not possible to calculate a leaching-based soil value for ammonia based on the potable water exposure pathway. CSR Schedule 6 groundwater standards do exist for ammonia for aquatic life protection, and for nitrate and nitrite for both drinking water and groundwater protection. Hence, site-specific leaching-based remedial objectives (SSROs) for soil values were determined for ammonia and nitrate.

CALCULATION OF A LEACHING-BASED SOIL VALUE FOR AMMONIA-N

The leaching-based SSROs for soil values were calculated using the simplified soil/water partitioning model (Equation 1) that describes the ability of contaminants to sorb to soil (EPA 1996) and accounts for the aerial extent of soil contamination.

$$C_s = C_w \times \left[K_d + \frac{E_p}{\rho_b} \right] \times DAF \quad (1)$$

Where:

- C_s = Leaching-Based Soil Value (mg/kg)
 C_w = Ground Water Quality Standard (mg/L)

K_d = soil/water partitioning coefficient (L/kg)
 E_w = water-filled soil porosity (L_{water}/L_{soil})
 ρ_b = dry soil bulk density (kg/L)
DAF = Dilution Attenuation Factor (unitless)

While there are far more complex and less conservative models for the calculation of leaching-based soil values for ammonia and nitrate, the often complex site-specific data required to use these models at the BX facility site were not available.

The K_d values used to calculate the leaching-based values for ammonia were obtained from Bohkle et al. (2006) and Bumb et al. (1981). The Dilution Attenuation Factor (DAF) accounts for the various physical, chemical, and biological processes that represent contaminant loss and mixing mechanisms in the unsaturated and saturated zones. The DAF also accounts for the aerial extent of soil contamination. A DAF of 10 was used to calculate the leaching-based soil values, which is believed to be generally protective of site conditions (EPA 1996; Ohio EPA 2008). This is based on the assumption that the aerial extent of soil contamination is approximately 0.5 hectares.

Overall, the BX facility SSRO soil ammonia leaching-based value for protection of groundwater to surface water used for aquatic life was calculated to be 143 mg/kg total ammonia, or 118 mg/kg ammonia-N.

Hemmera was unable to find any K_d values for nitrate that departed from zero (0) in primary literature. A K_d value of zero essentially indicates that nitrate in a soil/groundwater system will occur in predominantly dissolved phase with little to no sorption to soil surfaces. Biological uptake and N-conversions play a far greater role in N partitioning than physical sorption-desorption reactions. Since a soil-water partitioning co-efficient for nitrate or nitrite that departs from zero cannot be defined, a leaching-based soil value cannot be derived for nitrate or nitrite using the EPA (1996) method discussed above. An alternative approach for these contaminants, developed by the State of Kansas, was selected for the site. The details of the Kansas approach are presented below.

SELECTION OF A LEACHING-BASED SOIL VALUE FOR NITRATE-N

Based on sampling conducted at the site, the areas excavated to remove ammonia contamination in soil would also result in the removal of nitrate contamination in soil. Once the major source of nitrate and ammonia contamination is removed from the Site, it is reasonable to anticipate an appreciable reduction in the levels of ammonia and nitrate in groundwater.

The State of Kansas has developed a set of risk-based soil standards (updated Oct. 2010) for nitrate, nitrite, and ammonia in recognition of the fact that these are common soil contaminants in Kansas and several other mid-west states as a result of agricultural fertilizer spills, feedlots and animal wastes, septic systems and other sources (http://www.kdheks.gov/remedial/rsk_manual_page.htm; accessed October 14, 2011). Kansas has developed Tier 2 soil clean-up guidelines for many substances based on their potential to leach into groundwater, using methods very similar to those presented above for the ammonia leaching-based soil value. Because such an approach cannot be applied to nitrate or nitrite, the Kansas soil clean-

up guidelines were developed “*in consultation with Kansas State University agronomy experts to provide non-site specific soil clean-up goals that are generally protective of groundwater and capable of sustaining vegetative growth.*”

The technical basis of the Kansas derivations was not provided, but the leaching-based soil values presented are nonetheless considered to be in a credible range based on the dual role of nitrate and nitrite as nutrients for surface vegetation and as groundwater contaminants. The Kansas risk-based standards are presented below:

- Areas where no vegetation is present on soil:
 - Upper 0.2 m (8 inches): 85 mg/kg total nitrate+ammonia (- N)
 - >0.2 m depth: 40 mg/kg total nitrate+ammonia (- N)
- Vegetated areas (current or future, based on site reclamation goals):
 - Upper 0.6 m (24 inches): 200 mg/kg total nitrate+ammonia (- N)
 - >0.6 m depth: 40 mg/kg total nitrate+ammonia (- N)

These values were selected as additional leaching-based SSRO soil values for the purpose of risk-based remediation of the BX facility.

ATTENUATION CONSIDERATIONS

It should be noted that calculations were conservatively applied for ammonia-N. Remediation of soils using the leaching-based soil values described above do not consider additional environmental fate mechanisms that would reduce ammonia and nitrate flux into groundwater, and during groundwater transport to Kemess Creek. In particular, the approach described herein treats the ANFO derived contaminants of concern as essentially inert substances. In particular, some of the important processes not accounted for in the derivation of leaching-based soil values are described below:

- Assimilation: Both nitrate and ammonia (inorganic forms of N) are readily absorbed by plants and bacteria and converted to organic forms of N. This is a quantitatively important attenuation process.
- Nitrification: Ammonium can be converted to nitrate by soil dwelling nitrifying bacteria.
- Denitrification: Bacterial reduction of nitrates to elemental nitrogen ($N_2(g)$) under anaerobic conditions. Considerable denitrification typically occurs in apparently aerobic soil conditions as well, since: (i) several of the bacterial taxa involved are facultative, rather than obligate anaerobes; and, (ii) small scale reduced zones typically occur within oxidized soil environments based on the heterogeneous distribution of soil organic matter, and based on structuring on soil surface of bacterial biofilms.

Therefore, appreciable reductions in the dissolved concentrations of ammonia and nitrate would be expected based on abiotic and biotic reactions occurring along the transport pathway and at the outflow face for surface (i.e. slope face water seeps and/or Kemess Creek).

CONCLUSIONS

SSROs were determined for both ammonia-N and nitrate-N in soil to address potential human health drinking water and aquatic life risks at a former explosives manufacturing facility. Rather than bulk removal of all soils impacted with ammonia-N and nitrate-N ($>1,200\text{m}^3$), targeted excavations of $<400\text{m}^3$ removed soil with contamination above the SSROs (Figure 4); providing valuable efficiencies in effort and energy expended to complete remediation at this site in preparation for reclamation, while reducing risks to human and ecological receptors.



Figure 4. Remediation of Soil at the BX Facility

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