Estimates of water and solute release from a coal waste rock dump in the Elk Valley, British Columbia, Canada

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HIGHLIGHTS

• Long-term monitoring of efﬂuent discharge from a large scale waste rock dump
• Solute concentration varied through time due to pore volume ﬂushing and oxidation
• Elevated rates of net percolation into waste rock compared to natural water-shed
• First published long-term monitoring data of this kind

ABSTRACT

Long-term (1999 to 2014) ﬂow and water quality data from a rock drain located at the base of a coal waste rock dump constructed in the Elk Valley, British Columbia was used to characterize the release of three solutes (NO₃⁻, Cl⁻ and SO₄²⁻) from the dump and obtain whole dump estimates of net percolation (NP). The concentrations of dump derived solutes in the rock drain water were diluted by snowmelt waters from the adjacent natural water-shed during the spring freshet and reached a maximum concentration during the winter base ﬂow period. Historical peak base ﬂow concentrations of conservative ions (NO₃⁻ and Cl⁻) increased until 2006/07 after which they decreased. This decrease was attributed to completion of the ﬂushing of the ﬁrst pore volume of water stored within the dump. The baseﬂow SO₄²⁻ concentrations increased proportionally with NO₃⁻ and Cl⁻ to 2007, but then continued to slowly increase as NO₃⁻ and Cl⁻ concentrations decreased. This was attributed to ongoing production of SO₄²⁻ due to oxidation of sulﬁde minerals within the dump. Based on partitioning of the annual volume of water discharged from the rock drain to waste rock efﬂuent (NP) and water entering the rock drain laterally from the natural watershed, the mean NP values were estimated to be 446 ± 50 mm/a (area normalized net percolation/year) for the dump and 172 ± 71 mm/a for the natural watershed. The difference was attributed to greater rates of recharge in the dump from summer precipitation compared to the natural watershed where rain-fall interception and enhanced evapotranspiration will increase water losses. These estimates included water moving through subsurface pathways. However, given the limitations in quantifying these ﬂows the estimated NP rates for both the natural watershed and the waste rock dump are considered to be low, and could be much higher (e.g. −450 mm/a and −800 mm/a).

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1. Introduction

The global production of coal in 2013 reached 7823 M tonnes; coal generates >40% of the global electricity needs and is used in the production of over 70% of the world’s steel (World Coal Association, 2014). Surface mining of coal has increased globally over the last 30 years. In mountainous regions this can involve the removal of hundreds of meters of overburden which is then placed in adjacent valleys (Palmer et al., 2010). Fragmentation by blasting and exposure of previously saturated overburden to atmospheric conditions through dump placement results in accelerated weathering of the waste rock (Dang et al., 2002; Lindberg et al., 2011; Evans et al., 2014). When waste rock contains sulfide minerals such as pyrite, these activities result in oxidation of the pyrite and the release of chemical constituents of interest (Cl) to receiving groundwaters and surface waters (Lindberg et al., 2011; Griffith et al., 2012; Younger, 2004; Nordstrom, 2011). For example, this oxidation and buffering by carbonate minerals can release sulfate (SO$_4^{2−}$), calcium (Ca$^{2+}$), magnesium (Mg$^{2+}$), bicarbonate (HCO$_3^−$) and associated trace elements such as selenium (Se), iron (Fe), aluminum (Al), arsenic (As), zinc (Zn), and cadmium (Cd) (Cravotta, 2008; Griffith et al., 2012; Lindberg et al., 2011; Biswas et al., 2017; Essilfe-Dughan et al., 2017; Hendry et al., 2015). Nitrate (NO$_3^−$) from explosives used in mining can also be flushed from the waste rock dump and enter downgradient receiving waters (Mahmood et al., 2017). Other water-soluble compounds (e.g. NaCl, KCl, CaCl$_2$) in overburden or coal may be solubilized by water flowing through the waste rock (Yudovich and Kretis, 2006). Thus, chloride (Cl$^−$) can also occur at relatively elevated levels in dump effluent (Griffith et al., 2012).

The impact of Cl release from coal dumps on receiving surface waters is well documented in the literature. Electrical conductivity (as a measure of Total Dissolved Solids), Se, SO$_4^{2−}$, and other element concentrations have been observed to increase in receiving rivers and streams in proportion to upstream dump volume and the areal extent of mining (Lindberg et al., 2011; Bernhardt et al., 2012; Cormier et al., 2013; Hopkins et al., 2013; Ross et al., 2016). The release of Cls has been linked to increasing water salinization and aquatic life degradation (Palmer et al., 2010; Lindberg et al., 2011; Bernhardt et al., 2012). While a few studies show increased electrical conductivity and solute concentrations may last for decades (Lindberg et al., 2011; Evans et al., 2014), an understanding of the evolution of water and chemical releases from full-scale dumps over large spatial and long-time scales is lacking.

