Water Quality Effects and Beneficial Uses of Wyoming Produced Water Surface Discharges

Prepared for:

Petroleum Association of Wyoming
951 Werner Court, Suite 100
Casper, WY 82601

January 16, 2007

GEOMEGA

GOOD SCIENCE • HARD WORK • CREATIVE THINKING

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Executive Summary

The Wyoming Department of Environmental Quality (WDEQ) is reviewing a petition to change the current Wyoming effluent limits for total dissolved solids (TDS) and sulfate, and to add an effluent limit for barium for coal bed natural gas (CBNG) industry produced water. The petitioners argue that current effluent limits for produced water are not "protective of stock and wildlife."

In addition to evaluating injuries to livestock and wildlife, effects on the well-being of the people of Wyoming should be carefully weighed, consistent with Wyoming statute W.S. 35-11-302(vi). Changing current effluent limits would not only impact water *quality*, but also ultimately water *quantity*. This is 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 adequacy of the current effluent limits and the validity of the proposed limits were analyzed by Geomega, who performed an ecological risk assessment of TDS, sulfate and barium water quality to livestock and wildlife, reviewed social and economic benefits to Wyoming residents, and evaluated potential injuries caused by changes in effluent limits.

This report addresses water quality effects of both CBNG and conventional oil and gas produced water. Although the petition targets only CBNG production in Wyoming, conventional oil production operations could also be affected by state-wide amendments to water quality effluent limits, because constituent concentrations of many conventional produced water surface discharges is greater than the petitioners' proposed limits. Hence, impacts to this sector of the oil and gas industry were also considered.

Geomega's analysis shows that current WDEQ effluent limits pose no measurable adverse effect to the health and well-being of domestic livestock and wildlife. Furthermore, there would be no incremental reduction in wildlife or livestock injury if water quality effluent limits were changed to the petitioners' requested limits.

In addition, associated social and economic impacts of reduced water discharges and/or reduced exploration and development would be harmful to Wyoming residents.

Geomega reviewed literature-based toxicity studies and published guidelines for each of the constituents of interest, and gathered empirical data from several Wyoming ranchers who use produced water sources for their livestock. The ecological risk assessment followed US Environmental Protection Agency guidelines (US EPA 1998).

Ranchers' experiences indicate that water containing sulfates up to 3,100 mg/L and TDS up to 5,390 mg/L do not pose adverse risk to livestock in Wyoming. The ranchers' experiences were evaluated in conjunction with published literature; as a result, the following water quality benchmarks were recommended for each constituent as an alternative to the petitioner's proposed limits:

Benchmark/Limit	Barium	Sulfate	TDS
Recommended benchmark:	13	3,010	5,600
Current effluent limit:	None	3,000	5,000
Petition proposed limit:	0.2	500	2,000

Table E-1. Summary table of recommended water quality benchmarks for barium, sulfate and TDS that are protective of livestock and wildlife receptors, compared to the current WDEQ effluent limits and the petition's proposed effluent limits. All results in mg/L.

These recommended water quality benchmarks are consistent with current WDEQ effluent limits, other published local and national established benchmarks, and ranchers' experiences. They are not, however, consistent with the proposed limits in the petition. The recommended benchmarks are protective of wildlife and livestock such that ingestion of surface water with TDS concentrations up to 5,600 mg/L, sulfate concentrations up to 3,010 mg/L, and barium concentrations up to 13 mg/L will not result in injury to the animals. Thus, reducing effluent limits of sulfate and TDS to the petitioners' proposed limits will not result in any incremental reduction in risk to wildlife or livestock.

In the larger picture, however, CBNG and conventional oil extraction industries that surface-discharge produced water have additional social and economic value to residents in

Wyoming. Reductions in exploration/development and produced water surface discharge, due to unnecessarily stringent effluent limits, could result in substantial injury to the social and economic well-being of many Wyoming residents.

Numerous landowners in the Powder River and Bighorn basins benefit from produced water surface discharges through irrigation and/or livestock watering. This statement is supported by the many letters of beneficial use, rancher interviews, and other literature sources. Produced water surface discharges also support wildlife populations that may not otherwise be viable, including wild horse populations in the Bighorn basin, and migratory and waterfowl bird species at the Loch Katrine wetland complex. In addition, produced water discharges in certain circumstances improve water quality of natural drainages, as evidenced by the increased livestock capacities cited by several ranchers in the Salt Creek area of the Powder River basin.

To analyze the social and economic impacts of produced water surface-discharge in Wyoming, Geomega gathered US Census Bureau and US Department of Agriculture information on livestock use and economic indices in the Bighorn, Powder River and Platte River basins, and reviewed use attainability analyses and economic analyses authored by Gene R. George and Associates (2005), RETEC (2004), SWWRC et al. (2002), Taylor (1999). Economic effects of reduced exploration and development include lost revenue from oil and gas extraction facilities in the form of jobs and associated earnings, and basic oil and gas export revenue. Case studies include the following:

- Elimination of the South Casper Creek field in the Platte River basin would result in annual losses of $3 million (in 2002 dollars) to the basic exports of Natrona County, with additional losses of associated jobs with annual earnings that totaled $487,142 in 2002.
- Elimination of the Hamilton Dome oil field in the Bighorn basin would result in losses of $28.7 million (in 1997 dollars) in state total annual economic output, with associated losses of 136 jobs in Hot Springs county alone with earnings totaling $4.1 million in annual labor.
- Elimination of operations in the Salt Creek area in the Powder River basin would result in losses of jobs directly and indirectly related to oil and gas production, that result in an estimated $4.6 million in annual earnings for Natrona and Johnson Counties (in 1997 dollars).

Social impacts of reduced exploration/development include loss of financial contributions that go toward the improvement of local communities. County income from these operations supports various public facilities including schools, hospitals, libraries, fire departments, environmental programs, and the county general fund. Examples include the following:

- Elimination of the South Casper Creek field would result in reduced social contributions to Natrona County such as:
    - county property tax income by 2.5%,
    - severance taxes of 0.04%,
    - sales and use taxes of 0.16%, and
    - 2.5% of federal royalties for the county (on average, between 1997 and 2002).
    - State severance taxes; in 1997, severance taxes from the Salt Creek fields were estimated at $2.4 million. 2.6% ($62,257) of the total severance tax was received by Natrona County, and 0.2% ($4,789) was received by Johnson County.
- Elimination of the Hamilton Dome oil field would reduce social contributions to Hot Springs County (in terms of fiscal contributions) totaling:
    - 29% of total property taxes
    - 9% of total general fund revenues,
    - 27% of the library system's total revenues,
    - 2% of county hospital revenues,
    - 9% of county weed and pest management program,
    - 29% of the rural fire district budget, and
    - additional funds for school districts, averaging $1.4 million annually.

- Elimination of operations in the Salt Creek area in the Powder River basin would reduce social contributions to Natrona and Johnson Counties totaling (in 1997 dollars):
    - School funding of $2 million annually;
    - County government funding of $500,000 annually;
    - Community college funding of $300,000 annually.

Even with continued industry presence, lost opportunity to surface-discharge water would have a negative impact on Wyoming landowners and ranchers in many counties in the form of lost jobs and income from livestock and farming businesses. Additional negative impacts would result for the State general fund and federal mineral revenues. The following are examples of estimated economic losses from lost opportunity to surface-discharge water:

- In the Bighorn basin:
    - 15 to 20% loss of cattle in the Cottonwood Creek area, corresponding to an estimated $2 million in lost annual livestock sales for the Bighorn basin;
    - economic losses of 1.7% ($3.3 million) of total annual economic output in Hot Springs County, plus job losses totaling $645,000 in annual labor income;
    - an 8% loss of irrigated pastureland in the Cottonwood Creek area, corresponding to a loss of 1,600 acres of irrigated cropland and 4,000 tons of annual hay production;
    - livestock losses estimated between 30 and 50% by some ranchers in the Bighorn basin, resulting in estimated losses $387,000 to $645,000 in annual livestock sales;
    - lost access to federal funding and associated employment at the Loch Katrine wetland complex, which was created from produced water sources.

- In the Powder River basin:
  - livestock losses estimated between 20 and 40% in the Salt Creek area, corresponding to estimated losses of $590,175 to $1.1 million in annual livestock sales;
- All counties affected by loss of opportunity to surface discharge produced water would face:
  - Estimated herd losses between 15% and 50%, corresponding to lost annual livestock sales between $57 million and $192 million.
  - additional costs to ranchers to develop alternative water sources such as wells, water hauling and breaking ice;
  - associated job losses related to ranching and farming; and
  - lost revenue from hunting, fishing and tourism due to declining wildlife populations.

Economic and social injury of reduced exploration/development and loss of opportunity to surface-discharge produced water would not be limited to the case studies provided in this report. State-wide, the oil and gas industry supported 2,995 employees in 2002, with a total annual payroll of $162 million (US Bureau of the Census 2002). In addition, support activities for oil and gas operations, including drilling of oil and gas wells, employed an additional 9,200 employees with earnings totaling $332.6 million in 2002. The value of shipments, sales and receipts for oil and natural gas industries in Wyoming totaled $3.9 billion (in 2002), representing ~14% of the total sales, shipments and receipts for the state. At least a portion of the jobs, earnings and state revenue is expected to be negatively impacted by unnecessarily stringent effluent limits across Wyoming. A state-wide analysis of economic and social benefits and injury upon loss of produced water surface discharge, exploration and development is recommended to evaluate the total impact of the petitioners' proposed water quality amendments.

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1.1 Introduction

The Wyoming Department of Environmental Quality (WDEQ) is reviewing a petition to change current effluent limits of total dissolved solids (TDS) and sulfate, and to add a barium limit for coal bed natural gas (CBNG) produced water. The petitioners argue that the current effluent limits are not "protective of stock and wildlife."

To analyze the adequacy of the current effluent limits and the validity of the proposed limits to protect wildlife and livestock, Geomega performed an analysis of livestock and wildlife chemical risk from TDS, sulfate and barium constituents in surface water bodies created or impacted by produced water surface discharge in Wyoming. This was accomplished by investigation along two lines of evidence. The first line included peer-reviewed scientific literature on water quality effects on animal species; the investigation sought to determine the water quality attribute (TDS, sulfate, barium) levels that are protective of animal species of interest, including livestock (heifers, steers and sheep), and wildlife (mammals and birds).

The second line of evidence included data compiled from Wyoming ranchers who use produced and natural water sources for their livestock. In-person and telephone interviews were conducted with a handful of ranchers in the Bighorn and Powder River structural basins in Wyoming to gather information on the nature and extent of produced or natural water usage and effects noted from that use. Where available, data was obtained from these ranchers to quantitatively evaluate the effects of produced water usage.

1.1.1 Ecological risk assessment procedure

A quantitative evaluation of risks to livestock and avian and mammalian wildlife from exposure to surface water in produced water bodies was undertaken to determine if the water chemistry could cause unacceptable adverse effects.

This ecological risk assessment (ERA) follows the US Environmental Protection Agency's (EPA) Guidelines for Ecological Risk Assessment (US EPA 1998), as well as other supplementary guidance documents, including:

- Guidelines for Exposure Assessment (US EPA 1992a),
- Wildlife Exposure Factors Handbook (US EPA 1993),
- Generic Assessment Endpoints for Ecological Risk Assessments (Draft) (US EPA 2002),
- other relevant federal and state regulations and guidance, and
- the general literature.

With the goal of improving the quality and consistency of its own risk assessments, the US EPA published a set of guidelines to describe the assessment process of ecological risk assessment. The guidelines incorporate the elements needed to assess the likelihood that adverse ecological effects could occur as a result of exposure to one or more stressors. As outlined in the guidance, the basic steps in an ecological risk assessment include problem formulation, analysis, and risk characterization. This report addresses each of these steps.

The problem formulation stage of this ERA includes background information on the availability and quality of water bodies in Wyoming, both from natural and produced water sources. Subsequently, wildlife and livestock uses of produced water bodies are described and an ecological conceptual model is presented that describes the relationships between the stressors (produced water bodies) and biological components. Finally, a set of endpoints is identified to ensure that the risk assessment goals are consistent with the petitioners' statements regarding WDEQ water quality regulations.

The analysis phase of the risk assessment examines the two primary components of risk: exposure and effects. The objective of the analysis phase is "to provide the ingredients necessary for determining or predicting ecological responses to stressors under exposure conditions of interest" (US EPA 1998). The products of the analysis phase are summary profiles that describe exposure and the relationship between the stressors and response. These profiles provide the basis for estimating risks.

The analysis phase was divided into three sections: exposure analysis (Section 1.3 of this report), effects analyses using literature-based studies (Section 1.4) and effects analysis using field-based data (Section 1.5). Two methods to evaluate effects were undertaken, because during literature review and toxicity reference value (TRV) derivation (method 1), it was recognized that there are gaps between the constituent concentration clearly identified not to result in any effect, and the concentration found to result in a significant adverse effect. Concentrations in between these extremes have not yet been evaluated and hence the potential for risk is unknown. In addition, there are many differences between literature-based toxicity studies and environmental conditions of the open range in Wyoming. These differences have important impacts on animal tolerance to constituent exposure.

To reconcile the gaps in data and differences in study conditions from the Wyoming environment, a second method to evaluate effects was undertaken which involved a compilation of field-based data of water body users in Wyoming. Interviews with ranchers and other users of water bodies in Wyoming were undertaken to identify anecdotal as well as quantitative measures of effects. The field-based data served to support toxicity study results and fill in data gaps in the literature-based studies.

In the risk characterization step of the ERA, water quality concentrations were derived from the reviewed literature sources that would not result in any adverse effect on livestock or wildlife. Selected no observed adverse effects levels (NOAELs) and low observed adverse effects levels (LOAELs) were converted to water quality concentrations (WQCs). Subsequently, an uncertainty analysis was conducted and the ranges of WQCs were also compared to empirical data gathered from the Wyoming ranchers. Based on the WQCs, uncertainty analysis and empirical Wyoming studies, a recommended water quality benchmark was identified for each constituent at which risk to wildlife and livestock in Wyoming would be unlikely.

1.2 Problem Formulation

The problem formulation stage of the ERA integrates information about site characteristics, exposure opportunities, and chemical and biological information to generate a set of assessment endpoints (explicit statements of an environmental value that is to be protected) and an ecological conceptual model. Designed to establish the framework to evaluate hypotheses about what ecological effects can occur from the environmental conditions at the site, the problem formulation process is the foundation of the ecological risk assessment.

1.2.1 General description of areas containing produced water

There are more than 64,000 (WOGCC pers. Com. 2007) currently active CBNG and conventional oil and gas industry wells in Wyoming. The most active development is currently in the Wyoming portion of the Powder River structural basin, with ~25,000 currently active wells (Figure 1-1). The Bighorn and Platte River (also known as Wind River) basins also host conventional oil and gas production facilities. These basins are characterized as semiarid environments, with average annual precipitation in the Bighorn basin ranging from six to nine inches annually. To characterize produced water quality and exposure conditions, data was collected for the Powder River, Bighorn and Platte River basins. These three basins represent the majority of areas in Wyoming that receive produced water discharges from oil and gas extraction.

Some of the water produced as a result of oil and gas extraction is discharged into reservoirs or naturally occurring drainages. Drainages in these basins receiving produced water inputs include (but are not limited to) Dry Creek and Cottonwood Creek in the Bighorn basin; Powder River, Salt Creek, and tributaries in the Powder River basin; and Poison Spider Creek in the Platte River basin. Portions of all of these drainages are naturally ephemeral or intermittent creeks that have become perennial streams as a result of CBNG and conventional oil and gas industry discharges. Livestock, farmers and wildlife use the water in these drainages.

In addition, a number of reservoirs also regularly receive oil and gas produced water, including the Loch Katrine in the Bighorn basin, a playa lake enhanced and maintained by oil and gas produced water from the Oregon Basin oil field in Park County, Wyoming. Due to its large size and rich habitat structure relative to natural water bodies in Wyoming, the Loch Katrine has become an attractive nesting and breeding ground for a number of migratory birds and other wildlife. Smaller reservoirs created by oil and gas discharge water in the various basins primarily support livestock, but are utilized by wildlife species as well.

1.2.2 Water quality of natural and produced water bodies in Wyoming

Natural background water quality is an important consideration in determining potential effects of produced water on animals, since not only will natural background give some indication of incremental risk, but animals often adapt to suboptimal environmental conditions without any long-term effect on their health. Incremental risk is defined as the added risk of exposure to a new mass of a constituent compared to the baseline risk of the natural environment.

The surface water quality of both natural and produced water bodies in Wyoming is highly variable. The Powder River basin has been extensively characterized in a recent use attainability analysis reported by RETEC (2004). Natural water quality in Salt Creek and its tributaries (measured in 2003 and 2004) is characterized as having average TDS concentrations of ~6,400 mg/L and sulfate concentrations averaging ~3,800 mg/L, with maximums as high as 22,000 mg/L TDS and 12,000 mg/L sulfate (measured in Castle Creek).

Produced water discharges into Salt Creek have the effect of lowering TDS and sulfate levels to means of ~4,000 (max 4,580) and 1,130 (max 1,680) mg/L, respectively, at discharge points. These concentrations remain approximately the same downstream; concentrations were measured at 3,880 mg/L TDS and 1,240 mg/L sulfate. TDS measured in Salt Creek and its tributaries are dominated by sodium sulfate in background waters. With the addition of produced water, the TDS composition changes to a sodium chloride type.

Total salinity in the Powder River upstream of Salt Creek ranges from 670 to 2,840 mg/L (measured in the 2003-2004 period), with a mean of 1,650 mg/L. Sulfate averaged 930 mg/L. Downstream of Salt Creek and discharge points, the corresponding TDS ranged from 900 to 3,640 mg/L, with a mean of 2,200 mg/L, and sulfate averaged 920 mg/L. There is a moderate increase in Powder River salinity due to Salt Creek. Upstream of Salt Creek, the

Powder River is characterized as a calcium and sodium sulfate type. Downstream of discharge points and flows from Salt Creek, the signature changes to more sulfate- and chloride-dominated waters.

In the Bighorn basin, Dry Creek upstream of discharge points contains a TDS concentration as high as 2,310 mg/L and sulfates up to 1,180 mg/L, as measured in a residual stream flow during summer months (M. Blakesley, personal communication). The water is characterized as a sodium sulfate type. Downstream of discharges, TDS increases to an average 4,100 mg/L with average sulfate of 2,025 mg/L, although concentrations can be as high as 5,390 mg/L TDS and 3,100 mg/L sulfate (measured between 2002 and 2006). TDS contain an increasing amount of sodium and carbonates relative to upstream samples.

In Cottonwood Creek in the Bighorn basin, TDS and sulfate average 355 mg/L and 164 mg/L, respectively, upstream of discharges, while downstream of discharges water quality averages 3,320 mg/L TDS and 1,380 mg/L sulfate (SWWRC et al. 2002). Other tributaries in the Bighorn basin downstream of produced water inputs, characterized in 1997 (Ramirez 2002), contain average TDS of 3,700 mg/L and sulfates of 1,400 mg/L. Finally, the Loch Katrine wetland complex contains 1,370 mg/L TDS and 790 mg/L sulfate (Ramirez 2002).

In the Platte River basin, natural water quality in Poison Spider Creek was reported at 3,150 mg/L TDS and 1,700 mg/L sulfates (Gene R. George & Associates et al. 2005). Downstream of discharges, TDS averages 2,630 mg/L, with 1,130 mg/L sulfates.

A summary of several produced water effluent concentrations from the Powder River, Platte and Bighorn basins are shown in Table 1-1.

Natural background concentration of barium measured in eight different watersheds ranged between 0.1 and 0.3 mg/L (WDEQ 2000). Produced water typically discharges 1 mg/L barium or less (RETEC 2004, SWWRC et al. 2002).

1.2.3 Wildlife and livestock use of produced water bodies in Wyoming

In Wyoming, livestock and a variety of wildlife species utilize both natural and produced surface water bodies for food, shelter, breeding ground and water resources. In the Powder

River basin, the Salt Creek corridor is an important habitat to both upland and riparian plant and animal species. Local topography is varied, with a number of small canyons, outcrops, cliffs and rocky hills, which provide habitat for big game, carnivores, small mammals, upland game birds, raptors, waterfowl, a variety of migratory birds, and some semiaquatic species (RETEC 2004).

In the Bighorn basin, a variety of wildlife species inhabit the Cottonwood Creek area (Table 1-2). Produced water sources in this area have created additional forage and shelter grounds for big game species including pronghorn antelope, mule deer, and white-tailed deer, and for small game birds including chukar, ring-tailed pheasants, and sage grouse; foraging grounds for a variety of large and small mammals and, subsequently, important prey resources for raptors; stopover resting and foraging grounds for migratory birds and waterfowl species; habitat for threatened and endangered species; and critical habitat for water-dependent species such as beaver and muskrat (SWWRC et al. 2002).

