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Evaluation of Acceptable Sulfate Concentrations for Quitchupah and Ivie Creeks
Consolidation Coal Company
Utah Division of Water Quality
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The Consolidation Coal Company (CCC) is requesting an allowable discharge concentration for total dissolved solids (TDS) of 3800 mg/L (JBR, 2009) into Quitchupah Creek, Emery County, Utah. TDS is not a chemical-specific measurement and is a poor predictor of potential effects on animal health (Raisbeck, undated). The purpose of this analysis is to evaluate whether the proposed increase would continue to support the use of the water for cattle.

Agricultural beneficial uses include crops and animal husbandry. Use of the water for irrigation of crops is not an existing use and may not be viable because of remoteness, low quality soil, and topographic challenges in moving the water from the creek to the uplands. The viability of using the water for crops is not part of this evaluation. The existing agricultural use on Quitchupah Creek is limited to cattle grazing on land leased under permit from the U.S. Bureau of Land Management (JBR, 2009).

CCC submitted analytical data dated June 30, 2009 from samples collected of the groundwater that is discharged from the mine. The sulfate component of TDS was determined to be the constituent most likely to impact cattle based on a review of NRC (2005) and Raisbeck (undated), *i.e.*, the other TDS constituents are below levels shown to be adversely affect cattle and wildlife. Sulfate concentrations ranged from 2600 to 2700 mg/L in the two samples.

Sulfur Toxicology

Sulfur is an essential nutrient that can be toxic to some animals, especially to ruminants. Monogastric mammals are much less sensitive (NRC, 2005). Therefore, if ruminants are protected, other monogastric mammals such as deer or horses should be protected.

Adverse effects observed in cattle include diarrhea, decreased growth, decreased water intake, decreased food intake, interference with micronutrients, and polioencephalomalacia (POE). POE is characterized by brain lesions and can be fatal. POE is also associated with decreased water and food intake (Gould, 1997).

For cattle, potential sources of dietary sulfur include feed, water, and supplements. Feed intake is relatively constant when compared to water intake because water intake is affected by ambient temperature and lactation status. However, the concentration of sulfur in feed may vary significantly thereby resulting in corresponding variations in sulfur intake from feed. NRC (2000) reports sulfur concentrations in various cattle feeds ranging from 0.1 to 0.9% excluding feeds that are not likely present in Utah (*e.g.*, citrus). Raisbeck (undated) reports that sulfur concentrations in Wyoming forage range from 0.14 to 0.48% and that a concentration of 0.2% is "conservative" for evaluating sulfur intake from grazing. No Utah-specific values for the sulfur content of forage were found. For the purposes of this evaluation, a sulfur concentration of 0.2% in forage is assumed.

The NRC (2005) recommends that sulfur intake in cattle be restricted to nutritional requirements (0.15 percent sulfur in feed). The NRC (2005) also recommends a maximum tolerated dose (MTD) of sulfur equivalent to a concentration of sulfur in feed of 0.5 % for cattle whose feed is at least 40% forage. Water with sulfate up to 2500 mg/L should be safe (NRC. 2005).

Animals fed high concentrate diets, such as at feedlots, are limited to an MTD of 0.3% in feed. Water concentrations of sulfate should be limited to 300 mg/L (NRC, 2005). The high concentrate diets are hypothesized to favor the production of H_2S by the stomach flora in ruminants. H_2S is suspected to be a major causative agent of the POE from sulfur (Loneragan et al., 1998; Gould, 1998).

Sulfur intake from water depends on the sulfate concentration in water and amount of water ingested. Water intake increases as temperature increases above 40° F (Winchester and Morris, 1956; NDSU, 2008). Water intake as a percentage of body weight varies negatively with increasing size, e.g., calves consume a little more water as a percentage of body weight than mature bulls. Lactating cows intake more water than non-lactating cows because milk is mostly water. Recommendations for maximum sulfate concentrations in drinking water range from 1,000 to 3,000 mg/L (Table 1). Many of the recommendations are presented as a range demonstrating the variability and uncertainty in predicting acceptable levels of sulfur based on only the concentrations of sulfate in water.

The dose equivalent to the MTD of 0.5 percent sulfur content in feed is 1.5E-04 kg S/kg BW assuming a feed intake of 3 percent of body weight. If feed intake is changed to 2 percent of body weight, the MTD is 1.0E-04 kg S/kg BW.

For Quitchupah Creek, an acceptable maximum concentration of sulfate in water is estimated as 2,000 mg/L. A drinking water concentration of 2000 mg/L sulfate results in an estimated total sulfur dose of 1.4E-04 kg S/kg BW. This value was calculated assuming a 273 kg steer consumes 8 kg of forage (3 percent of body weight) that has an average sulfur concentration of 0.2% (Raisbeck, undated) and drinks 38 L/day of water (NDSU, 2008).

