Risk Management Considerations for Wyoming Livestock Water Quality Criteria

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Executive Summary

The Wyoming Environmental Quality Council (EQC) is considering updating numeric chemical constituent criteria in Chapter 1 of the Wyoming Water Quality Rules and Regulations. The updated criteria are proposed for the protection of livestock. The proposed ruling has been put on hold until the EQC reviews a risk assessment completed by the University of Wyoming (Raisbeck et al. 2007).

While a risk assessment is a valuable tool for identifying the nature and magnitude of animal risks, a risk assessment does not provide all of the information the EQC needs for a balanced decision-making process. As mandated by the state (W.S. 35-11-302), the EQC must consider a range of effects on the people, animals, and plants, as well as social and economic values. In effect, the state mandates that a risk management evaluation be performed before final selection of water quality criteria.

This paper reviewed the findings of the University of Wyoming's risk assessment ("UW report") in the context of a risk management framework. The review focused on three constituents: fluoride, sulfate and sodium, because these constituents are already regulated by the state and criteria recommended in the UW report appear to contradict other assessments (e.g., Geomega 2007) as well as published water quality criteria for livestock.

The review found that the UW report does not contradict the current fluoride, total dissolved solids (TDS) and sulfate criteria for the protection of livestock as defined by the EQC. The UW-recommended criteria for sulfate and fluoride differ from the current limits because toxicological endpoints considered in Raisbeck et al. (2007), which were consistent with protection of dry matter intake rates and dental hygiene, differ from the goals of the EQC: protection of growth and reproduction and prevention of acute effects. References provided in UW report support statistically significant effects from sodium exposure over 2,000 mg/L (5,000 NaCl equivalent) and sulfate exposure near 3,000 mg/L for protection of growth and reproductive endpoints. Additional literature review for sulfate, and anecdotal accounts from Wyoming livestock owners, indicate that exposure of cattle to as much as 3,100 mg/L sulfate is not likely to result in adverse effects on

growth and reproduction. Available fluoride literature pertaining to growth and reproductive effects supports a 4 mg/L water quality criterion.

The data presented in the UW report and elsewhere were also considered within the larger risk management framework by evaluating three kinds of balancing criteria relevant to Wyoming's citizens and their livestock industry: practicability, natural industry variability, and incremental risk. The analysis found that lowering these criteria to levels recommended by the UW report is not practicable and will not result in any incremental risk reduction in growth or reproductive effects to cattle. Moreover, changing the water quality criteria to those recommended in the UW report will not balance the potential positive effects on livestock from changing water quality compared to negative effects on ranchers, other industries, and potentially the state from lost water availability.

Many of the conventional oil and gas produced water discharges in Wyoming will not meet the UW report's recommended water quality criteria, as well as some coal bed methane gas producers. It is not practicable for these surface water producers to treat water to meet the proposed criteria. Many producers have indicated that re-injection will be a likely alternative if faced with unnecessarily stringent water quality standards, resulting in lost water availability to Wyoming citizens and their livestock. The ramifications of lost water quantity will far outweigh the potential benefits to livestock. Moreover, it is of questionable practicability for industry to meet the UW-recommended criteria for sulfate, sodium and fluoride when the reality in Wyoming is that natural background water quality alone does not meet these criteria in many cases.

Natural industry variability in cattle production was calculated from USDA data sets and compared to a metadata analysis of literature data on sulfate exposure to cattle (there was not enough data to run a similar analysis for fluoride or sodium). The metadata analysis shows that variability in cattle production as much as 5% may occur if cattle are exposed to sulfate levels between 1,200 mg/L and 3,000 mg/L. However, this potential variability in cattle production is within natural industry variability for Wyoming, suggesting that there is no added degree of injury to livestock from exposure to current sulfate limits.

The incremental risk to livestock growth, reproduction or acute effects from exposures to current water quality limits is essentially zero compared to natural background water quality. This is because cattle are already exposed in many cases to sulfate, sodium or fluoride concentrations near current limits. Thus, there would be no reduction in the "degree of injury" to animals if the water quality limits were changed.