The Loch Katrine, also in the Bighorn basin, is a nesting and feeding ground for many species of waterfowl and shorebirds (Table 1-3), including two threatened and endangered species (peregrine falcon and bald eagle) and three candidate species (long-billed curlew, white-faced ibis and ferruginous hawk) (Ramirez 1993, T. Enright 1989). Wild horse populations also frequent the Dry Creek area (G. Flitner, personal communication), and letters of beneficial use describe wild horse dependence on produced water sources in the Bighorn basin area (Appendix B).

Finally, 97 species of birds and mammals (Table 1-4) were surveyed in the area near Poison Spider Creek (Gene R. George & Associates et al. 2005).

Agricultural uses of the creeks and reservoirs are primarily for livestock ranching. Livestock species reported by Wyoming ranchers and the US Department of Agriculture (USDA) are predominately beef cattle, and some sheep and horses. Most beef cattle in Wyoming are raised on the open range, with typically <1% feedlotted (NASS 2005). Livestock use of surface water bodies tends to be year-round, sometimes with little variation among water bodies. Wildlife, on the other hand, often use water sources on a seasonal basis. Migratory birds, for example, may use Wyoming water bodies on a transient basis between summer and winter destinations, and mule deer and antelope migrate to different elevations depending on the time of year.

1.2.4 Conceptual model

An ecological conceptual model describes the relationship between stressors and ecological components of an environment. A conceptual model was developed based on life history characteristics of ecological receptors, environmental fate and transport properties of stressors, and ecological conditions of the Wyoming environment. The major ecological groups of wildlife in Wyoming include waterfowl, passerine birds and ruminant and nonruminant mammals (Figure 1-2). Livestock using produced water sources may include cattle, sheep and horses.

1.2.5 Endpoint selection

Assessment endpoints are explicit statements of an environmental value that is to be protected (US EPA 1998). Consistent with WDEQ water quality regulations, the assessment endpoint identified in this risk analysis is the protection of the health and well-being of populations of Wyoming livestock and wildlife species from adverse effects of consuming surface water. For this analysis, well-being is defined as the physiological condition of an animal insomuch as it impacts the social or economic welfare of the animal's owner.

From this broad assessment endpoint, more specific measurement endpoints can be identified. Measurement endpoints are defined as measurable environmental characteristics that are related to the values (i.e., assessment endpoints) that are to be protected (US EPA 1992b). Measurement endpoints to protect animal health in this analysis include developmental, behavioral, reproductive and longevity effects. Growth effects are usually considered less desirable in risk assessments for evaluation of health endpoints, because growth effects can be short-term or reversed, depending on the exposure program, and the relationship between growth and other adverse effects is uncertain. However, for livestock species, measurement endpoints that include growth rate or weight gain were considered in this risk analysis because these parameters relate to the well-being of the animal, as defined above. Feed or water intake rates and digestibility were not considered adequate endpoints in themselves to evaluate the well-being of livestock species, because research has shown that there is considerable individual variation in feed intake above and below that expected or predicted on the basis of size and growth. Individuals of the same body weight often require widely different amounts of feed for the same level of production (NRC 2000). Thus, in the risk analysis, only those studies that measured growth rates in addition to intake rates or other performance parameters such as digestibility were considered for water concentration derivation.

1.3 Exposure Analysis

In the exposure analysis, general fate and transport properties of constituents of interest in the aquatic environment and in biological organisms are described, and exposure profiles for indicator species are identified.

The fate and transport of constituents of interest in the environment play a significant role in determining toxicity to receptors. In general, constituents in water are available from solution as free ions for uptake into organisms, or are sometimes transported over biological membranes as inorganic complexes. The chemical composition of the water, e.g., pH, hardness, dissolved organic carbon content, etc., strongly influences the speciation of constituents and the degree of uptake by biological organisms. Specific fate and transport properties of barium, sulfate and TDS are described below.

1.3.1 Barium

In water, barium will form compounds in the +2 oxidation state. Barium compounds such as barium nitrate and barium chloride are soluble in water (ASTDR 2001). However, the solubility of barium is often limited by the presence of sulfate and carbonate, which bind the barium in sparingly soluble forms, including barium sulfate and barium carbonate compounds (McCauley and Washington 1983). These forms of barium are relatively nonbioavailable. Bioavailability is defined in this document as that fraction of the constituent that is available for absorption into biological receptors. Barium does not bioconcentrate through food chains (Moore 1991, Hope et al. 1996), for example, soil-to-mammal bioaccumulation factors are <0.05 (Sample et al. 1997). In biological organisms, barium competes with and replaces calcium in processes normally mediated by calcium, particularly those relating to the release of adrenal catecholamines and neurotransmitters, such as acetylcholine and noradrenaline (US EPA 2005).

1.3.2 Sulfate

Sulfate (SO_4^{-2}) is an inorganic, ionic form of aqueous sulfur that has a -2 valence. Aqueous sulfate reacts with and forms chemical complexes with nearly all constituents, from metals to salts to organic matter. In animals, inorganic sulfur is converted into organic sulfur, an essential component of proteins and numerous other organic compounds (NRC 1980, Henry

1995). Thus, sulfur is considered by many to be an essential nutrient. Most sulfur compounds are synthesized in animals in vivo from methionine and cystine, two amino acids. Monogastrics cannot manufacture organic sulfur compounds in vivo, and therefore must obtain the amino acids from outside sources. Methionine and cystine are routinely supplemented in poultry diets, for example. Although ruminants contain gut bacteria capable of synthesizing sulfur-containing amino acids and vitamins from inorganic sulfur sources, nutritional supplements for sulfate are sometimes recommended for these species as well.

1.3.3 TDS

Total dissolved solids (TDS) is a measure of all constituents dissolved in water. In natural and produced water bodies, the most abundant of these constituents are typically chlorides, carbonates, bicarbonates, sulfates (collectively referred to as ‘anions’), and calcium, magnesium, potassium, and sodium (collectively referred to as ‘cations’). Iron and manganese may also be present sporadically at minor to moderate concentrations in Wyoming water bodies. Thus, the components of TDS in natural and produced water bodies are variable.

Most compounds must be solubilized in water to be absorbed from the digestive tract. Solubility will affect the mass absorbed and rate of absorption (Church 1979). Solubility is also affected by the relative ratios of different constituents; availability of magnesium, for example, is ~60% when consumed on its own, but it can be reduced by high potassium intake. Sodium is almost completely absorbed as is chloride.

1.3.4 Receptor identification

In ecological risk assessments, the quantitative evaluation of point-of-contact-type stressor response requires that specific numerical information about the livestock or wildlife be measured, such as food and water intake rates and body weights. Because not all individual trophic components of an ecological system can be evaluated for risk, several representative indicator species were chosen in association with the assessment endpoints. Selection of the indicator species used in this analysis was based on consideration of various functional groups, their potential for exposure and regulatory concerns.

The receptors chosen for the risk analysis included a developing ruminant (growing heifer), a nonruminant small mammal (rodent), and waterfowl (mallard duck). These receptors are representative of the types of livestock and wildlife species in Wyoming that are exposed to surface water bodies, including locations where produced water effluent might be deposited. The growing heifer and small mammal represent two particularly sensitive animal types, since small body size and young, developing animals are generally at a greater risk for adverse effects at lower doses than are larger, adult animals. As an example, a sulfate water quality concentration was derived for an adult steer to compare with the concentration derived for a growing heifer (Section 1.6.2). It was assumed that the receptors are exposed year-round to the same water body, thus maximizing potential water ingestion rates.

Sheep were also considered in the initial risk analysis, however the tolerance of sheep for these constituents is much higher than cattle (as described in the analyses below), and hence specific water quality ranges were not derived for this species. Little information is available on horses, and therefore this receptor was not specifically evaluated; however, effects on other ruminants and mammals were selected to represent this species.

Water ingestion rates of wildlife receptors were calculated using empirically based ingestion models from Nagy (1987) or Calder and Braun (1983). Representative body weights of each receptor were obtained from either standard EPA information on laboratory animals or from the general literature. For the livestock receptor, average body weights and ingestion rates were obtained from NRC (2000). Exposure parameters for each indicator receptor are summarized in Table 1-5.

1.4 Effects Analysis I: Literature-Based Analysis

In this section, general toxicity characteristics of each constituent of interest are described and a quantitative evaluation of effects is undertaken using two different methods. The first method consists of a review and synthesis of published toxicity studies, from which no-effects and low-effects concentrations were derived in the risk characterization section. A description of the toxicity reference value (TRV) derivation process is included, followed by general effect profiles of each constituent. Discussion of toxicity studies selected for final TRV derivation is provided in the risk characterization step (Section 1.6).

1.4.1 Methods used to derive TRVs

TRVs are estimates of exposure levels below which unacceptable adverse effects are not expected to occur. TRVs were derived for each individual receptor and chemical combination, and are used as ecotoxicity screening values against which receptor-specific exposure estimates are compared.

To derive TRVs based on phylogenically similar species exposed via similar routes of exposure (i.e., through the diet) and that measured toxicological endpoints comparable to the assessment endpoints, several steps were taken:

<u>Step 1. Assemble toxicological databases</u>. Literature databases were assembled that contained all available chronic and subchronic studies on livestock, birds and mammals. Acute studies were excluded from the database since these studies do not assess long-term effects on animals and therefore do not accurately represent potential adverse risks associated with growth, reproduction and development of species. TRV information was obtained by review of several secondary sources, including NRC 1980, Sample et al. 1996, Eisler 2000, the Cal/EPA toxicity database, EPA IRIS, TerreTox/EcoTox databases, and the general literature.

<u>Step 2. Select appropriate studies from the databases</u>. As the databases show, the availability of toxicity studies varies widely by constituent and by species. Therefore, selection of the appropriate studies from these databases necessarily involves a detailed

assessment of the differences from one study to the next, with an objective selection process required to make decisions.

Selection of appropriate studies was based primarily on five principal decision factors, including:

- biological effects,
- technical quality of study,
- method of administration,
- duration of study / identification of a toxicological endpoint, and
- biological parameters.

Biological effects describe the effects that were measured in each study. They can be broadly classified into effects on reproduction, growth, development, or mortality. Effects on reproduction include eggshell thinning, low birth weights, reduced litter sizes or number of offspring, and decreased hatchability. Reproductive effects are considered one of the most sensitive measurement endpoints of species, and therefore a key response in assessing long-term chronic impacts on animals. Growth effects include weight loss or gain, and physiological impairment.

Feed or water intake rates and digestibility were not considered adequate endpoints in themselves to evaluate the well-being of livestock species, because research has shown that there is considerable individual animal variation in feed intake above and below that expected or predicted on the basis of size and growth. Individuals of the same body weight often require widely different amounts of feed for the same level of production (NRC 2000). Thus, in the risk analysis, only those studies that measured growth rates in addition to intake rates or other performance parameters such as digestibility were considered for water concentration derivation.

Developmental effects include decreased feed consumption and other individual responses such as biochemical effects, histopathological changes and behavioral effects. Developmental effects are sometimes not obvious and are difficult to quantify at times.

Mortality is not a preferred endpoint for study selection because its effects are final and usually is the cumulative result of other sublethal effects that are also detected at lower exposures, however in some instances mortality was the only endpoint identified in the study.

Technical quality of study includes assessment of critical parameters such as whether the chemical is isolated or in combination with other chemicals, and whether a normal nutritional level was maintained during the exposure period. It is important in this assessment to derive TRVs from studies involving exposure to isolated chemicals because many effects of one chemical can be masked by the addition of another chemical. Further, while it is recognized that exposure to a combination of constituents may sometimes reflect conditions in the field, the long term additive effects of multiple constituents are not known.

Normal nutritional levels are a second critical parameter for each study selected because malnourishment can interfere with chemical assimilation and metabolic functions, which can result in exacerbated or subdued effects from exposure (Newman 1998). Finally, the number of test organisms is an important consideration in the selection of studies because individual effects of chemicals can vary; statistically significant numbers of test individuals are important in order to assess population-level effects of constituents on receptors.

Method of Administration describes the route of exposure. Because wildlife populations are assumed to be exposed to chemicals in the environment primarily through their diets, studies that administered chemicals orally in the diet were considered more desirable than administration by capsule or gavage. Injection of chemicals directly was not considered acceptable because the route of exposure is significantly different.

Duration of Study and Identification of a Toxicological Endpoint identifies the exposure time of the test group to the constituent, and whether a no effects level or low effects level was identified in the study. Chronic exposure is defined for mammals as more than one year, and/or over a critical life stage, and greater than 10 weeks for birds (Sample et al. 1996). Acute studies were not considered appropriate for TRV derivation.

Biological Parameters are receptor-specific and consider the similarity in phylogeny between the test organism (ROC_t) and the wildlife receptor (ROC_w). Although it was considered most desirable to match the test species to the wildlife receptor, toxicological studies are typically limited to a few species. If the test organism had the same phylogenic characteristics of the wildlife receptor, this aspect of the study was preferred over a study for which the test organism had only a similar diet or physical traits as the wildlife receptor.

Step 3. Derivation of NOAELs and LOAELs. Once appropriate studies were selected, study NOAELs and LOAELs were derived. NOAELs and LOAELs are expressed as mg constituent/kg body weight per day.

If not provided in the report, ingestion rates were calculated using empirically based ingestion models from US EPA (1988), Nagy (1987) or Calder and Braun (1983) (Table 1-6). Other missing information needed to calculate NOAELs and LOAELs, such as body weights, was either obtained from standard EPA information on laboratory animals or from a paired study published separately. For the livestock receptor, average body weights and ingestion rates were obtained from NRC (2000).

Step 4. Apply uncertainty factors. Once study NOAELs and LOAELs were calculated, uncertainty factors were applied if warranted to extrapolate the study NOAELs and LOAELs to TRV_{NOAEL}s and TRV_{LOAEL}s. In general, application of uncertainty factors is not supported by science (Chapman et al. 1998), however in some cases where there were large gaps in understanding of effects, uncertainty factors based on US EPA (1995) methods were employed.

1.4.2 Review of the toxic effects of barium

Barium affects the nervous system of vertebrates; at low doses it is a muscle stimulant, but at high doses barium can lead to hypertension, vomiting, muscular tremors, diarrhea, gastrointestinal hemorrhage, and eventually paralysis and cardiac arrest (Sample et al. 1997). Subchronic toxicity in rats includes increased arterial pressure and decreased weight gains (US EPA 1984); in birds, ingestion of toxic amounts of barium salts results in growth suppression (Mehring et al. 1960, Taucins et al. 1969). Barium poisoning can be treated by ingesting a solution of sodium or magnesium sulfate, which forms insoluble barium sulfate.

Relevant studies on ruminant species are lacking, and the few published studies address only lethal dose limits of barium salts (NRC 1980) or changes on a cellular level (e.g., Almudena et al. 1996, Aromolaran and Large 1999), the significance of which to the health or well-being of the animal is unclear. NRC (1980) recommended a maximum tolerable dose of 20 parts per million (ppm) barium (as highly bioavailable salts) for livestock, however this recommendation was based on two types of studies: (1) lethal dose studies of barium, none of which addressed effects on cattle; and (2) an in vitro study on the effects of rumen microorganisms. It is unclear how a 20 ppm threshold dose was derived from the acute studies, which show for a variety of animals, only a range in lethal doses between 50 and 733 mg/L Ba as $BaCl_2$ or $BaCO_3$. NRC (1980) stated that the in-vitro study on rumen microorganisms by Martinez and Church (1970) showed that depressed cellulose digestion above 30 ppm $BaCl_2$ occurred, but it is uncertain what the clinical significance of this effect was on the livestock in the study. Thus, the 20 ppm recommendation is not supported by the cited literature. In 2005, NRC (2005) revised its recommendation to 100 ppm barium for horses, poultry and swine based on the same acute studies cited in the 1980 publication. The US EPA does not recommend barium water quality criteria for livestock.

Geomega found no other US-published resources that had evaluated livestock risk to barium in surface water, however Canada's recommended water quality guidelines for livestock ranged between 5 and 300 mg/L, based on US-published studies (CCREM 1987).

1.4.3 Review of the toxic effects of sulfate

Because sulfate is a component of numerous biologically important compounds and metabolic processes (Murray et al. 2000), it has been suggested that sulfate is an essential nutrient, although other sources (e.g., NRC 2005) refute this claim. Nevertheless, daily requirements of sulfur for livestock and poultry are recommended between 10% and 45% of total water intake (NRC 1974). For nonruminants, dietary recommendations are between 0.28% and 0.69 % (NRC 1980). Sulfur derived from sulfate is retained in tissues throughout the body of ruminants, as part of sulfur-containing amino acids synthesized by rumen microorganisms. Nonruminants must obtain sulfate sources from the environment, and are limited to using sulfate for formation of sulfate esters that are required for various metabolic processes.

Sulfate is one of the least toxic forms of sulfur, but the ability of animals to tolerate exposure to elevated sulfur levels depends on the rate of exposure (Mudd et al. 1967). Acute levels administered to livestock produced muscular twitching, colic, dyspnea, blindness, coma and death (Coghlin 1944, White 1964). Subchronic effects of toxic quantities of sulfate (usually administered as sodium sulfate in water) on livestock include reduced weight gain, presumably as a result of reduced feed or water intake. The toxicity of sulfur is reduced in the presence of some sodium compounds such as sodium fluoride (Dziewiatowski 1954).

Relative to barium, research on inorganic sulfate impacts to livestock is more extensive, but other animal test studies are not as developed. Ruminant studies indicate that sheep are far more tolerant of high levels of sulfate in drinking water than cattle (NRC 1980). Sulfate levels up to 5,000 ppm were not found to be detrimental to sheep (Pierce 1960). Cattle, however, appear to be less tolerant of sulfate in drinking water. It has been reported that excessive sulfate consumption can produce a laxative effect in various livestock species, as well as inhibiting rumen fermentation (Hubbert et al. 1958). Despite this, however, total tract digestion of feed consumed by various livestock species does not appear to be adversely affected by excessive sulfate intake, as shown by Zinn et al. (1997) and Qi et al. (1993), and reviewed by NRC (2005).

High sulfate intake in ruminants has been associated with reduced copper absorption (Suttle 1974) and thiamine deficiency (Gould 1998). It has been suggested that thiamine deficiency in cattle is a leading cause of polioencephalomalacia (PEM), although results have been inconsistent (Gould 1998). For ruminants, NRC (2005) recommended a general range of 600 to 2,500 ppm SO_4 for cattle (the most sensitive ruminant receptor), based on reported increases in the incidence of PEM; however, this recommendation contrasts that of other studies, including Loneragan et al. (1998), Patterson et al. (2002), and Patterson et al. (2003), which found no increased incidence of PEM below 3,500 ppm. Other sources of water quality guidelines for livestock (US EPA 1972, NRC 1974) have no specific recommendations for sulfate. NRC (2005) recommends up to 2,500 mg/L sulfate, but this is applicable only to feedlotted cattle. Canada’s livestock guidelines range between 1,000 and 3,000 mg/L sulfate.

1.4.4 Review of the toxic effects of TDS

Several common components of TDS are required nutrients in animals. Calcium, magnesium, sodium, and chloride are involved in acid-base balance, muscle contraction, nerve signal transmission, nutrient transport and other functions (Murray et al. 2000). There are no recommended nutritional requirements for TDS; however, daily requirements of salt (as sodium chloride, NaCl) for livestock and poultry range between 6% and 40% of total water intake (NRC 1974).

Acute effects of excessive TDS intake in livestock include excess salivation, vomiting, diarrhea, ataxia, disorientation, blindness, seizures and paralysis (NRC 1980). Subchronic effects in mammals include reduced feed and/or water intake, and subsequent reduction in weight gains. In birds, effects include reduced reproductive rates and weight loss associated with prolonged reductions in food and water intake.

The toxicity of TDS to organisms will depend in part on the individual components. Sufficient research data is lacking on the toxic thresholds of individual TDS components for animals; however, the relative toxicity of TDS components is generally well understood. Embry et al. (1959), in a subchronic study on rats experimented with several different mixtures of TDS – sodium chloride, sodium sulfate, magnesium chloride, magnesium sulfate, or calcium chloride – and found that tolerance to sodium chloride was highest. Other salts affected growth rates at lower doses, with magnesium chloride and magnesium sulfate affecting growth at the lowest dose levels. Similar results were found by Weeth and Hunter (1971) and Rodenburg (1989) in their studies on cattle. The US EPA (1976) advised that "livestock and poultry can survive on saline waters up to 15,000 mg/L salts of sodium and calcium combined with bicarbonates, chlorides and sulfates. But only 10,000 mg/L of corresponding salts of potassium and magnesium could be tolerated. The approximate limit for highly alkaline waters containing sodium and calcium carbonates is 5,000 mg/L." NRC (1974) suggested that an upper limit of 5,000 mg/L TDS should be used as a benchmark for livestock (dairy and beef cattle, sheep, swine, and horses), based on a similar literature review.