Canada is one of the top ten steelmaking coal producers in the world, generating 34 M tonnes in 2013 (World Coal Association, 2014). The mines located along the Elk Valley (Fig. 1) in the Eastern Kootenay mountains of overburden to atmospheric conditions through dump placement results in accelerated weathering of the waste rock (Dang et al., 2002; Lindberg et al., 2011; Evans et al., 2014). When waste rock contains sulfide minerals such as pyrite, these activities result in oxidation of the pyrite and the release of chemical constituents of interest (Cl) to receiving groundwaters and surface waters (Lindberg et al., 2011; Griffith et al., 2012; Younger, 2004; Nordstrom, 2011). For example, this oxidation and buffering by carbonate minerals can release sulfate (SO$_4^{2−}$), calcium (Ca$^{2+}$), magnesium (Mg$^{2+}$), bicarbonate (HCO$_3^−$) and associated trace elements such as selenium (Se), iron (Fe), aluminum (Al), arsenic (As), zinc (Zn), and cadmium (Cd) (Cravotta, 2008; Griffith et al., 2012; Lindberg et al., 2011; Biswas et al., 2017; Essilfe-Dughan et al., 2017; Hendry et al., 2015). Nitrate (NO$_3^−$) from explosives used in mining can also be flushed from the waste rock dump and enter downgradient receiving waters (Mahmood et al., 2017). Other water-soluble compounds (e.g. NaCl, KCl, CaCl$_2$) in overburden or coal may be solubilized by water flowing through the waste rock (Yudovich and Kretis, 2006). Thus, chloride (Cl$^−$) can also occur at relatively elevated levels in dump effluent (Griffith et al., 2012).

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Teck has five open-pit mining operations in the Elk Valley: Coal Mountain Operations (CMO), Elkview Operations (EVO), Line Creek Operations (LCO), Greenhills Operations (GHO), and Fording River Operations (FRO) (Fig. 1). The site for this study was the West Line Creek (WLC) watershed and dump at LO. The WLC watershed is approximately 10 km$^2$ in area and ranges in elevation from 1450 m above sea level (masl) at the outlet to 2650 masl on the western edge along the Witsukilska range (Shatilla, 2013). The western flank of the watershed consists of five alpine cirques formed between limestone and sandstone peaks. The cirques drain along a series of ephemeral streams that flow within colluvial deposits towards the pre-disturbance West Line Creek in the valley bottom (Fig. 2; Golder Associates Ltd., 1979). Most of the water movement within the unaffected catchment, with the exception of intermittent surface flows during heavy rain and snowmelt, occurs within the shallow groundwater system (Golder Associates Ltd., 1979; AMEC, 2013). Drainage from the western natural watershed is eventually expressed as surface flows in West Line Creek (pre-development) or flows into the rock drain (post-development) and eventually discharges at the southern end of the watershed. The unconsolidated overburden deposits in the valley bottom at the southern end of the watershed can reach a thickness of 64 m, and were deposited primarily by glacio-fluvial processes (i.e. braided river) separated by intervals of glacio-lacustrine and till deposition (Szmigielski, 2015).

The region has a humid continental climate with low relative humidity and highly variable precipitation and temperature. Mean annual precipitation at Sparwood, BC (Fig. 1; ~23 km south of WLC; Environment Canada, 1981–2010 Climate Normal, elevation: 1138 m) is 613 mm with ~67% falling as rain. The mean annual temperature at Sparwood is 4.4 °C, ranging between mean monthly temperatures during the summer of 10 °C and winter from ~−4 °C to ~−7 °C. Based on a local annual temperature and precipitation lapse rate of approximately ~0.48 °C/100 m and ~21 mm/100 m (Barbour et al., 2016), mean annual precipitation for the WLC dump ranges from 689 to 823 mm and mean annual temperature from 2.7 to ~−0.4 °C.

The WLC dump covers approximately 2.7 km$^2$ (27%) of the watershed and runs along the eastern flank, extending from the northern most extent of the watershed to within 0.5 km of the southern end where the rock drain and creek flow into Line Creek (Fig. 2). Dumping at WLC began at the south end in 1981, with a final waste rock volume in 2011 of 2.1 × 10$^8$ BCM. The dump has surface elevations ranging from 1500 masl in the south to ~2155 masl in the north, a maximum dump thickness of ~255 m, and an average thickness of ~115 m. The waste rock consists primarily of mudstone and siltstone interbedded and
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