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1 Introduction

The Wyoming Environmental Quality Council (EQC) is considering updating numeric chemical constituent criteria in Chapter 1 of the Wyoming Water Quality Rules and Regulations. The updated criteria are proposed for the protection of livestock (the proposal is referred as the agricultural use rule). The proposed ruling has been put on hold until the EQC reviews a risk assessment completed by the University of Wyoming (Raisbeck et al. 2007).

While a risk assessment is a valuable tool for identifying the nature and magnitude of animal risks arising from exposure to environmental constituents, a risk assessment does not provide all of the information the EQC needs for a balanced decision-making process. As mandated by the state (W.S. 35-11-302), the EQC must consider a range of effects on the people, animals, and plants, as well as social and economic values. In effect, the state mandates that a risk management evaluation be performed before final selection of water quality criteria.

This paper presents a risk management framework and reviews the findings of the University of Wyoming's risk assessment ("UW report") in the context of this framework. Secondly, the data presented in the UW report and elsewhere are considered within the larger risk management process by evaluating some balancing criteria that are relevant to Wyoming's citizens and their livestock industry.

2 A Risk Management Framework

The risk assessment (Raisbeck et al. 2007) provided a toxicological analysis of some of the constituents under consideration in the proposed ruling. However, the risk assessment did not provide all of the information the EQC needs to achieve a risk management decision. In fact, Wyoming statute mandates that the state consider a range of criteria before recommending water quality standards. These criteria (W.S. 35-11-302(vi)) include:

(A) the character and degree of injury to or interference with the health and well-being of people, animals, wildlife, aquatic life and plant life affected;

(B) the social and economic value of the source of pollution;

(C) the priority of location in the area involved;

(D) the technical practicability and economic reasonableness of reducing or eliminating the source of pollution; and

(E) the effect upon the environment.

In effect, the state requires a risk management evaluation before setting water quality criteria. Risk management is the process of determining which action to take when a risk assessment indicates that a probability of harm exists. The goal of the risk management process should be to determine an acceptable threshold of effect that incorporates the values of the state's citizens and balances the benefits and costs to all affected parties.

Risk management is regularly employed at every level of regulatory decision-making following roughly the same procedure (Figure 1). Risk management evaluations will generally include:

1. Identification of a potential problem: a potential problem to public or animal health will be identified through anecdotal evidence, report or data collection. In the case of the proposed ruling, public input was basis of identifying a potential problem with water quality criteria for livestock.

2. Data collection: a complete characterization of the site or media in question is conducted, as well as collection of background or "baseline" conditions. This can include sample collection and/or toxicological literature review. Data collection so far for the proposed ruling has included some toxicological review.

3. Risk assessment: a rigorous protocol is typically followed, which includes problem formulation, exposure and effects analysis, and risk characterization. Considerations of background and site-specific data will be incorporated into the assessment. A risk assessment was submitted to the EQC (Raisbeck et al. 2007) for consideration in the proposed ruling.

4. Alternative evaluation: a feasibility study or equivalent is conducted that evaluatess a number of alternative actions to reduce risk. Alternative evaluation considers the impact of an action on protection of human health and the environment, of source control, feasibility of meeting the standards, and impacts to other resources as a result of the action (i.e., increased risks elsewhere). Wyoming mandates that several balancing criteria be evaluated, as listed in W.S. 35-11-302(vi)).

5. Alternative selection: the final step in the risk management evaluation is to select the best alternative. Alternative selection will involve a description of the selected remedy, and the justification for that selection. The final step for the EQC will be to select water quality criteria for livestock that are protective of growth, reproduction and acute effects.

The risk assessment partially fulfills the evaluation process for the ruling proposal (Figure 2), however, important data gaps remain. A key item needed to complete the risk management evaluation is to define the term "measurable decreases," a concept that forms the basis of EQC's criteria selection for livestock protection. This paper proposes to more precisely define "measurable decreases" by considering toxicological and statistical relevance of the UW report findings.

To achieve a risk management evaluation, however, it is not enough to identify a statistically significant and toxicologically relevant effect; the effect must be put into context of relevancy to Wyoming's citizens and their livestock industry (i.e., alternatives evaluation). Therefore, a number of balancing criteria are presented which put the risk assessment data in the context of some larger risk management considerations. These balancing criteria include practicability, normal industry variability and incremental risk.