According to the literature published to date, livestock species most susceptible to elevated TDS concentrations are growing cattle. Studies on sheep (Peirce 1957, 1959, 1962, 1963) indicate that sodium chloride levels up to 13,000 mg/L do not adversely affect sheep health, weight gain or wool production. Effects on sheep from other types of TDS (e.g., calcium chloride, bicarbonates, magnesium chloride) were typically evaluated in conjunction with sodium chloride. Peirce (1959) showed that combinations of sodium/magnesium chlorides (up to 11,800/1,000 mg/L) did not affect sheep health or performance; Peirce (1962) also demonstrated that calcium plus sodium chloride levels of 12,900 mg/L did not affect weight gain or wool production. In swine, Anderson and Stothers (1978) showed that 6,000 mg/L sodium chloride did not affect weight gain in pigs.

1.5 Effects Analysis II: Wyoming Field-Based Data Analysis

One limitation of a literature-based toxicity study review is that in most cases, the conditions employed in the studies are not representative of field conditions in Wyoming. Almost all livestock studies on TDS and sulfate toxicity involve feedlot environments, where test animals are given limited water and/or feed, and typically only short-term responses to sudden changes in the diet are measured. Differences between feedlot and field environments have been shown to result in large differences in response to TDS and sulfate toxicity in particular. Johnson and Patterson (2004) showed that cattle confined to feedlot environments and provided with natural water sources from South Dakota (with 3,000 mg/L sulfate) generally exhibited adverse effects, while cattle grazing on the open range did not exhibit adverse effects at water concentrations as high as 4,600 mg/L. The differences in tolerance thresholds were attributed to forage quality differences and more stressful conditions (higher temperatures, lack of shade, etc.) in feedlot environments.

Additionally, animals are known to adapt to higher levels of sulfate and TDS without long-term adverse effects (NRC 1974). In field populations, adaptation refers to the adjustment of an organism to its environment. Adaptation can produce large differences in the threshold of low-adverse effects levels. For example, in a review of laboratory toxicity trials, the consensus from NRC (1974) was that cattle (heifers) that were fed 7,000 mg/L or less of sodium chloride or sodium sulfate on a chronic basis did not experience adverse effects. In the field, however, tolerances were reported to be higher: Spafford (1941) and Ballantyne (1957) observed that cattle owned by various landowners could tolerate water containing up to 14,250 mg/L total salts (11,400 mg/L sodium chloride) with no reported adverse effects. In these cases, adverse effects were noted at 18,500 mg/L or higher of total salts. The omission of adaptive factors in many laboratory-based tests creates (perhaps an unnecessary degree of) conservatism inherent in extrapolating the results of laboratory-based toxicity tests to natural conditions.

Finally, it was revealed in the literature review that there is a large data gap between NOAELs and LOAELs; effects to receptors between these two extremes are unknown. Therefore, a field-based investigation was undertaken to gather effects data specific to users of water bodies in Wyoming. USDA and related livestock data for Wyoming and the US were obtained, interviews with a handful of ranchers in the Bighorn and Powder River basins were conducted, and further information was gleaned from letters written by users of produced water sources (Appendix B).

Overall, the ranchers indicated that water containing sulfates up to 3,100 mg/L and TDS up to 5,390 mg/L did not result in adverse risk to livestock in Wyoming's Bighorn and Powder River basins. Weaning rates, body condition, breeding percentage and mortality rates were no different between pastures associated with natural water sources and those with produced water, which typically contain higher concentrations of sulfates and TDS. Adverse effects were apparent in livestock exposed to evapoconcentrated surface water that originally contained more than 4,000 mg/L sulfate and 7,000 mg/L TDS. Analyses of effects of these concentrations on wildlife were less conclusive; however, it appears that no adverse risk to wildlife occurred from exposure to water at Loch Katrine, which contains relatively elevated sulfates and TDS compared to background. Individual interview statements are summarized below. Full interview statements are provided in Appendix A.

The Flitners

The Flitners ranch all their cows (~1,000 head in 2005) in the spring and fall on BLM lands adjacent to Dry Creek near the Cody Highway. In this area, Dry Creek has average sulfate and TDS concentrations of 2,720 mg/L and 5,080 mg/L, respectively. Produced water sources account for 100% of water availability on these lands, because drought has eliminated other natural reservoirs. The Flitners have additional, private lands in the Bighorn basin and on Heart Mountain, and the cattle typically graze there during the summer months. Water resources in these areas originate from natural sources, with estimated concentrations of 1,180 mg/L and 2,310 mg/L sulfate and TDS, respectively, based on average background concentrations measured upstream of discharges (M. Blakesley, personal communication).

Weaning rates were recorded for calves that started out the spring in various produced water and natural-water-associated pastures (Appendix A, Table A-1). These records demonstrate that no adverse effect on weaning rates occurred on calves that drank the produced water, which contains elevated sulfate (2,720 mg/L) and TDS (5,080 mg/L) relative to natural sources. The Flitners noted no other variation in cattle quality between those grazed on lands containing produced water versus land with natural water sources.

Mr. McCarty

Mr. Mike McCarty owns several ranches in the Bighorn basin. He utilizes four pastures (totaling 1,600 acres) on BLM lands that contain exclusively produced water sources originating from the Oregon Basin oil field. The herd sizes on these lands are between 650 and 700 head, all cattle. The pastures include Avon, South/North Oil Wells, Lake and Highway pastures. Surface water concentrations near these pastures average 4,830 mg/L TDS and 2,300 mg/L sulfate, with maximums as high as 5,390 mg/L TDS and 3,100 mg/L sulfate (measured between 2002 and 2006). Lake pasture has one well in addition to the produced water sources. Mr. McCarty owns another ranch near Cody, WY, which has natural water sources associated with the pasture. Surface water concentrations at the ranch are not precisely known, but assumed to be in the range of natural background concentrations for the Bighorn basin area, i.e., between 1,180 mg/L sulfate and 2,310 mg/L TDS.

The cows utilize the pastures associated with produced water sources between November and May. Two out of four pastures are used per year (allowing a 2-year fallow period). The cattle are allowed to forage on the open range, and are provided a mineral supplement package. The supplement contains a chelated copper form, recommended by Mr. Patterson (pasture manager for Mr. McCarty) for areas with higher sulfate concentrations associated with water or forage.

Mr. McCarty noted that there were no adverse effects on the livestock that use the pastures with produced water, which contains elevated sulfate (3,100 mg/L) and TDS (5,390 mg/L), compared to his other pastures at which there are natural water sources. He related the following measurement comparisons:

	Measure:	Produced water	Natural water
1)	Body condition	5	same
2)	Breeding percentage	96%	same
3)	Death rate	</= 2%, all cows < 10-11 yrs	same
4)	Calf weaning rate	94-95%	same

Additionally, Mr. Patterson related that the cattle in this area perform very well, above industry standards and production numbers.

Mr. Patterson

Mr. Trey Patterson manages the Padlock ranch, located in northern Wyoming in the Powder River basin. Cattle graze year-round in the area. The ranch lands receive produced water from a CBNG facility near Decker, MT. The produced water is discharged to a fenced-off reservoir, and into stock tanks.

Water quality samples are taken periodically by Mr. Patterson. Concentrations generally reported are between 1 and <500 mg/L sulfate and up to ~3,600 mg/L TDS (as measured in 2001 and 2002). Sodium makes up a large proportion of the total TDS. Natural water in the area contains between 1,500 and 2,000 mg/L sulfate and up to 3,700 mg/L TDS. Weaning weights recorded over several years do not indicate any difference between cows raised on land with produced water compared to land with other water sources. No negative effects of consuming produced water have been seen or noted in cattle. Generally, Mr. Patterson notes that the increase in available water has resulted in an increase in cattle performance and forage quality.

Mr. Patterson also related his experience with a cattle ranch in North Dakota. Natural water sources at the ranch, containing about 4,000 mg/L sulfates, resulted in incidences of polio in the cattle that consumed this water. A supplemental mineral program was instituted there to help mitigate the effects of the high sulfates, and although some cattle continued to be affected, the ranch continued to use the water source because it was the only water available in the area. Despite this, the ranch was able to make a profit.

Mr. Shepperson

Mr. Shepperson recounted his experiences with cattle drinking from various locations in Salt Creek. He noted that in the summertime, evapoconcentration of the water upstream of produced water outfalls, with concentrations originally as much as 4,000 mg/L sulfate (average 1,200 mg/L) and ~15,000 mg/L TDS (average 2,000) (RETEC 2004), resulted in cattle disorientation and symptoms similar to PEM. Downstream of produced water outfalls, sulfate concentrations of ~1,100 mg/L and TDS concentrations averaging 4,300 mg/L did not produce any adverse effects. His observations are supported by a use attainability analysis for Salt Creek (RETEC 2004).

Mr. Shepperson also noted that wildlife appeared to be using the water downstream of the outfalls, where population densities appear greater than upstream of the outfalls. Mr. Shepperson speculates that this phenomenon is a result of changes in water quantity as well as quality.

Mr. Schlaf and Mr. Meike

Interviews given by Mr. Schlaf and Mr. Meike relate experiences similar to the above examples, citing that the use of produced water sources in the Bighorn and Powder River basins did not result in any measurable adverse effect on their livestock herds.

Beneficial Use Letters

Beneficial use letters written to industry, BLM and state DEQ offices cite long-term dependence on produced water sources for cattle, sheep and horses without adverse effects. Concentrations were noted as high as 5,000 mg/L TDS, and 3,000 mg/L sulfates, in accordance with NPDES permits (e.g., J. Barquin et al. 2002, J. Fike 2002, J. Turnell 2002, E. Ledder 1988, M. Pitz and L. Meisinger 1988, M. Zinn 1988, D. Grabbert 1988).

Loch Katrine

Oil field discharges have created a number of wetland and riparian habitats in Wyoming, which attract a variety of wildlife. In particular, Loch Katrine, a playa lake maintained and enhanced by produced water in the Oregon Basin oil field in Park County, WY, provides breeding habitat for a variety of aquatic migratory birds (Ramirez 1993). A Fish and Wildlife Service analysis of avian risk in Loch Katrine (Ramirez 1993, 2002) and letters sent regarding wildlife use of the Loch Katrine wetland complex (Appendix B) indicate that chemical constituent concentrations in the water are not impacting avian populations or other types of wildlife that use this area. In addition, the area typically produces an estimated 100 to 150 broods of waterfowl and 50 to 100 broods of shorebirds, and is considered to have an above-average reproductive success rate (Audubon Wyoming 2006). Sulfate and TDS levels measured in the wetland in 1997 were 797 and 1,372 mg/L, respectively (Ramirez 2002). Produced water discharges with TDS concentrations up to 5,000 mg/L, and sulfate concentrations up to 2,050 mg/L, contributed to the Loch Katrine without noticeable impacts on wildlife (Ramirez 2002).

1.6 Risk Characterization

This section contains reviews of specific studies in which water quality concentrations (WQCs) were derived. The WQCs were then used to identify a single recommended water quality benchmark for each constituent of interest.

A range of WQCs (mg/L) is presented for each constituent-receptor combination. The lower extreme of the range is based on the no observed adverse effect level (NOAEL) TRV. The NOAEL selected represents the highest dose reported not to have an adverse effect on the receptor. The upper extreme of the range is based on the low observed adverse effects level (LOAEL) TRV. The LOAEL selected represents the lowest dose reported to have a significant, sublethal adverse effect on the receptor. Selected TRV-NOAELs and TRV-LOAELs were converted to WQCs by the equation:

$$\text{WQC} = \frac{\text{N/LOAEL (mg constituent/kg body weight/day)} \times \text{water ingestion rate (L/day)}}{\text{body weight (kg)}}$$

As part of every risk assessment, an uncertainty analysis should be conducted to identify data gaps and the magnitude of uncertainties associated with characterizing risk (US EPA 1998). Therefore an uncertainty analysis was conducted on the derived WQCs, and ranges were compared to the empirical data gathered from Wyoming ranchers. Based on the WQCs, uncertainty analysis and field-based data, a recommended water quality benchmark was identified for each constituent at which risk to wildlife and livestock in Wyoming would be unlikely.

1.6.1 Determination of water quality concentrations and benchmark for barium

There are few toxicity studies available for barium. Perry et al. (1983) and Deitz et al. (1992) showed a range of reported NOAELs for nonruminant mammals. These NOAELs are consistent with the LOAEL identified in Deitz et al. (1992). There were no ruminant-specific studies that addressed sublethal effects that could clearly be interpreted for the health or well-being of these receptors, and hence the Perry et al. (1983) and Deitz et al. (1992) studies were used as a basis for both ruminant and nonruminant receptor TRVs. For birds, there were also limited studies from which to draw upon; Johnson et al. (1960) identified a subchronic

NOAEL and LOAEL in chicks, and hence these concentrations were used to derive WQCs for birds. Subchronic is defined the duration of toxicity test of less than 1 year for mammals, or less than 6 weeks for birds.

A summary of all studies reviewed, and final studies selected to derive WQCs for barium, are shown in Table 1-7. Because a ruminant-specific study addressing chronic health or well-being effects was not identified, studies on other mammals were used, and an uncertainty factor of 10 applied to these results consistent with US EPA (1995) methodology. The final WQCs for barium for which there will be no risk to receptors include:

Nonruminant mammal (rodent)	100 - <915
Ruminant (growing heifer)	13 - <120
Passerine bird (mallard)	360 - <735
Petition proposed limit:	**0.2**
Recommended benchmark:	**13**

Table 1-8. Barium water quality range from no adverse effects to low adverse effects, compared to the proposed surface water effluent limit for Wyoming. Water quality concentrations between the extremes will not likely result in risk to receptors. All results in mg/L.

The degree of uncertainty associated with the recommended benchmarks is moderate to high, because there is a general lack of toxicity studies on ruminants and birds. Although uncertainty factors were employed in the derivation of water quality benchmarks for ruminants, the technical basis for the use of a 10-factor is weak (Chapman et al. 1998). Nevertheless, even the lowest barium water quality benchmark derived (13 mg/L for ruminants) was over an order of magnitude higher than the proposed limit. Similarly, Canada’s lowest recommended water quality criteria for livestock at 5 mg/L is also over an order of magnitude higher than the proposed limit. Finally, NRC (2005) recommends 100 ppm barium for horses, poultry and swine.

Due to the high level of uncertainty, **the recommended water quality benchmark for livestock and wildlife protection is 13 mg/L,** which is not only the lowest derived WQC, but is also consistent with published water quality criteria for livestock.

The recommended water quality benchmark for barium, however, is not consistent with the proposed limit. Reported support in the petition for the 0.2 mg/L barium limit is based on a Utah Extension Service publication (Bagley et al. 1997), which lists a US EPA water quality recommendation for livestock of 0.2 mg/L. The US EPA citation in Bagley et al. (1997) is presumably the 1972 water quality criteria publication referenced in the document; however, there is no recommendation for barium in this literature source. No other studies supporting a 0.2 mg/L barium limit were found, including Colorado State University's extension service bulletin which revised its guidelines to exclude any limit for barium.

1.6.2 Determination of water quality concentrations and benchmark for sulfate

In the review and selection of toxicity studies for indicator species, special emphasis was placed on matching the form of sulfur that will be found in surface water bodies (SO_4) to the form of sulfur administered in the study, because animal tolerance and metabolism of sulfur will vary depending on its chemical form.

Upon review of rodent studies, Brown and Gamatero (1970) found a subchronic NOAEL of 18.1 mg/kg/d in rats; however, a LOAEL was not identified in the study. Weeth and Hunter (1971) later reported a subchronic NOAEL of 668 mg/kg/d for rats. No LOAEL could be identified from a literature review. Although Cohen et al. (1958) and Daniel and Waisman (1969) identified subchronic LOAELs in the range of 410 - 515 mg/kg/d, the form of sulfate in these studies was organic, administered as DL-methionine in the diet, and hence these studies were not considered adequate to derive a LOAEL for inorganic sulfate.

In birds, no adverse effects were found at doses of >1,000 mg/kg/d reported by Krista et al. (1961); however, Harter and Baker (1978) reported reduced growth rates at 288 mg/kg/d. Both studies administered sodium sulfate in water to chickens over a subchronic duration period. In another study with laying hens, Adams et al. (1975) identified a NOAEL of 101 mg/kg/d, finding no effects on egg production, feed intake rates or mortality.

Of the subchronic toxicity studies evaluated for growing cattle (no chronic studies exist), NOAELs were typically identified in the studies at 604 mg/kg/d or less (Embry et al. 1959). Fewer LOAELs were adequately identified in the available studies; Embry et al. (1959) identified a LOAEL at 699 mg/kg/d, noting decreased weight gains and feed intake rates. Although Grout et al. (2006) reported a LOAEL at 170 mg/kg/d, this LOAEL was lower than the reported NOAEL (270 mg/kg/d) from the same study. Weeth and Hunter (1971) found that at 337 mg/kg/d, significant effects on weight gain were seen in growing cattle. However, this study (as well as many others) was performed in a feedlot environment; Johnson and Patterson (2004) demonstrated that the conditions in feedlots are more stressful to the animal, resulting in reduced sulfate toxicity thresholds to growing cattle compared to conditions in open rangeland environments. Patterson et al. (2003) and Johnson and Patterson (2004) reported a feedlot-associated LOAEL of 251 mg/kg/d, but a NOAEL from the open rangeland tests at 360 mg/kg/d (Johnson and Patterson 2004), noting that although declines were seen in water intake rates, no effect on weight gain was found.

The open rangeland-associated NOAEL from Johnson and Patterson (2004) is not only more consistent with most other studies, but is also consistent with the Wyoming field-based empirical data, which shows that at concentrations up to 3,100 mg/L sulfate (~259 mg/kg/d), no adverse effects are seen in livestock. Hence, the NOAEL identified for water quality derivation in this risk analysis is 360 mg/kg/d (from Johnson and Patterson 2004), and the LOAEL identified is 699 mg/kg/d (from Embry et al. 1959).

Effects on growing cattle were noted at lower concentrations in these studies than for adult cows and steers. Weeth and Caps (1972) noted no effects on intake rates, feed efficiency or growth rates in adult cattle fed 122 mg/kg/d sodium sulfate. The lowest LOAEL at which effects on adult cattle were noted were reported by Patterson et al. (2004) at 327 mg/kg/d, noting significant declines in growth rates of adult cows, though no effects were noted on cow reproduction or calf weight gain (calf-cow pairs were evaluated in the study). Results of Ward and Patterson (2004) and Patterson et al. (2002) were consistent with Patterson et al. (2004), reporting LOAELs of 352 and 381 mg/kg/d, respectively.

A summary of all studies reviewed, and final studies selected to derive WQCs for sulfate, are shown in Table 1-9. To show the relative differences in the sensitivity of developing ruminants versus adult ruminants, sulfate WQCs were derived for an adult steer to compare with the concentration derived for a growing heifer. From these results, it is apparent that the upper end of acceptable WQCs is much lower for the growing heifer than the adult steer.

The final WQCs for sulfate for which there will be no risk to receptors include:

Nonruminant mammal (rodent)	5,070
Ruminant (growing heifer)	3,660 – <7,100
Ruminant (adult steer)	2,800 – <7,500
Passerine bird (mallard)	1,780 – <5,080
Current effluent limit:	**3,000**
Petition proposed limit:	**500**
Recommended benchmark:	**3,010**

Table 1-10. Sulfate water quality range from no adverse effects to low adverse effects, compared to the current and proposed surface water effluent limits for Wyoming. Water quality concentrations between the two extremes will not likely result in risk to receptors. All results in mg/L.

There is a considerable range of lower-end WQCs for the various receptors, from 1,780 to 5,070 mg/L. Studies on growing cattle and adult steers are the most abundant for sulfate, and associated uncertainties with the range of water quality is low. However, very few NOAELs were reported for adult steers, and doses administered to adults were less than those of studies with growing heifers. Hence, the NOAEL derived in the table above is actually lower for adults (2,800 mg/L) than for growing heifers (3,660 mg/L) despite the reported higher sensitivity of growing heifers compared to adults. All of the adult steer studies were conducted in feedlot environments, which probably contributed to the lower reported NOAELs.

Additionally, there is a large gap between the lower-end 2,800 mg/L) and the upper-end (<7,500 mg/L) extremes for adult steers, due to fewer toxicity studies on adults rather than growing heifers. These differences in data availability are not surprising, since the most commonly reported adverse effect from sublethal sulfate intake is reduced growth rates, hence growing organisms are typically used to evaluate toxicity.

Uncertainties associated with bird and nonruminant receptors were moderate. The relative paucity of data for these types of species contributed to lower-end WQCs derived for birds and mammals being lower than for livestock, with a large difference between lower- and upper-end concentrations.

The ranges of WQCs were used to derive a single recommended water quality benchmark for sulfate. Only NOAELs were reported for rodent receptors, indicating that concentrations up to 5,070 mg/L would still be protective of these types of mammals. For remaining receptors, the geometric mean of the low- and high-end concentrations was taken to obtain an estimated concentration at which risk to these receptors would be unlikely (methods based on EPA guidance for ecological risk assessments, e.g., US EPA 2003). Geometric means of the water quality benchmarks are 5,100, 3,010 and 4,590 mg/L for growing and adult cattle and birds, respectively. Therefore, **the recommended water quality benchmark for sulfate is 3,010 mg/L** because this number is the lowest of the geometric means for cattle and birds, it is within the range of NOAEL-based WQCs for rodents, and it is consistent with the field-based data from Wyoming water users. This benchmark also takes into account the effects on both growing and adult cattle.