Using the Colorado State University (CSU) online calculator at http://www.dlab.colostate.edu/webdocs/tools/calculator.htm with the assumptions of an average sulfur content of feed of 0.2 percent and a sulfate concentration in water of 2000 mg/L results in a sulfur intake equivalent of 0.47 and 0.68 percent depending on the quantity of water ingested. The 0.68 percent equivalent in feed assumes a water ingestion rate of 48 L/day and results in a sulfur dose equivalent to 1.7E-04 kg S/kg BW. This dose exceeds the MTD equivalent of 1.5E-04 kg S/kg BW.

These estimates demonstrate that the proposed acceptable concentration of 2000 mg/L sulfate is likely protective of severe health effects in cattle at Quitchupah and Ivie Creeks. This amount of sulfate in water will exceed the nutritional requirement for sulfur but will be less than the MTD. At 2000 mg/L sulfate in water, intake of sulfur may result in less-than optimal growth rates and interfere with trace element absorption, specifically copper (Table 1). Cattle are often copper deficient in Utah and increasing dietary sulfur could exacerbate copper deficiencies (USU, 1997a).

Table 1
Recommended Maximum Concentrations of Sulfate in Drinking Water for Beef Cattle

Source	Concentration	Comments
Ellis (undated)	500-1500	Generally safe, trace mineral availability may be reduced, may decrease performance in confined cattle
NDSU (2008)	1000	
SDSU (2004)	1500-2500	Notes that water may be significant source of total sulfur.
Raisbeck (undated)	1000	
NRC (2005)	2500	<40% of diet from forage
USU (1997)	1700	
NMSU (2009)	500-1500	Generally safe, may interfere with trace element nutrition
MSU (undated)	2500-3500	Very laxative; not recommended for pregnant or lactating cows, cattle in confinement, horses, or sheep; Unacceptable for poultry. 4500 mg/L not recommended for use under any circumstances.
Patterson and Johnson, 2003	2000-3000	Generally safe but may reduce performance.
Weeth and Hunter (1971) Weeth and Capps (1972)	2500	Assuming hay diet

The NRC (2005) MTD is based on a percentage of sulfur in feed. NRC (2005) concludes that 2500 mg/L sulfate would be acceptable for range cattle but the assumptions for sulfur content in feed and quantity of feed are not documented. The estimates of acceptable dose are relatively insensitive to the assumption of the amount of feed cattle consume. This insensitivity is an artifact of the MTD being expressed as a percentage in feed. Assuming that cattle consume 2 percent of their body weight in feed results in a lower intake and a lower MTD dose (kg S/kg BW). These two factors tend to offset each other indicating that the food intake assumption is not a critical parameter.

Considerations for Utah

Several factors need to be considered before applying this standard to other locations in Utah. Climate, dairy cow water consumption rates, lactation condition, and sulfur in cattle feed all need to be considered. Other husbandry animals such as poultry and crop irrigation should also be explicitly evaluated.

Cattle fed concentrate diets have lower tolerances for sulfur intake. The epigenesis of POE in cattle from sulfur is mult-factorial but high protein or readily fermentable carbohydrate diets common in concentrate diets increase the sensitivity to sulfur (Loneragan et al., 1998; Gould, 1998). The NRC (2005) recommends an MTD equivalent to 0.3 percent sulfur in feed if their diet is less than 15 percent forage. POE has been observed at dietary concentrations of 0.35 percent sulfur for confined cattle (NRC, 2005).

Zinn et al. (1997) observed reductions in feed and weight gain for feedlot cattle when dietary sulfur was increased from 0.2 to 0.25 percent. The findings of Zinn et al. (1997) are clouded because ammonium, as part of ammonium sulfate, may have contributed to the observed effects (NRC, 2005). Loneragan et al. (2001) observed decreases in weight gain in feedlot cattle given water with 600 mg/L. The etiology of the weight gain decreases was not identified. No good experimental studies were found that evaluate sulfur intake on growth for grazing cattle as compared to confined cattle. Many of the existing studies are observational or with a small number of animals making extrapolation difficult. Based on Loneragan et al. (2002), a reasonable conclusion is that effects on growth likely occur at concentrations lower than cause POE and MTDs for protecting foraging cattle from POE may not be protective for growth. An increasing amount of POE is being reported in the literature but the focus on POE may overlook other significant adverse effects (Gould, 1998).

Several of the extension services in nearby states have investigated POE cases when sulfate concentrations in water appeared to be acceptable. Hayden (2003) observed a high incidence of POE in grazing cattle with access to water containing 3400 mg/L sulfate. The apparently small difference between nutritional requirements (0.15 percent sulfur in food) and toxic effects (0.3 to 0.5 percent sulfur in food) supports that caution should be exercised when setting standards for sulfate in cattle drinking water because of the narrow margin between no observable effects and frank effects (i.e., POE).

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