3 Review of UW Report in a Risk Management Framework

This review focused on three constituents: fluoride, sulfate and sodium, because these constituents are already regulated by the state and criteria recommended in the UW report (Raisbeck et al. 2007) are incongruous with other assessments (e.g., Geomega 2007) as well as published water quality criteria for livestock.

According to the proposed ruling, the aim of the surface water quality criteria is to prevent a "measurable decrease" in livestock production (Appx H, a, p H-1). The proposed ruling explains that the basic concept behind protecting livestock production is to "ensure that water quality is not acutely toxic to livestock or does not contain pollutants in concentrations that would affect growth or reproduction. (section b.i., p. H-2)."

No further definition of livestock protection is provided in the proposal. Consequently, what constitutes a "measurable decrease" in livestock production is subject to wide interpretation, but not all interpretations are relevant, given the more explicit definition that follows, which is the protection of growth and reproduction, and prevention of acutely toxic responses.

Moreover, protection of livestock endpoints relevant to the livestock industry is implicit in the definition of "livestock protection" because livestock is a commodity. Thus, indices of growth, reproduction or acute effects should have industry values in mind, and these values can differ from considerations of non-commodity populations of animals.

We propose that the term "measurable decreases" can be more precisely defined by selecting appropriate toxicological endpoints and evaluating statistical relevance that are relevant to livestock industry values, and reviewing the findings of the UW report within this context. Statistical relevance and toxicological endpoints are two basic concepts utilized in risk assessments and risk management evaluations. Statistical analysis provides an objective means to determine what constitutes a "measurable" effect. Toxicological endpoints are explicit statements of an environmental value that is to be protected.

3.1 Statistical Relevance

Statistical analysis provides an objective means to determine whether an observed phenomena is the result of random chance or if there is a relationship between two variables, such as exposure to sodium and effects on milk production. Thus, statistical relevance is the essence of a "measurable" effect. A toxicological study or data analysis that does not identify a statistical effect therefore can not objectively identify a "measurable decrease."

Statistical significance is often expressed in terms of a p-value (the probability of error). The p-value represents an index of reliability of a result. The lower the p-value, the more probable that the relation between 2 (or more) variables in the test is a reliable indicator of the relation between those variables in the population. Standard statistical analyses for environmental effects include determining significant differences between populations to $p<0.05$ or in some cases, $p<0.1$ (ASTM 2002).

Furthermore, when quantifying a threshold of effect on a species, statistical differences between populations exposed to varying levels of an environmental constituent are needed. Ideally a no-adverse effect threshold or level (NOAEL) and low-adverse effect level (LOAEL) should be identified by statistical analysis. The NOAEL selected represents the highest dose reported not to have an adverse effect on the test animal, while the LOAEL represents the lowest dose reported to have a significant adverse effect on the test animal. Both LOAELs *and* NOAELs are important to the risk analysis process, because the two numbers essentially characterize the full range of probability of effect. Both risk assessments and risk managers must consider the full spectrum of probability of effect in order to draw conclusions about risk. A risk assessment which has only considered NOAEL effects, for example, has not identified a "threshold of effect;" consequently, a risk management decision based only on an evaluation of a NOAEL can bias decisions unnecessarily low.

3.1.1 Sodium

Of the endpoints identified in UW report's derivation of criteria, only sodium's endpoints are consistent with EQC's objectives for chronic livestock protection (growth and reproduction). However, upon review of the references provided for the sodium criteria (Table 1), none of the references supplied identify a 1,000 mg/L sodium (Na) NOAEL. In fact, only 2 references are provided that report effects on milk production in which only Jaster et al. (1978) shows a marginally significant effect ($0.05<p<0.08$) on milk production at 5,000 ppm Na (12,600 mg/L sodium chloride (NaCl) equivalent). Additional studies not referenced in the UW report (Table 2) show no effect on milk production from sodium intake of at least 3,500 mg/L NaCl (Bahman et al. 1993). Solomen et al. (1995) reported a faster rate of decline in milk production in cows exposed to 870 mg/L NaCl compared to a control group exposed to 325 mg/L NaCl; however both groups were essentially sodium deficient, as daily nutritional requirements of sodium for cattle are at least 0.1%, or 1,000 mg/L NaCl (NRC 2005).