This recommended water quality benchmark is consistent with the current regulatory effluent limits for sulfate. In contrast, the petitioners' proposed limit (500 mg/L) is not supported by this risk analysis. The proposed amendment to sulfate water quality was based on a recommended limit of 500 mg/L for calves. Support for this recommendation is lacking, however, and cannot be found in the literature. The support referenced in the petition is the Utah State University Extension service bulletin. This bulletin references Kober (1993) in support of its sulfate guideline for livestock. However, the Kober (1993) paper, recommends that 3,500 ppm is unfit for sows, and "[w]ater with levels above 4,500 ppm should not be used." "Slight" effects on livestock were cited in the paper for 1,500 ppm and above, although those effects were not elaborated upon beyond the possibility of temporary diarrhea. The other reference provided is from the Wyoming Department of Agriculture Analytical Service. This web publication does not reference any support for its recommendation of ≤ 1000 mg/L sulfate as "suitable" for livestock. Furthermore, the web publication does not define "suitable," referencing only that the criteria are for classification purposes only.

1.6.3 Determination of water quality concentrations and benchmark for TDS

Because variation in TDS makeup will affect toxicity thresholds, and much of produced water effluent is dominated by sodium chloride, this review focused on compiling studies which addressed toxicity to sodium chloride. Other types of TDS constituent studies were also reviewed, although far fewer exist. Studies involving sulfate-dominated TDS waters were not considered for TDS analyses, since sulfate toxicity is addressed elsewhere.

Review of chronic or subchronic toxicity studies on growing cattle shows a wide range in NOAEL and LOAEL thresholds for NaCl-type waters. Growth effects in growing cattle have been reported in the range of 800 mg/kg/d to >2,100 mg/kg/d (Weeth and Haverland 1961). This wide range in toxic thresholds appears to depend on the season in which the cattle are exposed, as well as other factors, such as diet and timing of watering and feeding (Ray 1989). Interestingly, significant growth effects were seen at a lower dose (800 mg/kg/d) during winter months than in summer months (900 mg/kg/d) The lower LOAEL, in winter, reported by Weeth and Haverland (1961) could be attributed to reported differences in drinking rates and body weights between experimental groups.

NOAELs reported by Spafford (1941), Weeth and Hunter (1971), Weeth (1962) and Embry et al. (1959) are consistent with the LOAEL reported in Weeth and Haverland (1961); only Weeth et al. (1960) found that a dose of over 1,600 mg/kg/d TDS (as NaCl) did not result in any adverse effects on growth. Other studies evaluated effects only on food/water intake and aspects of digestibility, including Lassiter and Cook (1963), Ray (1989) and Johnson et al. (1959). Although growth was not measured in these studies, NOAELs and LOAELs reported are still consistent with Weeth and Hunter (1971) and Weeth and Haverland (1961). A summary of all evaluated studies on growing cattle are shown in Table 1-11.

Fewer studies have focused on evaluating effects in adult cattle, but the effects of TDS (as NaCl) on milk production in dairy cows has been widely studied. Significant declines in milk production have been reported between 380 and 600 mg/kg/d (Challis et al. 1987 and Jaster et al. 1978, respectively) but Bahman et al. (1993) did not see any effect on milk production at 610 mg/kg/d, and no effects were reported by Frens (1946) at over 900 mg/kg/d. Experiment durations and seasonal differences varied among studies, as did the source of water. Jaster et al. (1978) added NaCl to tap water, the sources of water in the Challis et al. (1987) and Bahman et al. (1993) studies were natural well waters. Only Challis et al. (1987) reported all individual constituent concentrations, which showed the water to be a calcium sulfate type, while data from the Bahman et al. (1993) study suggest that water contained primarily sodium and magnesium, which is more consistent with the makeup of produced water in Wyoming.

Studies on nonlivestock species are primarily limited to rat studies. The most comprehensive and quantitative study was initiated by Embry et al. (1959), who demonstrated a range of effects on rats that were administered different types of TDS components. Effects were seen at lower concentrations for water containing MgCl and $MgSO_4$ (790 mg/kg/d) compared to NaCl waters (>1,540 mg/kg/d). Calcium chloride resulted in reduced water consumption and growth rates at the lowest level (365 mg/kg/d). These results appear roughly consistent with Heller (1932, 1933) and Heller and Larwood (1930), as reported by NRC (1974).

Toxicity studies for birds were conflicting. Only one study, by Krista et al. (1961), tested the effects of NaCl on mallard duckling growth and intake rates. The NOAEL and LOAEL from this study were 269 and 385 mg/kg/d, respectively. A related series of studies on hens, measuring eggshell defects, demonstrated LOAELs as low as 104 mg/kg/d (Belnave and Yolowitz 1987, Belnave et al. 1989, Yolowitz et al. 1990) but all other studies on poultry demonstrated LOAELs at 350 mg/kg/d or higher (Heller 1933, Scrivner 1946, Krista et al. 1961). NOAELs demonstrated for these other studies were not lower than ~115 mg/kg/d (Heller 1933, Scrivner 1946). Particular details regarding the environmental conditions of the hens and feed/water diet are lacking in the Belnave and Yolowitz study series, which created unacceptable uncertainties associated with the study selection process.

Studies selected for ruminant and birds receptors were restricted to NaCl-dominated water only, as few (if any) studies were published on other types of TDS. Findings published by Weeth and Haverland (1961) and Weeth and Hunter (1971) were found to be most representative of the range of concentrations for which risk is not likely in growing cattle. Embry et al. (1959) was selected as the representative study on rats, and two NOAELs were identified as representative of the range of study effects: a low NOAEL based on MgCl exposure, and a higher NOAEL based on NaCl exposure. The range of study effects selected for the passerine bird included the NOAEL and LOAEL from Krista et al. (1961), as this study addressed effects specifically on mallard ducks.

The final WQCs for TDS for which there will be no risk to receptors include:

Nonruminant mammal (rodent)	4,750 – <11,700
Ruminant (growing heifer)	7,380 – <8,200
Passerine bird (mallard)	4,750 – <6,790
Current effluent limit:	**5,000**
Petition proposed limit:	**2,000**
Recommended benchmark:	**5,600**

Table 1-12. TDS water quality range from no adverse effects to low adverse effects, compared to the current and proposed surface water effluent limits for Wyoming. Water quality concentrations between the two extremes will not likely result in risk to receptors. All results in mg/L.

Uncertainty associated with the range of WQCs derived for growing cattle is low. When compared to barium and sulfate, a larger dataset was available for growing cattle; toxicity thresholds were largely consistent among studies but N/LOAELs varied widely between studies. The wide diversity in NOAELs is the result of lack of data at higher exposures rather than differences in cattle response. Most studies identified NOAELs but not LOAELs, hence uncertainties were slightly greater for the upper-extreme ranges of WQCs. However, almost all studies conducted experiments in feedlot-type environments that are not representative of conditions in Wyoming associated with higher TDS concentrations due to produced water outputs. The Johnson and Patterson (2004) study suggests that general toxicity thresholds in feedlot environments will be lower than in open range environments due to harsher environmental conditions in the feedlots. Hence, the studies used to derive WQCs for growing cattle are conservatively based.

The literature-based toxicity review primarily looked at effects of sodium chloride-dominated TDS water, which is consistent with much of produced water discharges. In some locations, discharges have significant components of carbonates as well. Literature review on general effects (Section 1.4) indicates that carbonate-dominated TDS waters result in toxicity to nonruminant mammals at slightly lower concentrations. However, literature-based toxicity thresholds for TDS in growing cattle are consistent with the field-based data gathered from Wyoming ranchers at locations with variable TDS makeup, including those with carbonate-dominated waters. Data from these interviews indicate that concentrations up to 5,390 mg/L do not result in adverse effects on growing or adult cattle.

Uncertainties associated with WQCs for nonruminant mammals and birds are moderate to high. There were very few available studies for rodents, although results were relatively consistent between studies. Toxicity studies on birds were conflicting; most studies such as Krista et al. (1961) were adequately designed, and confidence using these studies to derive WQCs is high, but particular details regarding the environmental conditions of the hens and feed/water diet are lacking in other studies (i.e., the Belnave and Yolowitz series), which showed lower toxicity thresholds.

To derive a single recommended water quality benchmark for TDS, the geometric mean of the low- and high-end concentrations was taken to obtain an estimated concentration at which risk to these receptors would be unlikely. Geometric means of the water quality benchmarks are 7,460, 7,800, and 5,680 mg/L for rodents, growing cattle and birds, respectively. Therefore, **the recommended water quality benchmark for TDS is 5,600 mg/L,** because this number is the lowest of the geometric means for cattle and birds (rounded down), it is within the range of NOAEL-based water quality criteria for other types of livestock (i.e., dairy cows), and it is consistent with field-based data from Wyoming water users.

The recommended water quality benchmark for TDS derived in this paper is consistent with the current regulatory effluent limits, as well as other published benchmarks for livestock from extension services around the country (e.g., Bagley et al. 1997, Faries et al. 1998, Looper and Waldner 2002). In contrast, the petitioners' proposed TDS limit of 2,000 mg/L does not represent the maximum tolerable level in livestock or wildlife. The citation provided as support lacks consistency with Wyoming produced water. Whereas Wyoming produced water typically has a sodium-bicarbonate or sodium-chloride signature, the reference, a South Dakota extension bulletin (Lardy and Stoltenow 1988) recommends ≤3,000 mg/L for *sulfate*-dominated TDS water for conditions in South Dakota. Thus, this recommendation more accurately describes toxicity thresholds for sulfate. It is important to note that all of the references cited in the petition are non-peer reviewed recommendations based on a review of either scientific literature or other extension publication bulletins.

1.7 Summary and Conclusions

To analyze the adequacy of the current effluent limits and the validity of the petitioners' proposed limits to protect wildlife and livestock, a risk analysis was done of livestock and wildlife chemical risk from TDS, sulfate and barium levels in surface water bodies created or impacted by produced water in Wyoming. This was accomplished by investigation along two lines of evidence. The first line included peer-reviewed scientific literature on water quality effects on animal species; the investigation sought to determine the water quality attribute (TDS, sulfate, barium) levels that are protective of animal species of interest, including livestock (cattle and sheep) and wildlife (mammals and birds). The second line of evidence included data compiled from ranchers and others in Wyoming who use produced and natural water sources for their livestock or farming use.

The analysis followed the US EPA's Guidelines for Ecological Risk Assessment (US EPA 1998), which outlines three basic steps for ERAs: problem formulation, analysis, and risk characterization.

1.7.1 Problem Formulation Summary

In the problem formulation stage, background information on the availability and quality of water bodies in Wyoming (both from natural and produced water sources) was reviewed, and animal use of those water bodies was described. There are more than 64,000 currently active CBNG and conventional oil and gas industry wells in Wyoming. Some of the water produced as a result of oil and gas extraction is discharged into reservoirs or naturally occurring drainages. Livestock and a variety of wildlife species utilize both natural and enhanced (from produced waters) surface water bodies for food, shelter, breeding ground and water resources. Examples of the water quality from active produced water discharges across Wyoming compared to the petition proposed standards are shown in Table 1-1. Much of this water could not be discharged if the petition-proposed water quality effluent limits were adopted by the WDEQ.

An ecological conceptual model was presented to describe the relationships between the stressors (produced water bodies) and biological components. Finally, a set of endpoints was identified to ensure that the risk assessment goals are consistent with the petitioners' statements and goals regarding WDEQ water quality regulations. The assessment endpoint identified in this risk analysis is the protection of the health and well-being of populations of Wyoming livestock and wildlife species from any adverse effects due of consuming surface water.

1.7.2 Exposure Analysis Summary

The analysis phase of the risk assessment examined the two primary components of risk: exposure and effects. In the exposure analysis, the exposure profiles for barium, sulfate and TDS were reviewed and exposure profiles for indicator species were identified. The fate and transport of constituents of interest in the environment play a significant role in determining toxicity to receptors. The chemical composition of the water, e.g., pH, hardness, dissolved organic carbon content, etc., strongly influences the speciation of constituents and the degree of uptake by biological organisms.

Barium compounds such as barium nitrate and barium chloride are soluble in water. However, the solubility of barium is often limited by the presence of sulfate and carbonate which bind the barium in sparingly soluble forms including barium sulfate and barium carbonate compounds. These forms of barium are relatively nonbioavailable.

Aqueous sulfate reacts with nearly all constituents, from metals to salts to organic matter, to form chemical complexes. In animals, inorganic sulfur is converted into organic sulfur, an essential component of proteins and other organic compounds.

Total dissolved solids (TDS) is a measure of all constituents dissolved in water. In natural and produced water, the most abundant of these constituents are typically chlorides, carbonates, bicarbonates and sulfates (collectively referred to as ‘anions’), and calcium, magnesium, potassium, and sodium (collectively referred to as ‘cations’). Most compounds must be dissolved in water to be absorbed from the digestive tract.

The receptors chosen for the risk analysis included a developing ruminant (growing heifer), a nonruminant small mammal (rodent), and waterfowl (mallard duck). These receptors are representative of the types of livestock and wildlife species in Wyoming that are exposed to surface water bodies, including locations where produced water effluent might be deposited.

1.7.3 Effects Analyses Summary

The effects analysis was divided into two parts. In the first part, existing toxicity studies and published guidelines were reviewed for each of the constituents of interest, and the methods used to derive TRVs were described. During the literature review, it was recognized that there were gaps between the constituent concentration clearly identified not to result in any effect, and the concentration found to result in a significant adverse effect. Concentrations in between these extremes (NOAEL, LOAEL) have not yet been evaluated and hence the potential for risk is unknown. We conservatively based the water quality benchmarks on the lowest of geometric means between the NOAEL and LOAEL. In addition, there are many differences in the environmental conditions between literature-based toxicity studies and environmental conditions in Wyoming. These differences have important impacts on animal tolerance to constituent exposure.

To reconcile the gaps in data and differences in study conditions from the Wyoming environment, a second method of effects evaluation was undertaken that involved a compilation of field-based data of water body users in Wyoming. Interviews with ranchers and other users of water bodies in Wyoming were undertaken to identify anecdotal as well as quantitative measures of effects. The field-based data served to support toxicity study results and fill in data gaps in the literature-based studies.

Overall, the ranchers indicated that water containing sulfates up to 3,100 mg/L and TDS up to 5,390 mg/L did not result in adverse risk to livestock in Wyoming's Bighorn and Powder River basins. Weaning rates, weaning weights, body condition, breeding percentage and death rates were no different between pastures associated with natural water sources, and those with produced water, which typically contain higher concentrations of sulfates and TDS. Adverse effects were apparent in livestock exposed to evapoconcentrated surface water that originally contained more than 4,000 mg/L sulfate and 7,000 mg/L TDS. Analyses of effects of these concentrations on wildlife were less conclusive; however, it appears that no adverse risk to wildlife occurred from exposure to water at Loch Katrine, which contains elevated sulfates and TDS relative to background.

1.7.4 Risk Characterization Summary

In the risk characterization step, ranges of WQCs were derived for each receptor-constituent combination from the reviewed literature sources. The WQCs were then used to derive a single recommended water quality benchmark for each constituent.

There were relatively few toxicity studies available for barium. Hence, additional uncertainty factors were employed to derive WQCs for livestock. The final WQCs for barium ranged from 13 to <915 mg/L. Although the degree of uncertainty associated with these benchmarks was high, even the lowest barium water quality benchmark derived (13 mg/L for ruminants) was over an order of magnitude higher than the proposed limit. Similarly, Canada's lowest recommended water quality criteria for livestock at 5 mg/L is also over an order of magnitude higher than the proposed limit.

Sulfate toxicity thresholds for birds and nonruminant mammals were consistent between studies. NOAELs for growing cattle were typically identified in the studies at 604 mg/kg/d or less, though one or two studies identified LOAELs at lower concentrations. Most studies were performed in a feedlot environment. Johnson and Patterson (2004) demonstrated that the conditions in feedlots are more stressful to the animal, resulting in reduced toxicity thresholds to growing cattle compared to conditions in open rangeland environments. The reported NOAEL from the open rangeland tests was 360 mg/kg/d (Johnson and Patterson 2004).

The final WQCs for sulfate ranged from 1,780 mg/L (lowest NOAEL) to <7,500 mg/L (highest LOAEL). These WQCs were consistent with the concentrations identified in the field-based studies, which found that concentrations up to 3,100 mg/L do not result in adverse risk to either wildlife or livestock.

The toxicity of TDS depends in part on its dominant constituents. The literature review focused on sodium-chloride-dominated TDS waters. The WQCs for TDS ranged from 4,750 to <11,700 mg/L. Uncertainty associated with the range of WQCs derived for growing cattle is low. Relative to barium and sulfate, a larger dataset was available for growing cattle; toxicity thresholds were largely consistent among studies, but N/LOAELs varied widely between studies. However, due to the feedlot conditions in most toxicity studies, these

WQCs for livestock are conservative. Moreover, literature-based toxicity thresholds for TDS in growing cattle are consistent with the field-based data gathered from Wyoming ranchers, who indicate that concentrations up to 5,390 mg/L do not result in adverse effects on growing or adult cattle.

The results of the risk analysis yielded the following recommended water quality benchmarks for barium, sulfate and TDS:

Benchmark/Limit	Barium	Sulfate	TDS
Recommended benchmark:	13	3,010	5,600
Current effluent limit:	None	3,000	5,000
Petition proposed limit:	0.2	500	2,000

Table 1-13. Summary table of recommended water quality benchmarks for barium, sulfate and TDS that are protective of livestock and wildlife receptors, compared to the current WDEQ effluent limits and the petition's proposed effluent limits. All results in mg/L.

The recommended benchmarks derived in this analysis are consistent with the current WDEQ effluent limits for sulfate and TDS. Furthermore, this ERA shows that there would be no incremental reduction in the injury to the health and well-being of animals and wildlife if water quality effluent limits were reduced to the petitioners' requested limits. The petitioners' proposed limits for barium, TDS and sulfate are not supported either by this analysis or by the literature cited in the petition.

2 Economic and Social Effects of Water Quality Limits of Produced Water

2.1 Introduction

The Wyoming Department of Environmental Quality (WDEQ) is reviewing a petition to change the current effluent limits for total dissolved solids (TDS) and sulfate, and to add an effluent limit for barium, for coal bed natural gas (CBNG) industry produced water. The petitioners argue that the current effluent limits are not "protective of stock and wildlife." However, the State, before recommending water quality standards (including effluent limits) for Wyoming, must consider a range of criteria (W.S. 35-11-302(vi)), including:

(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 direct response to the petition, the ecological risk assessment (ERA, Chapter 1 of this report) evaluated W.S. 35-11-302(vi)(A), the character and degree of injury to the health and well-being of livestock and wildlife affected by effluent limits. However, other factors that bear upon the reasonableness of effluent limits should not be overlooked. Principally, the character and degree of injury to the well-being of the people, and the social and economic value of produced water discharge should be carefully weighed, because the decision to change current effluent limits would affect not only water *quality*, but ultimately water *quantity*. This is because unnecessarily stringent effluent limits for produced water discharges will result in reduced water discharge to surface water bodies, since the economics of treating large quantities of produced water are such that injection/reinjection, deep disposal, and/or reduced exploration and development are likely results of additional treatment requirements. For examples, see Table 1-1 for a comparison of current discharge water quality data to the petition proposed limits.

Social and economic value to residents in Wyoming, and possible injury caused by reductions in exploration/development and produced water discharge are described in subsequent sections of this report. Although the petition targets only CBNG production in Wyoming, conventional oil production operations could also be affected by state-wide changes in effluent limits, and hence the effects on these industries are also considered.

Counties principally affected by produced water discharges include Bighorn, Hot Springs, Washakie and Park counties in the Bighorn basin; Freemont and Natrona counties in the Platte River basin; and Converse, Campbell, Johnson, Natrona and Sheridan counties in the Powder River basin. Hence, for purposes of this report, economic and social considerations are focused on these areas only.