Of the studies on cattle growth (3 referenced), none identified a statistically significant NOAEL. Harvey et al. (1986) attempted to identify a NOAEL of 2,250 ppm Na (5,700 mg/L NaCl equivalent) based on a growth decrease of 0.18 kg per day in corn silage-fed cattle over the 84 day trial, but this rate of growth was not statistically different than the control group. Furthermore, the study reported a growth *increase* of 0.04 kg per day in livestock given 17,890 ppm Na (45,500 mg/L NaCl equivalent) when livestock were fed roughage diets.

Some studies were only partially referenced in the UW report, for example, the sodium experiment on rats by Heller (1933) was referenced, but not the experiments on cattle or other livestock. Other relevant studies were not referenced at all. An additional 16 studies specific to chronic sodium exposure to cattle are available (Table 2) that are peer reviewed and statistically identify NOAELs and/or LOAELs. These additional studies show that a concentration of 5,000 mg/L NaCl (1,970 mg/L Na equivalent) did not affect cattle growth or reproduction.

In the absence of sodium data, the UW report recommended a default limit of 500 ppm total dissolved solids (TDS) to protect livestock. The individual constituent makeup of TDS in Wyoming's surface water bodies is variable; some of produced water effluent is NaCl-dominated (Geomega 2007). However, even with magnesium or potassium-dominated TDS waters, no effects were found lower than 6,000 mg/L TDS (Embry et al. 1959). In fact, the US EPA (1976) advises that the lowest TDS water quality limit for livestock and poultry (those exposed to highly alkaline waters containing sodium and calcium carbonates) be 5,000 mg/L. This is also consistent with NRC (1974, 2005) recommendations of 5,000 mg/L TDS for all livestock.

Sulfate can also dominate TDS concentrations, but criterion for this constituent is already addressed. Thus, the 500 ppm TDS criterion is not supportable, either by the references provided in the livestock report or by the general literature.

3.2 Toxicological Relevance

Toxicological endpoints are explicit statements of an environmental value that is to be protected. Toxicological endpoints should be developed following consideration of the structure and function of the system that is to be protected, policy goals and other societal values (USEPA 1998). Endpoints are vaguely described in the proposed ruling as "ensur[ing] that water quality is not acutely toxic to livestock or does not contain pollutants in concentrations that would affect growth or reproduction. (section b.i., p. H-2)."

To more precisely define toxicological endpoints, adverse growth effects should be specifically defined as weight loss measured over a chronic (i.e., long term) time period. Indirect indices of growth, including feed or water intake rates and digestibility should not considered adequate endpoints in themselves to evaluate the potential effects on growth of livestock species, because research has shown that there is considerable individual variation in feed and water intake above and below that expected or predicted on the basis of size and growth (e.g., Zinn 1994, Hickman 2002, Schwartzkopf-Genswein 2004). Individuals of the same body weight often require widely different amounts of feed for the same level of production (NRC 2000). In addition, some early studies

considered microorganism changes in the ruminant gut, or other types of biochemical changes in the body, as an indicator of adverse effects (NRC 1980), but these effects have not been clearly correlated with growth impairment. Thus, only studies or risk assessments which measure the effect on weight loss or gain in addition to intake rates or other performance parameters such as digestibility should be used to form the basis of livestock water quality limits under consideration by the EQC.

Similarly, adverse reproductive effects should be defined as declines in calving rates, or milk production rates. Other measures of reproduction which are not relevant to the livestock industry should not be considered in the context of the proposed ruling.

Finally, the term "acutely toxic" should refer to the mortality or adverse effects clearly linked to death or loss of livestock marketability on organisms following soon after a brief exposure (less than 2 weeks; Hodgson and Levi 1987) to a chemical agent. Symptoms affecting marketability would include polioencephalomalacia (PEM), dyspnea, blindness, ataxia, hemorrhage, seizures, paralysis, cardiac arrest or coma. Conversely, symptoms such as diarrhea, dehydration, gut microbial changes, or mild behavioral changes are sometimes cited as "effects" in toxicological studies but should have no consequences to a livestock's potential marketability.