2.2 W.S. 35-11-302(vi)(B) - The Social and Economic Value of the Source of Pollution

Since the advent of conventional and CBNG produced water discharge in Wyoming, numerous livestock owners, farmers and wildlife populations have used the increase in water supply to their advantage. Letters of beneficial use, written by landowners and received by industry, BLM and state agencies, describe a heavy dependence on produced water discharge to support their livelihood in ranching and farming (Appendix B). Examples include:

- Produced water in Five Mile Creek supports over 2,500 head of livestock for two operators (B. Garland 2002, L. Mantle 2002).
- R. Pattison (2002) is able to generate income by renting irrigated pastureland to cattle and sheep ranchers. The productivity of the irrigated pastureland is the result of using produced water discharges.
- J. Wilson and T. Wilson (2006) rely on produced water sources from the Gebo and Little Sand Draw oil fields to maintain their cattle herds on 19,000 acres of BLM lands.
- R. Larson (2002) uses produced water discharges for livestock and irrigation operations in his 3,000-acre pasture.
- A. Baird (1988) was able to increase his crop production by 300% between 1968 and 1988 with the use of produced water. Similarly, P. Ward (2006) cites a 300% increase in alfalfa hay production attributable to produced water sources.
- Produced water from Hamilton Dome oil field has been used to irrigate about 500 acres of ranchland along Cottonwood Creek, which otherwise could not be irrigated (J. Baird 1988).

In addition to individuals' letters, use attainability analyses for Salt Creek and Cottonwood Creeks (RETEC 2004, SWWRC et al. 2002) surveyed agricultural uses of these areas, and found that most of the available land that receives produced water discharges is now used almost year-round for livestock grazing of cattle and sheep. Ranches in the Salt Creek area consist of both privately owned land and leased land. Almost all of the ranches have access to Salt Creek or related tributaries that receive discharged produced water. Ranching on the lands adjacent to Salt Creek produced over 4,500 head of cattle and 3,300 head of sheep in 2002. Distributed between eight operations, this inventory accounts for 0.3% of all cattle and

0.7% of all sheep raised in Wyoming in 2002 (NASS 2002). About 35 landowners have property adjacent to Cottonwood Creek; nearly all of them benefit from produced water discharges through irrigation and/or stock watering. An estimated two-thirds of all crop production in the Cottonwood Creek area was attributable to produced water discharges. A good portion of the crops includes grass hay and alfalfa, which are used to feed cattle in winter months, hence further benefiting ranchers.

Produced water discharges also support populations of wildlife species that may not otherwise be viable. Improved water quality of the streams from produced water discharges in the Powder River basin, and the perennial streams created in the Bighorn basin from produced water discharges, attract many wildlife species and supports greater populations, including big game, small game birds, and wild horses. The increase in game populations also generates greater revenue from hunting, fishing, and related tourism in the Cottonwood Creek area (SWWRC et al. 2002). The drainages create additional foraging areas for a variety of large and small mammals and, subsequently, important prey resources for raptors. The creeks are used as stopover resting and foraging areas for a variety of migratory birds and waterfowl species, and habitat for threatened and endangered species. Finally, discharges may also support critical habitat for water-dependent species such as beaver and muskrat (RETEC 2004, SWWRC et al. 2002).

In the Bighorn basin, the Loch Katrine, a playa lake enhanced and maintained by produced water from the Oregon Basin oil field in Park County, WY, is a nesting and feeding ground for many species of migratory birds, raptors and waterfowl, including two species of threatened and endangered species: peregrine falcon and bald eagle; and three candidate species: the long-billed curlew, white-faced ibis, and ferruginous hawk (Ramirez 1993). The The Loch Katrine has received state and federal grants to maintain and improve the wetland complex. These funds help support local jobs and bird conservation programs.

Letters of beneficial use cite other instances of wildlife use of newly created and improved habitat in the Bighorn and Powder River basins (e.g., J. Wilson 1988, I. Schultz 1988, D. Grabbert 1988). Wild horse populations also frequent the Dry Creek area (G. Flitner, personal communication), and letters of beneficial use cite heavy dependence on the discharges from the Oregon Basin oil field for maintaining wild horse herd sizes (FOAL 2006). Finally, in the Platte River basin, use attainability analyses identified 97 species of birds and mammals in the area near Poison Spider Creek that benefit from produced water discharges (Gene R. George & Associates et al. 2005).

The quality of produced water discharges in certain circumstances improves water quality of natural drainages. In drainages within the Powder River basin, natural background concentrations of TDS and sulfates can reach as much as 22,000 mg/L TDS and 12,000 mg/L sulfate, resulting in acute adverse effects in cattle and wildlife, including death (RETEC 2004, A. Baird 1988, J. Baird 1988). Ranchers in this area have indicated a preference for using produced water discharge, as concentrations from the effluent are lower than natural background concentrations in Salt Creek (RETEC 2004). In the Bighorn basin, increases in water flow in Dry Creek lessen the effects of evapoconcentration of natural waters, which can result in adverse effects on cattle (D. Schlaf; Appendix A).

2.3 W.S. 35-11-302(vi)(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

The ERA (Chapter 1) found that there would be no incremental reduction in injury to the health and well-being of animals and wildlife if effluent limits were changed to the petitioners' requested limits. In addition, the social and economic injury to the people was evaluated as a result of changing the effluent limits.

The decision to change current effluent limits would affect not only water *quality*, but ultimately water *quantity,* because unnecessarily stringent effluent limits for produced water would likely result in reduced water discharge to surface water bodies. The economics of treating large quantities of produced water are such that injection/reinjection, deep disposal, and/or reduced exploration and development are likely results of additional treatment requirements.

2.3.1 Economic injuries of reduced exploration and development

Economically, field revenue from oil and gas extraction facilities provides jobs and associated earnings, production taxes and royalties, as well as basic export revenue. State-wide, the oil and gas industry supported 2,995 employees in 2002, with a total annual payroll of $162 million (US Bureau of the Census 2002). In addition, support activities for oil and gas operations, including drilling of oil and gas wells, employed an additional 9,200 employees with earnings totaling $332.6 million in 2002. The value of shipments, sales and receipts for oil and natural gas industries in Wyoming totaled $3.9 billion (in 2002), representing ~14% of the total sales, shipments and receipts for the state. At least a portion of these revenues is expected to be negatively impacted by a loss of opportunity to surface discharge produced water.

For example, in the Bighorn basin, the Hamilton Dome oil field produces both oil and natural gas. Elimination of this oil field would result in a loss of $28.7 million of total annual economic output (in 1997 dollars), and 136 jobs in Hot Springs County, with earnings totaling $4.1 million annually (SWWRC et al. 2002). An additional 51 jobs across Wyoming are supported by this oil field.

In Natrona County, elimination of the South Casper Creek field, a crude oil production facility that surface-discharges produced water, would have resulted in the loss of over $3 million of the county's basic exports in 2002, and losses of associated jobs, with annual earnings totaling $487,142 in 2002 (Gene R. George & Associates et al. 2005).

Elimination of oil fields in the Salt Creek area of the Powder River basin would result in the loss of over 175 jobs and $4.6 million in annual earnings (in 1997 dollars) for Natrona and Johnson counties (Taylor 1999).

2.3.2 Social injury of reduced oil and gas exploration/development

The presence and activity of oil and gas extraction facilities significantly contribute to the well-being of local communities, via fiscal contributions of taxes and royalties. County income from these operations supports various public facilities, including schools, hospitals, libraries, fire departments, environmental programs, and the county general fund.

In Natrona County, elimination of the South Casper Creek field would result in a reduction of property tax income by 2.5%, severance taxes by 0.04%, sales and use taxes by 0.16%, and 2.5% of federal royalties for the county (on average, between 1997 and 2002; Gene R George & Associates et al. 2005). The total dollar amount (in 2002 dollars) of the loss of these tax and royalty contributions is estimated at $424,085.

Loss of funds associated with the Hamilton Dome oil field would reduce social contributions to Hot Springs County (in terms of fiscal contributions) totaling 29% of total property taxes, 9% of general fund revenues, 27% of the library system's total revenues, 2% of county hospital revenues, 9% of the county weed and pest management program, 29% of the rural fire district budget, and additional funds for school districts averaging $1.4 million annually (SWWRC et al. 2002).

Elimination of the Salt Creek fields would result in losses of $2.8 million in property tax revenue for Natrona County (in 1997 dollars): $2 million for public schools, $500,000 for county government, and $300,000 for community colleges (Taylor 1999). State severance taxes for the Salt Creek fields in 1997 were estimated at $2.4 million; 2.6% ($62,257) of the total severance tax was received by Natrona County and 0.2% ($4,789) was received by Johnson County.

2.3.3 Economic injury of eliminating produced water discharges

Farming and ranching is a mainstay of many local economies across Wyoming. There were 5,282 cattle and calf ranches in Wyoming in 2002 (4,590 being beef cow ranches) and 5,191 irrigated cropland farms (NASS 2002). The total number of cattle inventoried in 2002 in counties[1] impacted by produced water discharges was 598,000 head. The combined marketing receipts from agricultural sales in Wyoming totaled $864 million in 2002, with an average of ~$91,700 per operation. Of the total, $726 million was derived from livestock sales (~$645 per head). Operators incurred $518.5 million in production expenses, including livestock, feed, fuel, hired labor, and interest on loans. This leaves a residual net cash return of $207.5 million, or an average of ~$39,000 per livestock operation (before property taxes).

Drought conditions in an already semiarid climate with declining land availability and difficult market conditions have contributed to economic hardships for Wyoming farmers and ranchers in recent years. Rancher interviews in October and November 2006 cite drought-related herd reductions, between 10% and 30% or more (Appendix A). Others cite total dependence on produced water sources, as natural water bodies have disappeared (e.g., M. Brown 2006, L. Mantle 2002, D. Griebel 2002, J. Fike 2002, P. Renner 2002, M. May 2002, N. Sanford 2002, R. Larsen 2002, T. Brown and M. Brown 1988, D. Grabbert 1988). The number of cattle ranches across Wyoming declined 18% between 1997 and 2002. However, with the advent of produced water discharges, many ranchers and farmers are able to continue to make a living in Wyoming; in fact, cattle inventories have increased in recent decades, relative to national inventory numbers (Figure 2-1).

Data from the 2002 National Agricultural Statistics Service was gathered to evaluate economic indices in Wyoming and estimate losses from potential reductions in produced water outputs. In 2002, Wyoming farmers and ranchers reported an aggregate of 34.4 million acres of land in use as part of their operations. The total includes private, state and federal lands covered by grazing allotments, used as pastureland or grazing range. About

[1] Bighorn, Campbell, Converse, Fremont, Hot Springs, Johnson, Natrona, Sheridan, Washakie

1.54 million acres, mostly cropland, is irrigated. In the Cottonwood Creek area of the Powder River basin, 50% of irrigated land is pastureland, which provides winter and spring range and winter feed for the cattle and livestock herds (SWWRC et al. 2002).

Water loss from the Cottonwood Creek area would reportedly correspond to reductions in herd size, between 15% and 20%, resulting in an estimated loss of $2 million in livestock sales, according to the use attainability analysis for Hot Springs County (SWWRC et al. 2002). Additional loss of irrigated pastureland was estimated at 8%. These pasturelands correspond to 1,600 acres of irrigated cropland and 4,000 tons of annual hay production. The use attainability analysis also estimates economic losses of 1.7% ($3.3 million) of total annual economic output (in 1997 dollars) and $645,000 in annual labor income associated with direct reduction in annual livestock receipts.

Ranchers (McCarty, Flitner, and Schlaf) in the Bighorn basin estimated reductions in herd sizes between 30% and 50% from loss of produced water in Dry Creek (Appendices A and B), resulting in an estimated loss of $387,000 to $645,000 in annual livestock sales (@ $645 per head).

Herd reductions resulting from produced water losses in Salt Creek are estimated between 20% and 40% (RETEC 2004). This area supports more than 4,575 head of cattle (surveyed in 2002); corresponding losses of livestock sales from this area are estimated between $590,175 and $1.1 million (@ $645 per head).

Letters of beneficial use from individuals indicate that reduced discharge to surface water bodies would result in herd reductions in many counties across Wyoming. The total number of cattle inventoried in 2002 in counties[1] impacted by produced water discharges was 598,000 head. Combined herd losses of 15% to 50% in these counties would incur estimated losses between $57 million and $192 million in livestock sales (@ $645 per head).

Many ranchers cite additional costs of developing alternate water sources (wells, water hauling, ice breaking, etc.) if produced water were not available (e.g., M. Dennis 2006, D. Griebel 2003, N. Sanford 2002; G. Flitner and M. McCarty, personal communication; Appendix A). J. Kearns (1989) estimated an initial cost of $140,000 and $10,000 annually to maintain watering wells on Bighorn basin properties if produced water were not available. Associated job losses are cited in several areas: at Cottonwood Creek, an estimated 20 full- or part-time jobs would be eliminated if there were no produced water discharge; and D. Flitner estimates that a portion of the 40 full- or part-time jobs in his Bighorn basin pastures are maintained by the use of grazing lands supported by produced water discharges (D. Flitner 2006). B. Basse, chairman of the Hot Springs County Commissioners, cites a heavy economic dependence on agriculture, tourism, and oil/gas industries, all of which would be negatively impacted by reduced water discharges in this area (SWWRC et al. 2002).

Finally, the economic impact of loss of wildlife populations would primarily affect revenue generated from hunting, fishing and tourism. In 2001, tourism accounted for an estimated $1 billion in state revenue (Wyoming 2006). Sales from hunting and fishing licenses, travel, and lodging would be reduced as a result of loss of wildlife in many areas benefiting from produced water discharge. Revenues raised through license sales support state wildlife agencies, their conservation projects, and their hunter education and aquatic resources education programs. In addition, the Loch Katrine wetland complex receives governmental financial support for its maintenance and operation, which includes local jobs and bird conservation programs.

2.4 Summary and Conclusions

Wyoming DEQ must consider a range of criteria before recommending effluent limits (W.S. 35-11-302(vi)). These criteria include the character and degree of injury to the well-being of people, and the social and economic value of produced water discharge should be carefully weighed, because the decision to change current effluent limits would not only impact water *quality*, but also ultimately water *quantity*.

Numerous landowners in the Powder River and Bighorn basins of Wyoming benefit from produced water discharges, through irrigation and/or stock watering, with several examples highlighted above. Produced water also supports populations of wildlife species that may otherwise not be viable, including wild horse populations. In addition, produced water discharges in certain circumstances improve the water quality of natural drainages.

The risk assessment found that current WDEQ effluent limits pose no measureable adverse effect to the health and well-being of domestic livestock and wildlife. Furthermore, there would be no incremental reduction in wildlife or livestock injury if water quality effluent limits were changed to the petitioners' requested limits. The social and economic injury to people was evaluated as well.

Economic injuries of reduced exploration and development included lost revenue from oil and gas extraction facilities in the form of jobs and associated earnings, and basic export revenue:

- Elimination of the South Casper Creek field would result in losses of $3 million (in 2002 dollars) to the basic exports of Natrona County, with additional losses of 18 jobs with annual earnings totaling $487,142 (in 2002).
- Elimination of the Hamilton Dome oil field would result in losses of $28.7 million (in 1997 dollars) in state total annual economic output, with associated losses of 136 jobs in Hot Springs County alone with earnings totaling $4.1 million annually. An additional 51 jobs across the state of Wyoming are supported by this oil field.
- Elimination of the Salt Creek fields of the Powder River basin would result in the loss of over 175 jobs and $4.6 million in annual earnings (in 1997 dollars) for Natrona and Johnson counties.

Social impacts include loss of financial contributions toward the improvement and well-being of local communities. County income from operations supported by produced water discharges include various public facilities including schools, hospitals, libraries, fire departments, environmental programs, and the county general fund:

- In Natrona County, elimination of the South Casper Creek field would result in reduction of related taxes and royalty contributions totaling $424,085 (in 1997 dollars). These contributions account for 2.5% of county property tax income, 0.04% of severance taxes, 0.16% of sales and use taxes, and 2.5% of federal royalties for the county;

- Loss of funds associated with the Hamilton Dome oil field would reduce fiscal contributions to Hot Springs County totaling 29% of total property taxes, 9% of total general fund revenues, 27% of the library system's total revenues, 2% of county hospital revenues, 9% of the county weed and pest management program, 29% of the rural fire district budget, and additional funds for school districts averaging $1.4 million annually (in 2002 dollars).

- Elimination of the Salt Creek fields in Natrona County would result in losses of $2.8 million in property tax revenue (in 1997), of which $2 million went to public schools, $500,000 to county government, and another $300,000 to community colleges. Additionally, state severance taxes for the Salt Creek fields in 1997 were estimated at $2.4 million; 2.6% ($62,257) of the total severance tax was received by Natrona County, and 0.2% ($4,789) was received by Johnson County.

Even with continued industry presence, estimated costs of eliminating produced water discharges include:

- 15% to 20% loss of cattle in the Cottonwood Creek area, corresponding to an estimated $2 million in lost livestock sales;

- economic losses of 1.7% ($3.3 million) of total annual economic output and $645,000 in annual labor income in Hot Springs County;

- an 8% loss of irrigated pastureland in the Cottonwood Creek area, corresponding to a loss of 1,600 acres of irrigated cropland and 4,000 tons of annual hay production;

- livestock losses estimated between 30% and 50% by several ranchers in the Bighorn basin, resulting in estimated losses of $387,000 to $645,000 in annual livestock sales;

- livestock losses estimated between 20% and 40% in the Salt Creek area, corresponding to an estimated $590,175 to $1.1 million in lost annual livestock sales;

- negative impacts state-wide from loss of livestock revenue;

- additional costs to ranchers to develop alternative water sources such as wells, water hauling and breaking ice;
- associated job losses related to ranching and farming;
- lost revenue from hunting, fishing and tourism due to declining wildlife populations; and
- lost access to federal funding and associated employment at the Loch Katrine wetland complex.

Loss of opportunity to surface discharge water would have a negative impact on oil and gas production, as well as jobs, across the state of Wyoming. State-wide, the oil and gas industry supported 2,995 employees in 2002, with a total annual payroll of $162 million (US Bureau of the Census 2002). In addition, support activities for oil and gas operations, including drilling of oil and gas wells, employed an additional 9,200 employees with earnings totaling $332.6 million in 2002. The value of shipments, sales and receipts for oil and natural gas industries in Wyoming totaled $3.9 billion (in 2002), representing ~14% of the total sales, shipments and receipts for the state. At least a portion of this revenue is expected to be impacted by the loss of opportunity to surface discharge water. A state-wide analysis of economic and social benefits and injury from loss of produced water surface discharge, exploration and development is recommended to evaluate the total impact of the petitioners' proposed effluent limits.

3 References

Adams, A.W., F.E. Cunningham and L.L. Munger. 1975. Some effects of layers of sodium sulfate and magnesium sulfate in their drinking water. Poultry Sci. 54:707.

Almudena, A., G.Antonio, O. Baldomero and G. Luis. 1996. Re-evaluation of the p/q ca-2+ channel components of ba-2+ currents in bovine chromaffin cells superfused with solutions containing low and high ba-2+ concentrations. Pfluegers Archiv European Journal of Physiology. 432(6):1030-1038.

Anderson, D.M. and S.C. Stothers. 1978. Effects of saline water high in sulfates, chlorides and nitrates on the performance of young weanling pigs. J. Anim. Sci. 47:900.

Aromolaran, A. S. and Large, W. A. 1999. Comparison of the effects of divalent cations on the noradrenaline-evoked cation current in rabbit portal vein smooth muscle cells J. Physiol. (Cambridge U. K.) 520(3):771-782.

ASTDR (Agency for Toxic Substances and Disease Registry). 2001. Toxicological profile for arsenic. Atlanta, GA: Agency for toxic substances and disease registry. US Department of Heath and Human Services.

Audubon Society of Wyoming. 2006. Online at http://www.audubonwyoming.com

Bagley, C.V., J.Kotuby-Amacher and K. Farrell-Poe. 1997. Analysis of Water Quality for Livestock. Utah State Univ. Ext. Animal Health Fact Sheet AH/Beef/28.

Bahman, A. M., J. A. Rooket, and J. H. Topps. 1993. The performance of dairy cows offered drinking water of low or high salinity in a hot arid climate. Anim. Prod. 57:23-28.

Baird, A. 1988. Inter-office memo to Marathon Oil Co. Oct. 28. Cody, WY.

Baird, J. 1988. Inter-office memo to Marathon Oil Co. Oct. 30. Worland, WY.

Ballantyne, E.E. 1957. Drinking waters toxic for livestock. Can. J. Comp. Med. Vet. Sci. 21:254-257.

Barquin, J., Barquin, J., Nicholls, T., Nicholls, B. Scheer, J., Griebel, D. 2002. Inter-office memo to Marathon Oil Co. Feb. 10.

Basse, B. 2006. Inter-office memo to Environmental Quality Council of Wyoming. Feb. 16.

Belnave, D. and T.A. Scott. 1986. The influence of minerals in drinking water on eggshell quality. Nutr. Rep. Intl. 34:29-34.

Belnave, D. and I. Yolowitz. 1987. The relation between sodium chloride concentration in drinking water and egg-shell damage. British J. of Nutr. 58:503-509.

Belnave, D., I. Yoselewitz and R.J. Dixon. 1989. Physiological changes associated with the production of defective eggshells by hens receiving sodium chloride in the drinking water. British J. of Nutr. 61:35-43.

Blosser, T.H. and B.K. Soni. 1956. Comparative influence of hard and soft water on milk production of dairy cows. J. Anim. Sci. 1519-1525.

Borzelleca, J.F., L.W. Condie Jr. and J.L. Egle Jr. 1988. Short-term toxicity (one-and ten-day gavage) of barium chloride in male and female rats. J. American College of Toxicology 7:675-685.

Brown, M. 2006. Inter-office memo to Environmental Quality Control Council. Feb. 13.

Brown, R.G. and A. Gamatero. 1970. Effect of added sulfate on the utilization of peanut protein by the rat. Can. J. Anim. Sci. 50:742-744.

Brown, M., Brown, T. 1988. Inter-office memo to Marathon Oil Co. Oct. 25. Thermapolis, WY.

Calder, W.A., Braun, E.J. 1983. Scaling of osmotic regulation in mammals and birds. American Journal of Physiology 224:R601-R606.

CCREM. 1987. Canadian water quality guidelines. Prepared by the Task Force on Water Quality Guidelines. Canadian Council of Resource and Environmen Ministers.

Challis, D.J., J.S. Zeinstra and M.J. Anderson. 1987. Some effects of water quality on the performance of high yielding cows in an arid climate. Vet. Rec. 120:12-15.

Chapman, P.M., A. Fairbrother and D. Brown. 1998. A critical evaluation of safety (uncertainty) factors for ecological risk assessment. Environmental Toxicology and Chemistry 17:99-108.

Church, D.C. 1979. Digestive Physiology and Nutrition of Ruminants. 2nd ed. O & B Books, Inc., Portland, OR.

Coghlin, C.L. 1944. Hydrogen sulfide poisoning in cattle. Can. J. Comp. Med. 8:111.

Cohen, H.P., H.C. Choitz and C.P. Berg. 1958. Response of rats to diets high in methionine and related compounds. J. Nutr. 64:555.

Daniel, R.G. and H.A. Waisman. 1969. Adaptation of the weanling rat to diets containing excess methionine. J. Nutr. 99:299.

Dennis, M. 2006. Inter-office memo to Environmental Quality Council. Feb. 15. Pavillion, WY.

Dietz, D.D., M.R. Elwell, W.E. Davis, Jr. and E.F. Meirhenry. 1992. Subchronic toxicity of barium chloride dihydrate administered to rats. Fundam. Appl. Toxicol. 19:527.

Digesti, R.D. and H.J. Weeth. 1976. A defensible maximum for inorganic sulfate in drinking water of cattle. J. Anim. Sci. 42:1498-1502.

Dziewiatowski, D.D. 1954. Effect of age on some aspects of sulfate metabolism in the rat. J. Exp. Med. 99:283-298.

Eisler, R. 2000. Handbook of chemical risk assessment. First CRC Press LLC Printing. Boca Raton, FL.

Embry, L.B., M.A. Hoelscher and R.C. Wahlstrom. 1959. Salinity and livestock water quality. SD. Agric. Expt. St. Bull. 481:5.

Enright, T. 1989. Inter-office memo to Marathon Oil Co. Feb. 8. Cody, WY.

Faries, F. Jr., J.M. Sweeten and J.C. Reagor. 1998. Water quality: Its relationship to livestock. Texas Agric. Ext. Service, L-2374, 6-98.

Fike, J. 2002. Inter-office memo to Marathon Oil Co. Jan. 18.

Flitner, D. 2006. Inter-office memo to Marathon Oil Co. Aug. 24. Greybull, WY.

FOAL. 2006. Inter-office memo to M. Gordon, Environmental Quality Council of Wyoming. Sept. 27. Cheyenne, WY.

Frens, A.M. 1946. Salt drinking water for cows. Tijdschr. Diergeneeskd. 71:6-11.

Garland, B. 2002. Inter-office memo to Marathon Oil Co. Jan. 9. Pavillion, WY.

Gene R. George & Associates, Inc., HAF, Inc and Hayden-Wing Associates. 2005. Use attainability analysis of Poison Spider Creek, Natrona County, Wyoming. February 14.

Gould, D.H. 1998. Polioencephalomalacia. J. Anim. Sci. 76:309.

Grabbert, D. 1988. Inter-office memo to Marathon Oil Co. Oct. 19. Emblem, WY.

Griebel, D. 2002. Inter-office memo to Marathon Oil Co. Kinnear, WY.

Griebel, D. 2003. Inter-office memo to Marathon Oil Co. Nov. 6. Kinnear, WY.

Grout, A.S., D.M. Veira, D.M. Weary, M.A.G. von Keyserlingk and D. Fraser. 2006. Differential effects of sodium and magnesium sulfate on water consumption by beef cattle. J. Anim. Sci. 84:1252-1258.

Harter, J.M. and D.H. Baker. 1978. Factors affecting methionine toxicity and its alleviation in the chick. J. Nutr. 108:1061.

Henry, P.R. 1995. Sodium and chlorine bioavailability. In: Bioavailability of nutrients for animals: Amino acids, minerals, and vitamins. C.B. Ammerman, D.H. baker and A.J. Lewis (eds). Academic Publishing, San Diego, CA. pp. 337-348.

Heller, V.G. 1932. Saline and alkaline drinking waters. J. Nutr. 5:421-429.

Heller, V.G. 1933. The effect of saline and alkaline waters on domestic animals. Okla. Agric. Exp. Stn. Bull. 217. 23 pp.

Heller, V.G. and C.H. Larwood. 1930. Saline drinking water. Science 71:223-224.

Hope, B., C. Loy and P. Miller. 1996. Uptake and trophic transfer of barium in a terrestrial ecosystem. Bulletin of Environ. Contam. Toxicol. 56:683-689.

Hubbert, F. Jr., E. Cheng and W. Burroughs. 1958. Mineral requirements of rumen microorganisms for cellulose digestion in vitro. J. Anim. Sci. 17:559.

Jaster, E.H., J.D. Schuh and T.N. Wegner. 1978. Physiological effects of saline drinking water on high producing dairy cows. J. Dairy Sci. 61:66.

Johnson, C.E., L.H. Herbers and J.M. Prescott. 1959. Effect of alkaline drinking water on the pH and microbial activity of the rumen.

Johnson, D., A.L. Mehring and H.W. Titus. 1960. Tolerance of chickens for barium. Proc. Soc. Exp. Biol. Med. 104:436.

Johnson, P.S. and H.H. Patterson. 2004. Effects of sulfates in water on performance of steers grazing rangeland. Proc. Western Section, Am. Soc. Anim. Sci. 55:261.

Kare, M.R. and J. Biely. 1948. The toxicity of sodium chloride and its relation to water intake in baby chicks. Poult. Sci. 27:751.

Katz, R.S. and D.H. Baker. 1975. Toxicity of various organic sulfur compounds for chicks fed crystalline amino acid diets containing threonine and glycine at their minimal dietary requirements for maximal growth. J. Anim. Sci. 41:1355.

Kearns, J. 1989. Inter-office memo to Bureau of Land Management. May 15. Cody, WY.

Kober, J.A. Water: the most limiting nutrient. Agri-Practice 14:39-42. February 1993.

Krista, L.M., C.W. Carlson and O.E. Olson. 1961. Some effects of saline waters on chicks, laying hens, poults and ducklings. Poul. Sci. 40:938.

Lardy, G. and C. Stoltenow. 1988. Livestock and water. South Dakota State University Extension Service Bulletin AS-954. June.

Larsen, R. 2002. Inter-office memo to Marathon Oil Co. Jan. 3. Meeteetse, WY.

Lassiter, J.W. and M.K. Cook. 1963. Effect of sodium bicarbonate in the drinking water of ruminants on the digestibility of a pelleted complete ration.

Leach, R.M., T.R. Zeigler and L.C. Norris. 1960. The effect of dietary sulphate in the growth rate of chicks fed a purified diet. Poult. Sci. 39:1577.

Ledder, E. 1988. Inter-office memo to Marathon Oil Co. Oct. 18. Medicine Bow, WY.

Loneragan, G.H., D.H. Gould, R.J. Callan, C.J. Sigurdson and D.W. Hamar. 1998. Association of excess sulfur intake and an increase in hydrogen sulfide concentrations in the ruminal gas cap of recently weaned beef calves with polioencephalomalacia. J. Am. Vet. Med. Assoc. 213:1599-1604.

Loneragan, G.H., J.J. Wagner, D.H. Gould, F.B. Garry and M.A. Thorens. 2001. Effects of water sulfate concentration on performance, water intake, and carcass characteristics of feedlot steers. J. Anim. Sci. 79:2941-2948.

Looper, M.L. and D.N. Waldner. 2002. Water for Dairy Cattle. Guide D-107. New Mexico State Univ. Coop. Ext.

Mantle, L. 2002. Inter-office memo to Marathon Oil Co. Jan. 3. Cody, WY.

Martinez, A. and D.C. Church. 1970. Effect of various mineral elements on in vitro rumen cellulose digestion. J. Anim. Sci. 31:982.

May, M. Inter-office memo to Marathon Oil Co. Feb. 22. Cody, WY.

McCauley, P.T. and I.S. Washington. 1983. Barium bioavailability as the chloride, sulfate or carbonate salt in the rat. Drug and Chem. Toxicol. 6:209.

McCauley, P.T., B.H. Douglas, R.D. Laurie and R.J. Bull. 1985. Investigations into the effect of drinking water barium on rats. Environ. Health Perspect. Calabrese, ed. Princeton Scientific Publications, Princeton, NJ. 197 pp.

Mehring, A.L., J.H. Brumbaugh, A.J. Sutherland and H.W. Titus. 1960. The tolerance of growing chickens for dietary copper. Poultry Science 39:713-719.

Moore, J.W. 1991. Inorganic contaminants of surface waters, research and monitoring priorities. Springer-Verlag, New York.

Mudd, S.H., F. Irreverre and L. Laster. 1967. Sulfite oxidase deficiency in man: demonstration of the enzymatic defect. Science 156:1599-1601.

Murray, R.K., D.K. Granner, P.A. Mayes and V.W. Rodwell. 2000. Harpers Biochemistry. 25th ed. Appleton and Lange, Stamford, Connecticut.

Nagy, K.A. 1987. Field metabolic rate and food requirement scaling in mammals and birds. Ecological Monographs 57:111-128.

NASS. 2002. Cattle. Released February 1, 2002, Agricultural Statistics Board, U.S. Department of Agriculture. National Agricultural Statistics Service.

NASS. 2005. Cattle on Feed. Released January 21, 2005, Agricultural Statistics Board, U.S. Department of Agriculture. National Agricultural Statistics Service.

Newman, M.C. 1998. Fundamentals of ecotoxicology. Ann Arbor Press, Ann Arbor, MI.

NRC. 1974. Nutrients and Toxic Substances in Water for Livestock. National Academy of Sciences, Washington, D.C. National Research Council.

NRC. 1980. Mineral Tolerances of Domestic Animals. National Academy of Sciences, Washington, D.C. National Research Council.

NRC. 2000. Nutrient Requirements of Beef Cattle. 7th revised edition update. National Academy of Sciences, Washington, D.C. National Research Council.

NRC. 2005. Mineral Tolerances of Animals. National Academy of Sciences, Washington, D.C. National Research Council.

Patterson, H.H., P.S. Johnson, T.R. Patterson, D.B. Young and R. Haigh. 2002. Effects of water quality on performance and health of growing steers. Proc. Western Section, Am. Soc. Anim. Sci. 53:217.

Patterson, H.H., P.S. Johnson and W.B. Epperson. 2003. Effect of total dissolved solids and sulfates in drinking water for growing steers. Proc. Western Section, Am. Soc. Anim. Sci. 54:378.

Patterson, H.H., P.S. Johnson, E.H. Ward and R.N. Gates. 2004. Effects of sulfates in water on performance of cow-calf pairs. Proc. Western Section, Am. Soc. Anim. Sci. 55:265.

Pattison, R. 2002. Inter-office memo to Marathon Oil Co. Pavillion, WY.

Peirce, A.W. 1957. Studies on salt tolerance of sheep. I. The tolerance of sheep for sodium chloride in the drinking water. Aust. J. Agric. Res. 8:711.

Peirce, A.W. 1959. Studies on salt tolerance of sheep. II. The tolerance of sheep for mixtures of sodium chloride and magnesium chloride in the drinking water. Aust. J. Agric. Res. 10:725.

Peirce, A.W. 1960. Studies on salt tolerance of sheep. Aust. J. Agric. Res. 11:548.

Peirce, A.W. 1962. Studies on salt tolerance of sheep. IV. The tolerance of sheep for mixtures of sodium chloride and calcium chloride in the drinking water. Aust. J. Agric. Res. 11:548.

Peirce, A.W. 1963. Studies on salt tolerance of sheep. V. The tolerance of sheep for mixtures of sodium chloride, sodium carbonate and sodium bicarbonate in the drinking water. Aust. J. Agric Res. 14:815.

Perry, H.M., E.F. Perry, M.N. Erlanger and S.J. Kopp. 1983. Cardiovascular effects of chronic barium ingestion. In Proc 17th Ann. Conf. Trace Substances in Environ. Health. Vol 17. University of Missouri Press, Columbia, MO.

Pitz, M., Meisinger, L. 1988. Inter-office memo to Marathon Oil Co. Cody, WY.

Ramirez, P. 1993. Contaminants in oil field produced waters discharged into the Loch Katrine wetland complex, Park County, Wyoming and their bioconcentration in the aquatic bird food chain. U.S. Fish and Wildlife Service Contaminant Report No. R6/706C/93. Cheyenne, WY. Dec.

Ramirez, P. 2002. Oil field produced water discharges into wetlands in Wyoming. U.S. Fish and Wildlife Service Contaminant Report # R6/718C/02. Cheyenne, WY. Aug.

Ramsey, A.A. 1924. Waters suitable for livestock. Agri. Gaz. N.S.W. 339-342. May 1.

Ray, D.E. 1989. Interrelationships among water quality, climate and diet on feedlot performance of steer calves. J. Anim. Sci. 67:357.

Renner, P. 2002. Inter-office memo to Marathon Oil Co. Jan. 8.

RETEC. 2004. Use attainability analysis, Salt Creek and Powder River Natrona and Johnson County, Wyoming. November 10.

Robertson, B.M., T. Magner, A. Dougan, M.A. Holmes and R.A. Hunter. 1996. The effect of coal mine pit water on the productivity of cattle. I. Mineral intake, retention and excretion and the water balance in growing steers. Aust. J. Agr. Res. 47:961-974.

Rodenberg, J. 1989. Practical water evaluation for dairy cattle. Ontario Ministry of Agriculture and Food. Ontario, Canada.

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological benchmarks for wildlife: 1996 revision. Oak Ridge National Laboratory, Oak Ridge, TN. 227 pp.

Sample, B.E., Suter, G.W., II, Sheaffer, M.B., Jones, D.S., Efroymson, R.A. 1997. Ecotoxicological profiles for selected metals and other inorganic chemicals. ES/ER/TM-210. Oak Ridge, TN: Oak Ridge National Laboratory.

Sanford, N. 2002. Inter-office memo to Marathon Oil Co. Feb. 25. Cody, WY.

Sasse, C.E. and and D.H. Baker. 1974. Factors affecting sulfate sulfur utilization by the young chick. Poul. Sci. 53:652.

Schroeder, H.A. and M. Mitchener. 1975. Life-term studies in rats: effects of aluminum, barium, beryllium, and tungsten. J. Nutr. 105:421-427.

Schultz, I. 1988. Inter-office memo to Marathon Oil Co. Oct. 19. Cody, WY.

Scrivner, L.H. 1946. Experimental edema and ascites in poults. J. Am. Vet. Med. Assoc. 108:27-32.

Selye, H. 1943. Production of nephrosclerosis in the fowl by sodium chloride. J. A.V.M.A. 140-143.

Smith, J.T. 1973. An optimal level of inorganic sulfate for the diet of a rat. J. Nutr. 103:1008.

Solomon, R., J. Miron, D. Ben-Ghedalia and Z. Zomberg. 1995. Performance of high producing dairy cows offered drinking water of high and low salinity in the Arava Desert. J. Dairy. Sci. 78:620-624.

Spafford, W.J. 1941. South Australian natural waters for farm livestock. J. Dep. Agric. S. Aust. 44:619-628.

SWWRC et al. 2002. Merit Energy Company Use Attainability Analysis. December 20. States West Water Resources Corporation, Western EcoSystems Technology, Inc. and Blankenship Consulting LLC.

Tardiff, R.G., M. Robinson and N.S. Ulmer. 1980. Subchronic oral toxicity of barium chloride in rats. J. Environ. Pathol. Toxicol. 4:267-276.

Taucins, E., A. Svilane, A. Valdmanis, A. Buike, R. Zarina and E. Fedorova. 1969. Barium, strontium, and copper salts in chick nutrition. Fiziol. Akt. Komponenty Pitan Zhivotn. 199.

Taylor, D.T. 1999. Economic importance of Salt Creek oil fields. University of Wyoming Cooperative Extension Service, Laramie, WY. March.

Turnell, J. 2002. Inter-office memo to Marathon Oil Co. March 15.

US Bureau of the Census. 2002. 2002 Economic Census – Wyoming. US Department of Commerce.

US EPA. 1972. Water quality criteria. Prepared by the National Academy of Sciences and the National Academy of Engineering for the US Environmental Protection Agency, Washington D.C.

US EPA. 1976. Quality criteria for water. Office of Water and Hazardous Materials, Washington, D.C. July.

US EPA. 1984. Health effects assessment for barium. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment office, Cincinnati, OH, for the Office of Emergency and Remedial Response, Washington, D.C.

US EPA. 1988. Recommendations for a documentation of biological values for use in risk assessment. Environmental Criteria and Assessment Office, Cincinnati, OH. EPA/600/6-87/008.

US EPA. 1992a. Guidelines for exposure assessment. US Environmental Protection Agency, Risk Assessment Forum. Washington, D.C. 600/Z-92/001.

US EPA. 1992b. Framework for ecological risk assessment. US Environmental Protection Agency, Office of Solid Waste and Emergency Response. Washington, D.C.

US EPA. 1993. Wildlife exposure factors handbook. Volume 1 and 2. EPA/600/R-93/187a and b. US Environmental Protection Agency, Office of Research and Development, Washington D.C.

US EPA. 1995. Great Lakes water quality initiative technical support document for wildlife criteria. Office of Water, Washington D.C. EPA/820/B-95/009.

US EPA. 1998. Guidelines for ecological risk assessment. USEPA EPA/630/R095/002F. 01 Apr 1998. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, DC, 175 pp.

US EPA. 2002. Generic assessment endpoints for ecological risk assessments (external review draft). US Environmental Protection Agency Risk Assessment Forum, Washington, DC. 75pp.

US EPA. 2003. Guidance for developing ecological soil screening levels. US Environmental Protection Agency, Office of Solid Waste and Emergency Response. Washington, DC.

US EPA. 2005. Ecologial soil screening levels for barium. Interim final. U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response. Washington, D.C. February.

Ward, E.H. and H.H. Patterson. 2004. Effects of thiamin supplementation on performance and health of growing steers consuming high sulfate water. Proc. Western Section, Am. Soc. Anim. Sci. 55:375.

Ward, P. 2006. Inter-office memo to Department of Environment Quality Water Quality Division. Feb. 13.

WDEQ. 2000. Wyoming department of environmental quality water quality division antidegradation review, analysis and findings. http://deq.state.wy.us/wqd/WYPDES_Permitting/WYPDES_cbm /downloads /12258-doc.pdf. Wyoming Department of Environmental Quality.

Weeth, H.J. 1962. Effect of drinking water containing added manganese on cattle (abstr.). J. Anim. Sci. 21:656.

Weeth, H.J., L.H. Haverland and D.W. Cassard. 1960. Consumption of sodium chloride water by heifers. J. Anim. Sci. 19:845.

Weeth, H.J. and L.H. Haverland. 1961. Tolerance of growing cattle for drinking water containing sodium chloride. J. Anim. Sci. 20:518.

Weeth, H.J. and J.E. Hunter. 1971. Drinking of sulfate-water by cattle. Journal of Animal Science 32:277-281.

Weeth, H.J. and D.L. Caps. 1972. Tolerance of cattle for sulfate water. J. Anim. Sci. 34:256-260.

Wilson, J. 1988. Inter-office memo to Marathon Oil Co. Oct. 21. Kirby, WY.

Wilson, J., Wilson, T. 2006. Inter-office memo to Environmental Quality Council. Feb. 15. Kirby, WY.

Winchester, C. F., and M. J. Morris. 1956. Water intake rates of cattle. J. Anim. Sci. 15:722-740.

White, J.B. 1964. Sulphur poisoning in ewes. Vet. Rec. 76:278-280.

Wyoming. 2006. Official Wyoming visitor website. Online at http://wyoming.gov/general/narrative.asp.

Yolowitz, I., D. Zhang and D. Balnave. 1990. The effect on eggshell quality of supplementing saline drinking water with sodium or ammonium bicarbonate. Aust. J. Agric. Res. 41:1187-1192.