3.2.1 Fluoride

The UW report stated that the recommended water quality criterion for fluoride (F) was based on dental and osteal (skeletal) effects. The report concluded that a water quality criterion of 2 mg/L F should protect livestock from fluorosis, which generally consists of tooth discoloration and mottling. Except in extreme cases, this endpoint is neither a toxicologically nor an economically significant adverse effect. The U.S. Center for Disease Control and Prevention considers this a cosmetic effect harmless to the health of humans and Phillips et al. (1960) noted that there was no instance where tooth mottling decreased the economic value of livestock. In all of the studies on the effects of fluoride in animals, none have shown that tooth mottling causes injury to cattle or other animals

that is measurable in terms of milk production, feed consumption, weight gain, growth, reproduction, development, life span, or other effects relevant to livestock producers or toxicologists.

The National Research Council (NRC) review of fluoride toxicity in livestock identifies a criterion of 2 mg/L F for the protection of tooth mottling, but states, "At least a several-fold increase [from 2 mg/L] seems, however, required to produce other injurious effects." In fact, NRC (2005) recommends a limit of 40 ppm F for cattle, and higher limits for other types of livestock.

Of the studies reviewed in NRC (1980) that measured F effects on livestock growth and reproductive effects (Table 3), a minimum of 49 ppm F is identified to result in decreased milk production in dairy cows as reported by Stoddard et al. (1963). The current fluoride criterion for the protection of livestock is 4 mg/L; fluoride levels in Wyoming forage are low, about 25 mg/kg (Newman 1984), and hence there is no essentially no risk of additive dosing from forage content. The range of NOAELs identified from the studies on all types of livestock effects on growth or reproductive was 25 ppm F to over 200 ppm F. These findings are not consistent with a recommended fluoride criterion of 2 mg/L.

3.2.2 Sulfate

The sulfate (SO_4) review of effects on cattle was the most comprehensive compared to the other constituents (Table 4). "Acute" effects (PEM, death) from exposure to 2,000 mg/L SO_4 were stated in the UW report (but not referenced; p.54-55) but the references reviewed in earlier paragraphs provided do not support this statement. In fact, cattle exposed to at least 3,780 mg/L SO_4 (S content in dry matter not reported) resulted in suspected but unconfirmed cases of PEM (Ward and Patterson 2004). Other references indicate higher sulfate doses required to produce acute effects. Furthermore, in the Ward and Patterson (2004) study, death rates between groups given 390 mg/L SO_4 or 3,780 mg/L SO_4 were not statistically different. It should also be noted that the Ward and Patterson (2004) study occurred over a subchronic time period, not an acute timeframe. In fact, studies which met acute conditions reported PEM and other effects at much higher sulfate concentrations (>5,500 ppm SO_4 equivalent).

Although chronic water quality criteria were supposedly derived from growth endpoints, the chronic criteria were more consistent with feed efficiency and feed intake endpoints. The UW report stated that sulfate levels between 500 and 1,500 mg/L can result in adverse effects on growth, but none of the references provided support this statement. The provided references show that growth appeared not to be significantly affected at much greater sulfate exposures. Patterson et al. (2002) showed growth effects on cattle in a feedlot environment occurred at 8,780 ppm sulfate equivalent; if Wyoming's cattle are routinely exposed to 0.2% S in open range grasses (Raisbeck et al. 2007), the resulting water exposure would have to be ~2,700 mg/L sulfate to match the LOAEL identified by Patterson et al. (2002). Feedlot environments are relatively more stressful to cattle than open range; Johnson and Patterson (2004) demonstrated that the stressful conditions in feedlots resulted in reduced sulfate toxicity thresholds to growing cattle compared to conditions in open rangeland environments. In fact, on the open range, Johnson and Patterson (2004) found that 3,000 mg/L sulfate in drinking water did not affect growth. The findings in Johnson and Patterson (2004) match anecdotal accounts from Wyoming livestock owners, who have indicated that their cattle do not appear to be negatively affected by sulfate levels as high as 3,100 mg/L (Geomega 2007).

The form of S administered to livestock should be considered in a toxicology review. Sadler et al. showed negative growth effects at 7,200 ppm sulfate equivalent, but S supplements were administered in a magnesium-potassium compound, and growth effects have been found to occur and lower dosages from these constituents (Grout et al. 2006, Embry et al. 1959). Although Albert et al. (1956) reported a LOAEL of 500 ppm sulfur (S), the form administered was methionine, an organic form of S; it is well known (NRC 2005) that toxicity of sulfur depends heavily on the form of S administered, with sulfate being one of the least toxic forms of S. The water quality criterion under consideration is an inorganic S form (sulfate); thus, only inorganic forms of S should be considered in any toxicity review relating to this criterion.

The chronic sulfate limit identified in the UW report is consistent with the studies referencing effects on dry matter and water intake rates. As reported by Harper et al. (1997), dry matter intake rates of cattle exposed to 1,000 mg/L SO_4 were statistically

lower when on a low nutritional diet. Sulfate content of the dry matter consumed was not reported, so at a minimum of 0.01% sulfate in dry matter, this would result in an equivalent LOAEL of 1,200 mg/L SO_4.

4 Balancing Criteria

It is not enough to identify a statistically significant and toxicologically relevant effect; the effect must be put into context of relevancy to Wyoming's citizens and their livestock industry. As mandated by the state (W.S. 35-11-302), the EQC must consider a range of effects on the people, animals, and plants, as well as social and economic values. An acceptable threshold of effect should be determined for each constituent that incorporates the values of the Wyoming livestock industry and the state's citizens, and balances the benefits and costs to all affected parties.

It is beyond the scope of this report to address all risk management considerations, however this paper will address the fundamental basis of the proposed ruling, which is defining unacceptable harm to livestock from chemical exposure to surface water bodies in Wyoming. The data presented in the UW report were evaluated within the larger risk management process by considering three types of balancing criteria relevant to Wyoming's citizens and their livestock industry: practicability, natural industry variability and incremental risk.

4.1 Practicability

Practicability of meeting the recommended water quality criteria is a fundamental issue in risk management evaluations, and a criteria listed in the Wyoming statute (W.S. 35-11-302(vi)D).

Many of the current discharges in Wyoming from coal bed natural gas (CBNG) and conventional oil and gas producers will not meet the UW report's recommended criteria. Available outfall data from conventional oil and gas producers in the Bighorn and Platte River basins show exceedences of proposed criteria for sulfate (Table 5). Most, though not all, CBNG producers in the Powder River basin will meet recommended criteria (Table 5), however CBNG water quality is less pristine elsewhere in Wyoming (Bensen et al. 2005), with concentrations regularly exceeding 500 mg/L TDS (Jackson and Reddy 2007). Many current producers do not monitor sodium water quality at all; if the

alternative TDS benchmark of 500 mg/L were employed in these cases, nearly all basins everywhere would exceed the recommended limit.

It is not practicable for surface water producers to treat water to meet the recommended criteria. Many producers have indicated that re-injection will be a likely alternative if faced with unnecessarily stringent water quality standards, resulting in lost water availability to Wyoming citizens and their livestock.

Moreover, it is of questionable practicability for industry to meet the recommended water quality criteria for sulfate, sodium and fluoride when the reality in Wyoming is that natural background water quality alone does not meet these criteria in many cases. In the Powder River Basin, an estimated 30% of livestock ground water sources, 23% of non-stock ground water sources, and half of surface water bodies sampled in and around the Powder River, exceed the chronic sulfate, fluoride and/or sodium criteria recommended in the UW report (Table 6). Available data on natural ambient surface water quality in the Bighorn and Platte River basins suggests a similar trend in these areas. Statewide, 15% or more of ground water sources do not meet the criteria for either sulfate or fluoride (Table 6).

Statewide application of water quality criteria to Wyoming's surface water bodies may impact livestock managers who would have to treat their water sources to meet State-sanctioned livestock water quality criteria. Changes in statewide application of water quality criteria could also have ramifications for multiple industries that affect surface water bodies, requiring new management practices and additional State regulation.

4.2 Natural Livestock Industry Variability

An index of natural livestock industry variability was compared to the magnitude of effect identified from the literature to understand the ramifications of "effects" identified in the literature when applied to the Wyoming livestock industry. Establishing baseline variability within the livestock industry is complex; one source of available data includes USDA livestock production data. Methods and results are presented below. The metadata analysis was performed for growth effects of sulfate. Sufficient data was not available to evaluate fluoride or sodium.