Zimmerman, A.S., D.M. Veira, D.M. Weary, M.A.G. von Keyserlingk, and D. Fraser. 2003. Sodium and magnesium sulphates reduce water consumption by beef cattle. J. Anim. Sci. 81:336 (Abstr.)

Zinn, M. 1988. Inter-office memo to Marathon Oil. Co. Cody, WY.

Zinn, R.A., E. Alvarez, M. Mendez, M. Montano, E. Ramirez and Y. Shen. 1997. Influence of dietary sulfur level on growth performance and digestive function in feedlot cattle. J. Anim. Sci. 75:1723.

Table 1-1. Water quality concentrations of TDS, sulfate and barium of some outfalls and downstream sampling locations of oil and gas facilities in the Bighorn, Platte and Powder River basins.

Basin	Associated Oil/Gas Facility	General Location	Drainage or Outfall	Avg - TDS	Max- TDS	Avg - Sulfate	Max- Sulfate	Barium	Data source
Platte (Wind) River	S. Casper Creek field	North Platte and tributaries	Poison spider & Oregon Trail	3,153	3,450	1,561	1,746		Gene R. George & Assoc. 2005 (2002-2004 data)
Bighorn	Hamilton Dome field	Cottonwood Creek	Cottonwood B, WY0000680, WY0000175	4,011	7,320	1,640	3,270		SWWRC et al. 2002 (2002 data)
Bighorn	Oregon Basin oil field	Dry Creek	Maverick Springs	1,161		492			M. Blakesly, pers. comm
			Chatterton	1,204		511			
			Circle Ridge	703		80			
			Byron Battery #2 Injection			1,815			
			Garland Unit Battery	2,900		1,450			
			Battery #1 South Outfall	4,475	4,600	2,080	2,180		
			Battery #2 North Outfall	5,345	5,390	2,735	2,950		
			Battery #3-5 South Outfall	4,530	4,530	1,870	1,870		
			Battery #1 North	5,100		3,085			
			Pitchfork	2,065		772			
			Steamboat Butte - North	3,838		1,690			
			Steamboat Butte - South	1,297		532			
Powder River	Fidelity facilities	Downstream locations	Tongue River	1,508					R. Edds, pers. comm.
			Wrench Ranch	1,054					
			Lake de Smet	830					

Basin	Associated Oil/Gas Facility	General Location	Drainage or Outfall	Avg - TDS	Max-TDS	Avg - Sulfate	Max-Sulfate	Barium	Data source
Powder River	Anadarko facilities	Outfall	Alpha Pod #2	2,400		<10		1.7	J. Cline, pers. comm.
		Outfall	County Line Alpha Pod	3,000				1.9	
		Outfall	Delta/Epsilon Skew Inlet IMR	2,800	3,500	ND	ND	3.8	
		Outfall	County Line Beta Pod #1	2,708		64			
Powder River	Lance operations	Powder River	Powder River water compositions typical of Lance CBNG operations	2,500		4		1.6	D. Stephens, pers. comm.
Powder River	Salt Creek fields	Salt Creek	Salt Creek at main discharge area	3,995	4,580	1,132	1,680		RETEC 2004
		Salt Creek	Salt Creek downstream of discharges	3,876	4,610	1,235	1,700		
		Powder River	Powder River downstream of discharges	2,202	3,640	920	1,340		
			Petition Proposed effluent limits:	**2,000**		**500**		**0.2**	

Notes:
all results in mg/l
Data reflects samples collected between 2002 and 2006.
ND = non-detect

Table 1-2. Wildlife species recorded in the Cottonwood Creek area near the confluence of the Bighorn River.

Mallard duck
Blue-winged teal
Canada goose
Great blue heron
Sandhill Crane
Wilson's phalarope
Spotted Sandpiper
Killdeer
Mountain Plover
Gray partridge
Chukar
Sage grouse
Ring-necked pheasant
Mourning dove
Northern harrier
Red-tailed hawk
Golden eagle
Bald eage
Prairie falcon
Merlin
American kestrel
Great horned owl
Borrowing owl
Yellow-billed cuckoo
Belted kingfisher
Common nighthawk
Western kingbird
Cassin's kingbird
Horned lark
Black-billed magpie
Western meadowlark
Brewer's blackbird
Pine siskin
Vesper sparrow
Savannah sparrow
Grasshopper sparrow
Lark sparrow
Song sparrow

Table 1-3. Wildlife species recorded in the Loch Katrine wetland complex.

Canada goose	Branta canadensis
Redhead	Aythya americana
lesser scaup	A. affinis
mallard	Anas platyrhynchos
pintail	A. acuta
gadwall	A. strepera
American wigeon	A. americana
northern shoveler	A. clypeata
greenwinged teal	A. crecca
blue-winged teal	A. discors
cinnamon teal	A. cyanoptera
eared grebe	Podiceps nigricollis
American coot	Fulica americana
black-necked stilt	Himantopus mexicanus
American avocet	Recurvirostra americana
sandhill crane	Grus canadensis
white-faced ibis	Plegadis chihi
long-billed curlew	Numenius americanus
killdeer	Charadrius vociferus
black tern	Chlidonias niger
Wilson's phalarope	Phalaropus tricolor

Table 1-4. Birds and mammals surveyed in the South Casper Creek field near Poison Spider Creek.

Mallard
Gadwall
Wigeon
Ruddy Duck
Virginia Rail
Sora
American Coot
Killdeer
Baird's Sandpiper
California Gull
Turkey Vulture
Golden Eagle
Northern Harrier
Greater Sage Grouse
Mourning Dove
Western Kingbird
Say's Phoebe
Western Flycatcher
Horned Lark
Unknown Swallow
Black-billed Magpie
House Wren
Gray Catbird
Sage Thrasher
European Starling
Wilson's Warbler
Common Yellowthroat
Brewer's Sparrow
Chipping Sparrow 1
Savannah Sparrow
Vesper Sparrow
Unknown Sparrow
Lark Bunting
Western Meadowlark
Brewer's Blackbird
Northern Oriole

Table 1-5. Exposure parameters for each indicator receptor.

Receptor class	Species	IR_{water} (L-day)		IR_{food} (kg wet-day)		BW (kg wet wt)	
Rodent	rat	0.046	EPA 1988	0.028	US EPA 1988	0.35	US EPA 1988
Ruminant-juvenile	growing steer	29.5	Winchester and Morris 1956	6.24	NAS 2000	300	NAS 2000
Passarine bird	mallard	0.064	US EPA 1993	0.251	US EPA 1993	1.13	US EPA 1993
Ruminant-adult	adult steer	34.8	Winchester and Morris 1956	7.76	Winchester and Morris 1956	800	NAS 2000

Notes:

IRwater = ingestion rate of water

IRfood = ingestion rate of food

BW = body weight

Table 1-6. Ingestion rate equations.

Equation	Species	Reference
$IR_{water} = 0.059(BW)^{0.67}$	for birds (L-day)	Calder and Braun 1983
$IR_{water} = 0.10(BW)^{0.7377}$	for laboratory mammals (L-day)	US EPA 1988
$IR_{food} = 0.648(BW)^{0.651}$	for birds (g-day)	Nagy 1987
$IR_{food} = 0.056(BW)^{0.6611}$	for laboratory mammals (kg-day)	US EPA 1988

Notes:

IRwater = ingestion rate of water

IRfood = ingestion rate of food

BW = body weight

Table 1-7. Barium toxicity study database and selected studies to derive water quality concentrations

Constituent	Receptor type	Reference	Chemical Form Administered	Organism	Route of Administration	Endpoints	Study Duration	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)
Barium	**bird**	**Johnson et al. (1960)**	**BaOH2**	**chicken (chicks)**	**oral in diet**	**mortality**	**4 weeks**	**208**	**417**
Barium	bird	Taucins et al. (1969)	BaCl2 and BaCO3	chicken	oral in diet	weight gain, mortality		N/A	10.05
Barium	mammal (rat)	Borzelleca et al. (1988)	BaCl2	rats	gavage	growth, reproduction	10 days	138	198
Barium	**mammal (rat)**	**Dietz et al. (1992)**	**BaCl2**	**rats**	**oral in water**	**growth, reproduction, development, mortality**	**92 days**	**61.1**	**121**
Barium	mammal (rat)	McCauley et al. (1985)	BaCl2	rats	oral in water	absorption	16 to 46 weeks	N/A	N/A
Barium	**mammal (rat)**	**Perry et al. (1983)**	**BaCl2**	**rats**	**oral in water**	**growth, hypertension**	**16 months**	**13.2**	**N/A**
Barium	mammal (rat)	Schroeder and Mitchener (1975)	BaCl2	rats	oral in water	growth	lifetime	0.25	N/A
Barium	mammal (rat)	Tardiff et al. (1980)	BaCl2	rats	oral in water	adrenal weights	90 days	45.7	N/A

Notes:

Bolded text indicates studies selected to derive recommended water quality benchmarks for barium, sulfate and TDS.

Table 1-9. Sulfate toxicity study database and selected studies to derive water quality concentrations.

Constituent	Receptor type	Reference	Chemical Form Administered	Organism	Route of Administration	Endpoints	Study Duration	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)
Sulfate	**bird**	**Adams et al. (1975) (exp 1)**	**Na2SO4, MgSO4**	**chicken (hens)**	**oral in water**	**water/food intake, reproduction, mortality**		**101.2**	**404.9**
Sulfate	bird	Adams et al. (1975) (exp 2)	Na2SO4, MgSO4	chicken (hens)	oral in water	water/food intake, reproduction, mortality		303.7	1619.2
Sulfate	**bird**	**Harter and Baker (1978)**	**Na2SO4, KSO4**	**chicken**	**oral in diet**	**growth**	**28 days**	**N/A**	**288.3**
Sulfate	bird	Katz and Baker (1975)	KSO4	chicken	oral in diet	feed efficiency, growth rate	7 weeks	1.1	N/A
Sulfate	bird	Krista et al. (1961)	Na2SO4	chicken	oral in water	egg production, intake rate		1196.0	1214.4
Sulfate	bird	Leach et al. (1960)	L-methionine	chicken	oral in diet	feed efficiency, growth rate	8 days	N/A	81.9
Sulfate	bird	Sasse and Baker (1974)	L-methionine	chicken	oral in diet	growth	8 days	N/A	81.9
Sulfate	mammal (livestock)	Digesti and Weeth (1976)	Na2SO4	growing cattle	oral in water	food/water intake, weight gain	90 days	245.8	N/A
Sulfate	**mammal (livestock)**	**Embry et al. (1959) (exp 1)**	**Na2SO4**	**growing cattle**	**oral in water**	**food/water intake, weight gain**	**84 days**	**489.2**	**698.9**
Sulfate	mammal (livestock)	Embry et al. (1959) (exp 2)	Na2SO4	growing cattle	oral in water	food/water intake, weight gain	112 days	604.7	N/A
Sulfate	mammal (livestock)	Grout et al. (2006) (exp 1)	Na2SO4	growing cattle	oral in water	water intake	11 days	421.9	N/A
Sulfate	mammal (livestock)	Grout et al. (2006) (exp 2)	MgSO4	growing cattle	oral in water	water intake	11 days	270.1	170.3
Sulfate	mammal (livestock)	Johnson and Patterson (2004)	natural water sources	growing cattle	oral in water	food/water intake, weight gain (feedlot)	112 days	N/A	251.4
Sulfate	mammal (livestock)	Johnson and Patterson (2004) (exp 1)	natural water sources	growing cattle	oral in water	food/water intake, weight gain	63 days	570.7	N/A
Sulfate	**mammal (livestock)**	**Johnson and Patterson (2004) (exp 2)**	**natural water sources**	**growing cattle**	**oral in water**	**food/water intake, weight gain (open range)**	**112 days**	**360.4**	**N/A**
Sulfate	mammal (livestock)	Loneragan et al (2001)	natural or treated water sources.	adult steers	oral in water	water intake, growth, feed efficiency	112 days	N/A	N/A
Sulfate	mammal (livestock)	Patterson et al. (2002)	natural/well water sources	adult steers	oral in water	food/water intake, weight gain, PEM	84 days	55.7	380.6
Sulfate	mammal (livestock)	Patterson et al. (2003)		growing cattle	oral in water	food/water intake, weight gain	3 months	N/A	N/A
Sulfate	mammal (livestock)	Patterson et al. (2004)	Na2SO4	adult cows	oral in water	water intake, weight gain, reproductive impacts	84 days	47.7	326.8
Sulfate	mammal (livestock)	Ward and Patterson (2004)	Na2SO4	adult cows	oral in water	water intake, weight gain, reproductive impacts	84 days	47.7	351.8
Sulfate	mammal (livestock)	Weeth and Caps (1972)	Na2SO4	growing cattle	oral in water	water intake, growth, feed efficiency	30 days	365.8	N/A
Sulfate	mammal (livestock)	Weeth and Hunter (1971)	Na2SO4	growing cattle	oral in water	food/water intake, weight gain	30 days	11.0	343.5
Sulfate	mammal (livestock)	Zimmerman et al. (2003)	MgSO4	cattle	oral in water	water intake, behavior	unknown	N/A	N/A
Sulfate	**mammal (rat)**	**Brown and Gamatero (1970)**	**Na2SO4**	**rats**	**oral in diet**	**feed efficiency, growth rate**	**28 days**	**18.08**	**N/A**
Sulfate	mammal (rat)	Cohen et al. (1958)	DL-methionine	rats	oral in diet	growth	72 days	N/A	412.8
Sulfate	mammal (rat)	Daniel and Waisman (1969)	L-methionine	rats	oral in diet	growth	24 days	172	516
Sulfate	mammal (rat)	Smith (1973)	methionine and CaSO4	rats	oral in diet	sulfate metabolism	7 days	16	N/A
Sulfate	**mammal (rat)**	**Weeth and Hunter (1971)**	**Na2SO4**	**rats**	**oral in water**	**growth**	**unknown**	**668.0**	**N/A**

Notes:

Bolded text indicates studies selected to derive recommended water quality benchmarks for barium, sulfate and TDS.

Table 1-11. TDS toxicity study database and selected studies to derive water quality concentrations.

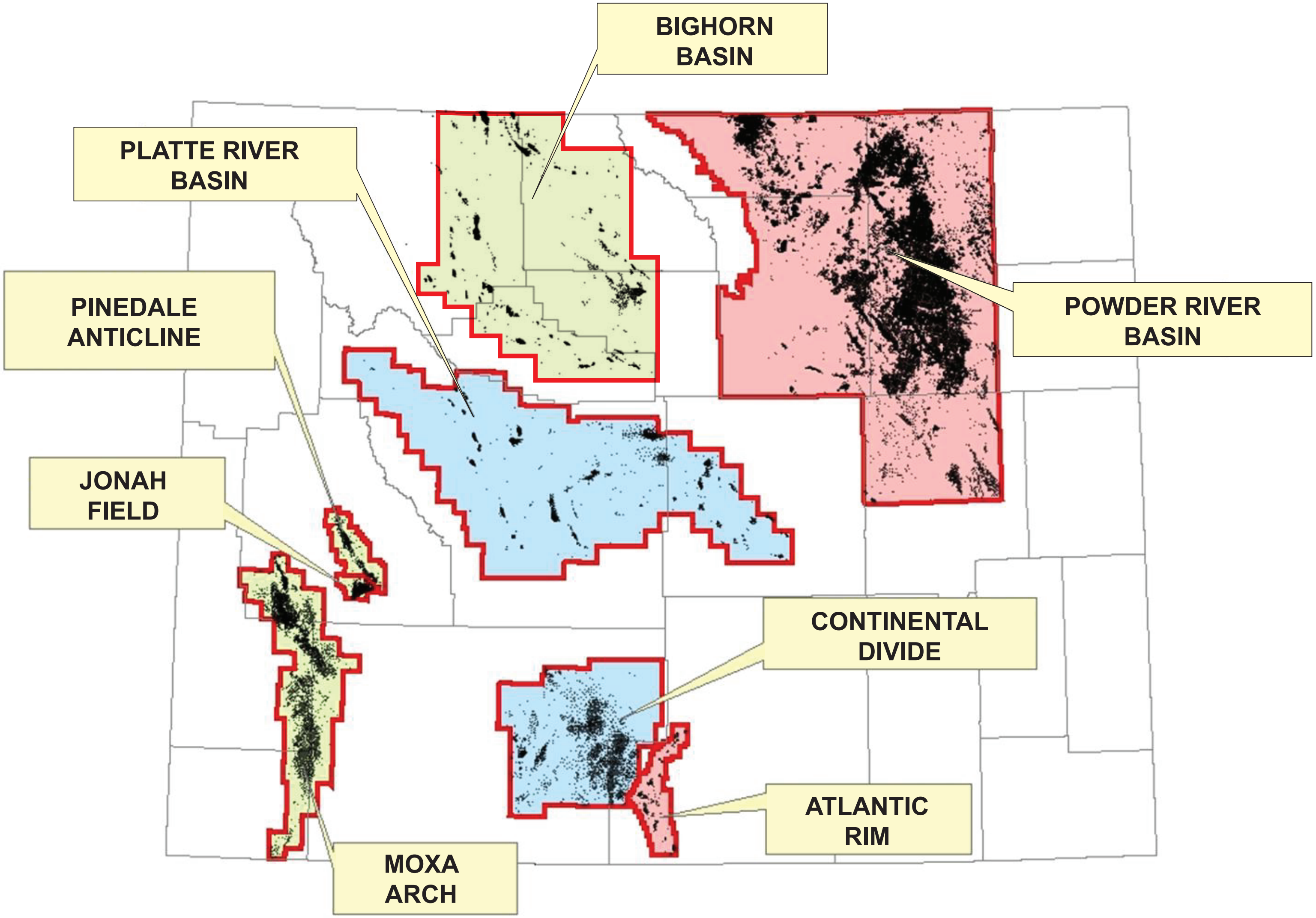
Constituent	Receptor type	Reference	Chemical Form Administered	Organism	Route of Administration	Endpoints	Study Duration	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)
TDS	bird	Belnave and Scott (1986) (exp 1)	NaCl	chicken (hens)	oral in water	food intake, reproduction		N/A	37.4
TDS	bird	Belnave and Yolowitz (1987)	NaCl	chicken (hens)	oral in water	eggshell quality	5 weeks	N/A	111.2
TDS	bird	Belnave et al. (1989)	NaCl	chicken (hens)	oral in water	egg production, food/water intake	5 weeks	20.0	104.1
TDS	bird	Heller (1933)	NaCl	chicken (hens)	oral in water	egg production, growth	10 weeks	304.6	456.8
TDS	bird	Heller (1933)	MgSO4	chicken (hens)	oral in water	egg production, growth	10 weeks	456.8	N/A
TDS	bird	Heller (1933)	CaCl	chicken (hens)	oral in water	egg production, growth	10 weeks	N/A	456.8
TDS	bird	Kare and Biely (1948)	NaCl	chicken (chicks)	oral in food & water	feed efficiency, weight gain, mortality	29 days	7073.0	N/A
TDS	bird	Krista et al. (1961) (exp 1)	NaCl (municipal water)	chicken (chicks)	oral in water	food/water intake, growth	4 weeks	598.8	1047.9
TDS	bird	Krista et al. (1961) (exp 2)	NaCl (municipal water)	chicken (hens)	oral in water	food/water intake, growth	16 weeks	598.8	1497.0
TDS	**bird**	**Krista et al. (1961) (exp 3)**	**NaCl (municipal water)**	**ducklings**	**oral in water**	**food/water intake, growth**	**21 days**	**269.2**	**384.6**
TDS	bird	Scrivner (1946)	NaCl	1-day old turkey	oral in water	mortality	2 weeks	116.7	350.0
TDS	bird	Selye (1943)	NaCl	chicken (chicks)	oral in water	mortality, nephrosclerosis	20 days	727.3	2181.8
TDS	bird	Yolowitz et al. (1990)	NaCl	chicken (hens)	oral in water	egg production, defects, food/water intake	7 - 8 weeks	N/A	131.2
TDS	mammal (livestock)	Bahman et al. (1993)	brackish water well, total TDS measured.	dairy cows	oral in water	milk production, growth	196 days	613.2	N/A
TDS	mammal (livestock)	Ballantyne (1957)	NaCl	growing & adult cattle	oral in water	mortality	not reported	84.6	N/A
TDS	mammal (livestock)	Ballantyne (1957)	NaSO4	growing & adult cattle	oral in water	mortality	not reported	169.2	N/A
TDS	mammal (livestock)	Ballantyne (1957)	MgSO4	growing & adult cattle	oral in water	mortality	not reported	169.2	N/A
TDS	mammal (livestock)	Blosser and Soni (1956)	"Dissolved solids @ 105C"	dairy cows	oral in water	milk production	6 weeks	23.1	N/A
TDS	mammal (livestock)	Challis et al. (1987)	well water (NaCl measured)	dairy cows	oral in water	milk production		51.5	386.1
TDS	mammal (livestock)	Embry et al. (1959)	NaCl	growing cattle	oral in water	food/water intake, growth	112 days	790.8	1129.7
TDS	mammal (livestock)	Frens (1946)	NaCl	dairy cows	oral in water	milk production		937.5	N/A
TDS	mammal (livestock)	Heller (1933)	NaCl	dairy cows and steers	oral in water	milk production, reproduction, weight gain	21 weeks	1833.9	N/A
TDS	mammal (livestock)	Jaster et al. (1978)	NaCl	dairy cows	oral in water	milk production	28 days	23.6	611.1
TDS	mammal (livestock)	Johnson et al. (1959)	CaCO3 (water source from settling pit)	growing cattle	oral in water	rumen pH, microbial activity	16 weeks	202.3	N/A
TDS	mammal (livestock)	Lassiter and Cook (1963)	NaHCO3	growing cattle (yearlings)	oral in water	food/water intake, digestibility	21 days	398.9	N/A
TDS	mammal (livestock)	Patterson et al. (2003)	NaCl	growing cattle	oral in water	food/water intake, weight gain	3 months	N/A	N/A
TDS	mammal (livestock)	Ramsey (1924)	NaCl	cattle	oral in water	water intake, weight gain, survival	3 mo - 2 yrs	747.8	N/A
TDS	mammal (livestock)	Ray (1989)	CaCl, NaSO4, NaHCO3, NaCl (all added together).	growing cattle	oral in water	food/water intake, efficiency of growth	112 days	189.7	875.3
TDS	mammal (livestock)	Robertson et al. (1996)	sulfate-dominated	steers	oral in water	food/water intake, digestibility	43 days	87	N/A
TDS	mammal (livestock)	Solomon et al. (1995)	natural water sources	dairy cows	oral in water	milk production, water intake	4 months	2.8	63.4
TDS	mammal (livestock)	Spafford (1941)	NaCl	cattle	oral in water	water intake, survival	unknown	619.9	804.8
TDS	mammal (livestock)	Weeth (1962)	MgSO4 added to a TDS of 245	growing cattle	oral in water	food/water intake, growth	4 months	73.3	N/A
TDS	mammal (livestock)	Weeth and Haverland (1961) (exp 1)	NaCl	growing cattle	oral in water	food/water intake, growth	30 days	14.6	2136.6

Table 1-11. TDS toxicity study database and selected studies to derive water quality concentrations.