Cattle production (expressed as average daily gain or ADG), compared to control populations, varied between -5% and +5% due to sulfate exposure in water between 1,200 and ~3,000 mg/L. This variability, however, is almost half the natural variability in cattle production (adults, per farm) according to the USDA cattle data set, which is 8.5%. The analyses suggest that potential variability in cattle production exposed to the current sulfate limit is within the natural variability of cattle production in Wyoming.

4.2.1 Data Analysis of Livestock Production

The entire livestock sulfate database from Raisbeck et al. (2007) and additional literature were considered for a metadata analysis of livestock production effects from sulfate exposure. Studies that were used in the metadata analysis were limited to those with exposure durations of at least 30 days, where cattle were exposed to sulfate in drinking water and the amount of S in dry matter was within the average S concentration (0.2% S) for Wyoming grasses (Raisbeck et al. 2007). Studies which met these criteria are shown in Table 7. Production rates of test groups in each study were calculated from ADG data and compared to ADG of control groups in the same study. The metadata analysis shows that that cattle drinking between 1,200 mg/L and 3,000 mg/L sulfate in water could result in a variation in production between -5% and +5% compared to within-study controls (Figure 3). Studies which found significant differences between test and control groups are distinguished from other data.

The metadata results were compared to Wyoming livestock production data. Variability in livestock production (measured in pounds) was calculated from ten-years' worth of USDA data (Table 8). The years used for the calculation were between 1990 and 1999, representing a relatively stable cattle production cycle (Mathews et al. 1999) as well as the most recent trends in production before the drought began in 2000. Precipitation affects forage quality and therefore livestock production (Clawson 1979), thus data after 1999 was not used to compute baseline variability. Precipitation records over this time period are stable and normal (Table 8). The variation in production was calculated by taking the standard deviation over the average (expressed as a percent). Between 1990 and 1999, production per head of cattle and calves varied by 8.7%. Production per farm varied by 8.5%.

The analyses shows that that the potential production variability in cattle exposed to concentrations of sulfate meeting current water quality criteria (and within the range of background water quality in Wyoming) is within normal industry variability in Wyoming's cattle production (Figure 3).

4.3 Incremental Risk

Wyoming statute W.S. 35-11-302(vi) states that "the degree of injury or interference with the health and well-being of people [and] animals" must be considered in the risk management evaluation. In Wyoming, where natural water quality is already less than ideal in many areas, the "degree of injury" or incremental risk to livestock is a key concept to consider. Incremental risk is defined here as the added risk from exposure to a new mass of a constituent compared to the baseline risk of the natural environment.

The literature review did not identify a statistical risk to cattle growth, reproduction or acute effects at levels lower than at least 2,800 mg/L sulfate, 5,000 TDS (~2,000 mg/L Na equivalent) or 4 mg/L fluoride. The incremental risk of cattle exposed to current limits for sulfate and TDS is practically zero compared to the natural environment, where cattle could potentially be exposed to concentrations as high or higher than current limits. The metadata analysis also showed that the variability in cattle weights from exposure to sulfate concentrations between 1,200 and 3,000 mg/L sulfate would not be larger than normal industry variability. Thus, there would be no reduction in the "degree of injury" to animals if the water quality limits were changed because there is no present injury to livestock from current limits.

Conversely, the degree of injury to livestock and Wyoming's citizens may be greater under the UW-recommended water quality criteria compared to current limits because the potential costs of treating current water sources or obtaining additional water sources could far outweigh any additional income from increased weight gains. Water quality limits are intimately tied to water availability in Wyoming, because unnecessarily stringent effluent limits for produced water discharges would likely result in reduced discharge to surface water bodies. The economics of treating large quantities of produced water to meet stringent effluent limits are such that injection/re-injection, deep disposal

and/or reduced exploration and development are likely results of additional treatment requirements.

The impact of declining water supply is already well documented in Wyoming due to the ongoing drought. Livestock owners respond to declining water availability in a number of ways, including purchasing additional land and feed, applying for government income assistance programs, or herd liquidation and early weaning. Livestock may expend more energy to reach fewer water sources, as well as lower forage quality in some cases, consequently impacting growth and milk production rates anyway. Finally, developing alternate water sources such as well installation can be well over $100,000 (Geomega 2007).

Other industries can be impacted by lost tourism from fishing and wildlife viewing, and increased costs to oil and gas industries to design alternative water management programs. These changes can negatively impact Wyoming's tax income and reserve for state assistance programs.

5 Summary and Conclusion

The Wyoming EQC is considering updating numeric chemical constituent criteria in Chapter 1 of the Wyoming Water Quality Rules and Regulations for the protection of livestock. The EQC will review a UW risk assessment before making a decision.

While the risk assessment partially fulfills the risk management evaluation that the EQC should undergo, important data gaps remain. In fact, Wyoming statute mandates that the state consider a range of criteria before recommending water quality standards (W.S. 35-11-302(vi)). In effect, the state requires a risk management evaluation before setting water quality criteria. Risk management is the process of determining which action to take when a risk assessment indicates that a probability of harm exists. The goal of the risk management process should be to determine an acceptable threshold of effect that incorporates the values of the state's citizens and balances the benefits and costs to all affected parties.

This paper reviewed the UW report in the context of a risk management framework. This review focused on three constituents: fluoride, sulfate and sodium, because these constituents are already regulated by the state and criteria recommended in the UW report appear to contradict other assessments (e.g., Geomega 2007) as well as published water quality criteria for livestock.

The UW report recommended constituent criteria based on a number of "performance" endpoints, which varied from feed efficiency and dry matter intake (sulfate) to dental hygiene (fluoride) to weight loss and decreased milk production (sodium). This paper's review found that the UW report does not contradict the current fluoride, TDS and sulfate standards for the protection of livestock as defined by the EQC. Differences between current livestock water quality limits and those recommended in the UW report were the result of differences in toxicological endpoint selection and statistical relevance.

However, it is not enough to identify a statistically significant and toxicologically relevant effect; the effect must be put into context of relevancy to Wyoming's citizens and their livestock industry. Wyoming statute (W.S. 35-11-302) mandates that the EQC

must consider a range of effects on the people, animals, and plants, as well as social and economic values. An acceptable threshold of effect should be determined for each constituent that incorporates the values of the Wyoming livestock industry and the state's citizens, and balances the benefits and costs to all affected parties.

As part of the risk management evaluation, risk assessment data were considered evaluating in the context of three kinds of balancing criteria relevant to Wyoming's citizens and their livestock industry: practicability, natural industry variability, and incremental risk. The analysis found that lowering these criteria to levels recommended by the UW report is not practicable and will not result in any incremental risk reduction. The potential costs to livestock owners, other industries and the state from changing the criteria to levels recommended by the UW report will likely be greater than potential benefits to livestock.

Many of the conventional oil and gas produced water discharges in Wyoming will not meet the UW report's recommended water quality criteria, as well as some coal bed methane gas producers. It is not practicable for these surface water producers to treat water to meet the proposed criteria. Many producers have indicated that re-injection will be a likely alternative if faced with unnecessarily stringent water quality standards, resulting in lost water availability to Wyoming citizens and their livestock. The ramifications of lost water quantity will far outweigh the potential benefits to livestock identified in the UW report. Moreover, it is of questionable practicability for industry to meet the UW-recommended criteria for sulfate, sodium and fluoride when the reality in Wyoming is that natural background water quality alone does not meet these criteria in many cases.

Natural industry variability in cattle production was calculated from USDA data sets and compared to a metadata analysis of literature data on sulfate exposure to cattle (there was not enough data to run a similar analysis for fluoride or sodium). The metadata analysis shows that variability in cattle production as much as 5% may occur if cattle are exposed to sulfate levels between 1,200 mg/L and 3,000 mg/L. However, this potential variability

in cattle production is within natural industry variability for Wyoming, suggesting that there is no added degree of injury to livestock from exposure to current sulfate limits.

The incremental risk to livestock growth, reproduction or acute effects from exposures to current water quality limits is essentially zero compared to natural background water quality. This is because cattle are already exposed in many cases to sulfate, sodium or fluoride concentrations near current limits. Thus, there would be no reduction in the "degree of injury" to animals if the water quality limits were changed.

In conclusion, this paper found that the UW report (Raisbeck et al. 2007) does not contradict the current fluoride, TDS and sulfate standards for the protection of livestock as defined by the EQC. Moreover, lowering these criteria to levels recommended by the livestock water quality study does not balance the potential positive effects on livestock compared to negative effects on ranchers, other industries, and the state.