Constituent	Receptor type	Reference	Chemical Form Administered	Organism	Route of Administration	Endpoints	Study Duration	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)
TDS	**mammal (livestock)**	**Weeth and Haverland (1961) (exp 2)**	**NaCl**	**growing cattle**	**oral in water**	**food/water intake, growth**	**30 days**	**912.8**	**809.3**
TDS	**mammal (livestock)**	**Weeth and Hunter (1971)**	**NaCl**	**growing cattle**	**oral in water**	**growth**	**30 days**	**725.7**	N/A
TDS	mammal (livestock)	Weeth et al. (1960)	NaCl	growing cattle	oral in water	food/water intake, growth	30 days	1675.5	1932.4
TDS	**mammal (rat)**	**Embry et al. (1959) (exp 1)**	**NaCl**	**rats**	**oral in water**	**water intake, growth**	**112 days**	**1540.9**	N/A
TDS	mammal (rat)	Embry et al. (1959) (exp 2)	MgCl	rats	oral in water	water intake, growth	112 days	627.2	940.7
TDS	**mammal (rat)**	**Embry et al. (1959) (exp 3)**	**MgSO4**	**rats**	**oral in water**	**water intake, growth**	**112 days**	N/A	**790.2**

Notes:

Bolded text indicates studies selected to derive recommended water quality benchmarks for barium, sulfate and TDS.



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C06450A
WDEQ TDS Standards

Current active oil and gas wells in Wyoming.

Figure
1-1

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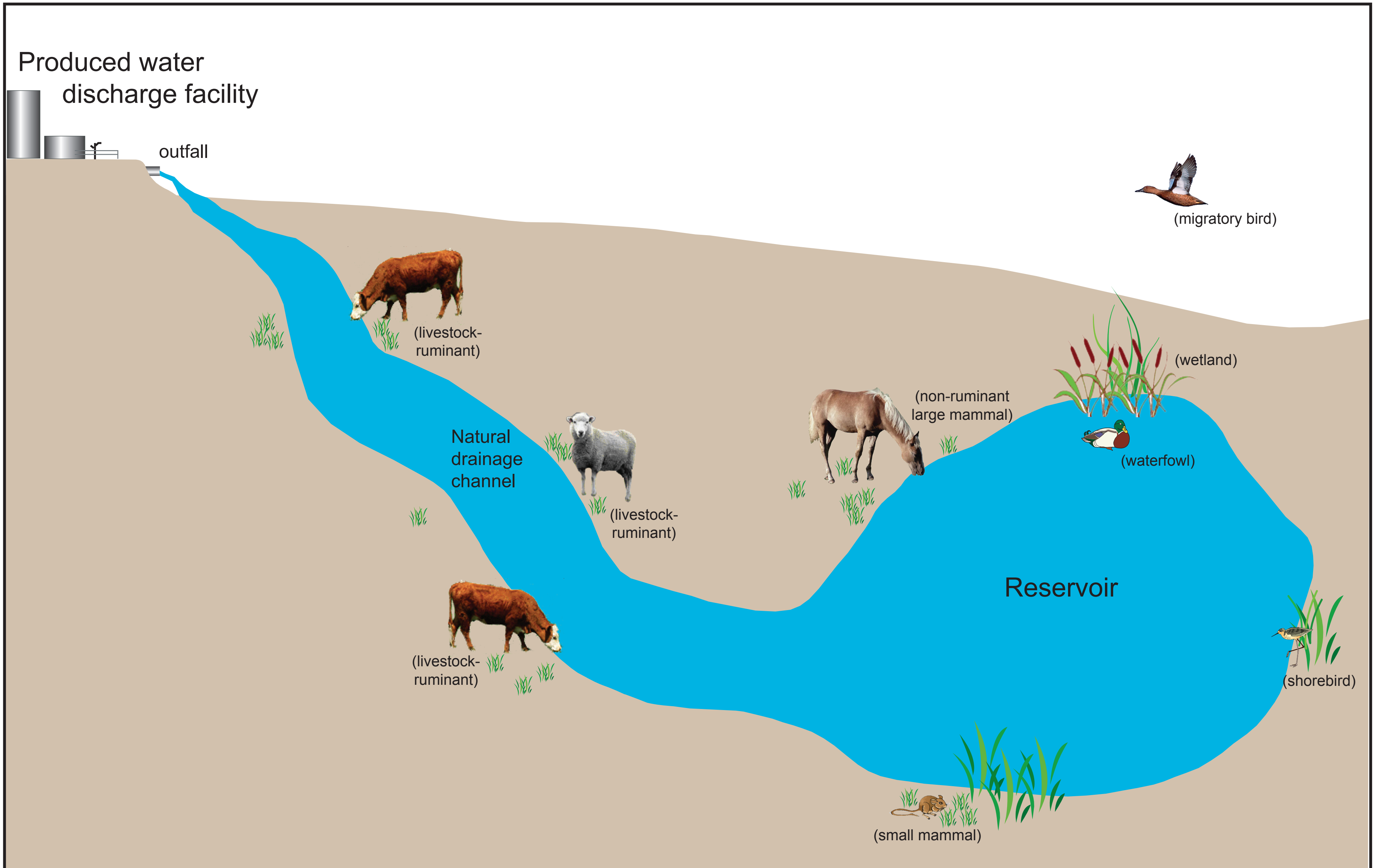

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WDEQ TDS Standards

Ecological conceptual model of source-receptor relationships between produced water discharge facilities and livestock and wildlife receptors.

Figure
1-2

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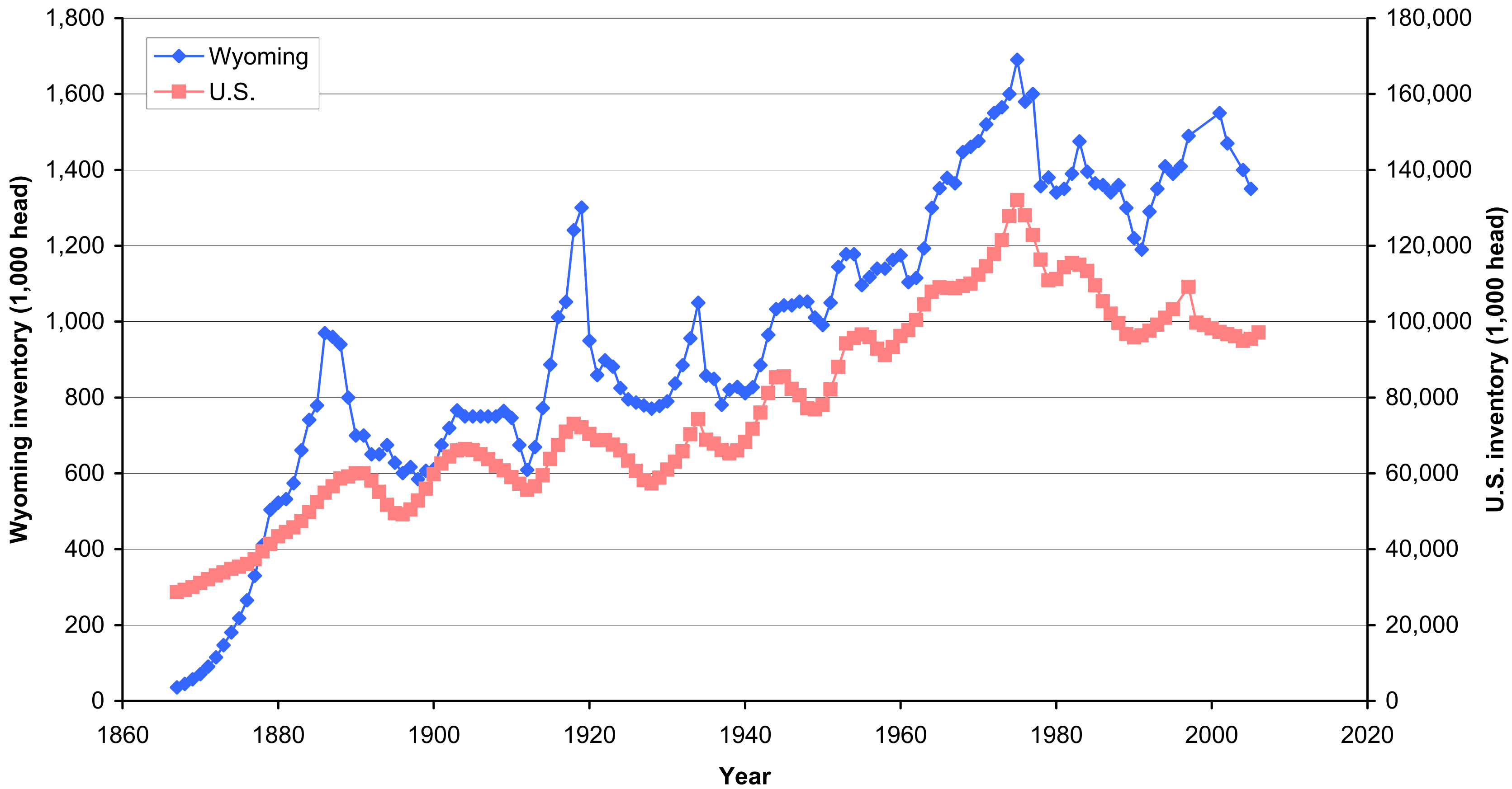

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WDEQ TDS Standards

Cattle and calf inventories (1,000 head) for Wyoming and the U.S. between 1860 and 2006.

Figure
2-1

Appendix A

Interviews with Local Ranchers in the Bighorn and Powder River Basins

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Introduction

A field-based data gathering and analysis exercise was undertaken to gather effects data specific to users of water bodies in Wyoming. In-person and telephone interviews were conducted on a handful of ranchers in the Bighorn and Powder River structural basins in Wyoming to gather information on the nature and extent of produced or natural water usage and effects noted from use. Where available, data was obtained from these ranchers to quantitatively evaluate the effects from exposure to the various sources of water. Interviews were given with:

Name	Basin Affiliation
1. Mr. Greg Flitner, and Mr. Dave Flitner	Bighorn
2. Mr. Mick McCarty	Bighorn
3. Mr. Don Meike	Powder River
4. Dr. Trey Patterson	Powder River
5. Mr. Don Schlaf	Bighorn
6. Mr. Frank Shepperson	Powder River

The following sections describe the information given by the various ranchers during the interviews.

In-person interview with Mr. Greg and Dave Flitner, 10/24/06

The Flitners manage beef cattle, sheep and some horses. They ranch all their cows (~950 head in 2005) in the spring and fall on BLM lands adjacent to Dry Creek near the Cody Highway. Dry Creek has average sulfate and TDS concentrations of 2,720 mg/L and 5,080 mg/L, respectively. Produced water sources account for 100% of water availability on these lands, because drought has eliminated other natural reservoirs. The Flitners have additional, private lands in the Bighorn basin and leases on Heart Mountain and Johnson County, and the cattle typically graze there during the summer months. Water resources in these areas originate from natural sources, with estimated concentrations of 1,180 mg/L and 2,310 mg/L sulfate and TDS, respectively, based on average background concentrations.

In 2005, herd size on produced water pastures totaled 950 cows. Total herd size was 950 cows, 800 yearlings, 150-200 qtr horses. Due to drought, herd size has been reduced an estimated 50% since 1997.

The Flitners noted no variation in cattle quality between lands containing produced water discharges and natural waters, and in fact related that sometimes production from pastures utilizing produced water is better due to increased water availability. No cattle refusal of water was noted. Weaning weights were recorded in calves that started out the spring in various produced water and natural water-associated pastures (Table A-1). These records demonstrate that no adverse effect on weaning weights occurred on calves that drank the produced water containing elevated sulfate and TDS relative to natural sources. Seven-year average weaning weights from the Dry Creek (produced water) pastures were in fact higher than the pastures that did not have produced water availability. The Flitners do not utilize a supplemental mineral program.

If produced water were to stop being available, Mr. Greg Flitner estimates they would have to cut ~50% of the herd size, with associated employee cuts. The Flitners currently employ 40 full and part time jobs. In addition, the Flitners stated that loss of the produced water in Dry Creek would result in them vacating these pastures, as they would no longer be economic to graze. Conflicts between cattle, wildlife, and wild horses would be expected to increase without the produced waters.

In-person interview with Mr. Mick McCarty, 10/23/06

McCarty Ranching, LLC, a family owned company, operates several ranches in the Bighorn basin, with a total herd size of about 2,000 head. They utilize 4 pastures totaling 1600 acres of private and 28,000 acres of BLM lands which contain exclusively produced water sources originating from the Oregon Basin facility. The herd size on these lands is between 400 and 600 head, all cattle. The pastures include Avon, South/North Oil Wells, Lake and Highway pastures. The produced water from the Oregon Basin is discharged into Dry Creek, which runs throughout these pastures. Oregon Basin produces approx. 500,000 barrels of water/day, of which 100,000 BPD is surface discharged and the rest reinjected (M. Blakesley, pers. comm). Surface water concentrations near these pastures average 4,830 mg/L TDS and 2,300 mg/L sulfate, with maximums as high as 5,390 mg/L TDS and 3,100 mg/L sulfate (measured between 2002 and 2006). Lake pasture has 1 water well in addition to the produced water sources. Mr. McCarty noted that the cattle seem to prefer drinking the water near the outfall point where the produced water is discharged to Dry Creek, perhaps due to the warmer temperature of the water.

The cows utilize the produced water pastures between November and May. Two out of 4 pastures are used per year (allowing a 2-year fallow period). The cattle only forage on the open range, plus they are given a mineral supplement package and protein formulated by Dr. Trey Patterson. They prefer winter fat, kochia, grasses, and salt sage where available. There are other ranches owned or leased by McCarty Ranching LLC that receive only natural water sources.

Upon acquiring the land associated with produced water sources, Mr. McCarty Ranching, LLC retained Dr. Trey Patterson to design a supplemental protein and mineral package to maximize production from these pastures. Because Dr. Patterson’s experience is that the higher sulfates in the water can render copper and other trace metals less available for absorption by the cattle, the mineral package contains a chelated copper form which remains bioavailable even when consumed with water containing high sulfates. Dr. Patterson related that the cattle in the area perform very well, above industry standards and production numbers.

Mr. McCarty noted that there were no adverse effects on the livestock that use the pastures with produced water as compared to their pastures at which there are natural water sources. He related the following measurement comparisons:

	Measure:	Produced water	Natural water
1)	Body condition	5	same
2)	Breeding percentage	96%	same
3)	Death rate	2%, cows	same
4)	Calf weaning rate	94-95%	same
5)	Weaning weight	Varies by calving time.	same

A few other natural water bodies used to exist on some of the land but have dried up due to drought. The pastures east of highway 120 rely exclusively on produced water sources. The droughts have also reduced their total herd size, from about 2,500 to 1,700 this year, and perhaps another drop in herd size next year.

The presence of produced water on the BLM lands has resulted in cost savings for McCarty Ranching LLC, since obtaining other water sources (wells, hauling water) would be very expensive. Ranching would not be economic to them without the produced water. He speculates that it would also affect hundreds of other ranchers in the Bighorn basin.

Telephone interview with Mr. Don Meike, 11/1/06

Mr. Don Meike ranches cattle (500 head) and sheep (2,500 head) on 45,280 acres along the in the Powder River basin near the juncture of Salt Creek and Powder River. He has ranched in this area since 1901. Herd sizes have declined 50% due to drought and rabbit infestation. Mr. Meike recalled that before 1950, Salt Creek and Powder River were unusuable 9 months out of the year due to the high salinity concentrations in the water. Cattle were typically moved to a meadow pasture or to lower Powder River, or to land in the mountains. In addition to the chemical concentrations causing adverse effects on cattle, physical risk of cattle getting stuck in the muddy river bottom was a concern.

With the advent of produced water, Salt Creek and Powder River are now usable on a year-round basis. Management of the herds has increased, and flexibility of management is greater, as a result of the increased water supply. No adverse effects on the cattle herds were seen using produced water sources compared to natural water sources previously. The cattle graze on the open range and also receive a mineral supplement package.

Telephone interview with Dr. Trey Patterson, 11/1/06

Dr. Patterson is a manager at the Padlock Ranch located in north central Wyoming and Southern Montana. The ranch is large, one of the top six in the US. From their website (www.padlockranch.com), the Padlock Ranch employs 45 people, and raise and market over 9,000 calves a year. The ranch grazes cow-calf pairs on native grassland in Montana and Wyoming. Grazing lands are a mixture of private and leased land. In support of grazing operations, the ranch irrigates 5,000 acres of farmland, including an annual production of 10,000 tons of dry hay, 20,000 tons of corn silage, 15,000 tons of hay silage and barley. The production supports the winter feeding program and feedlots.

Cattle graze year round in the area. The ranch lands receive produced water from a CBNG facility near Decker, Montana. The produced water is discharged to a reservoir which is fenced off, and into stock tanks.

Water quality samples are taken periodically.. Concentrations generally reported are between 1 mg/L and < 500 mg/L sulfate and up to ~3600 mg/L TDS (as measured in 2001 and 2002). Sodium is a large proportion of the total TDS. At times, the sodium level is high enough that the mineral supplementation program for the cattle is altered.

In contrast, some natural water in the area has much higher sulfate and TDS, between 1,500 and 2,000 sulfate and up to 3,700 TDS. Produced water contributions have helped to lower the levels of sulfate and TDS in year-round water that cattle consume.

No negative effects of consuming produced water on cattle have been seen or noted. Weaning weights recorded over several years do not indicate any difference between cows raised on land with produced water compared to land with other water sources. Generally, Dr. Patterson notes that the increase in available water has resulted in an increase in cattle performance and forage utilization. Costs to the rancher are reduced because additional water does not have to be hauled.

The drought has affected manynatural water sources, limiting their use or rendering them unususable. At times, the ranch has had to wean earlier due to drought levels.

Dr. Patterson also related that his experience with cattle ranch in South Dakota. Natural water sources at the ranch containing about 4,000 mg/L sulfates resulted in incidences of polio in the cattle that consumed this water source. A supplemental mineral program was instituted there to help mitigate the effects of the high sulfates, and although some cattle continued to be affected, the ranch continued to use the water source because it was the only water available in the area. Despite this, the ranch was able to make a profit.

Telephone interview with Mr. Don Schlaf, 11/1/06

Mr. Schlaf has ranched his lands since 1904. He currently ranches cattle (~300 head), and historically has also ranched sheep. Mr. Schlaf utilizes BLM pastures associated with the Dry Creek drainage, east of Cody. These allotments include Elk, 15-mile and Dorsey. He rotated his cattle on a 5-month schedule on each of the pastures at Dry Creek. At times, Dry Creek was the only source of water available as other stock ponds had dried up. Mr. Schlaf had a cow die inexplicably in the past, and sent brain tissue samples into the veterinarian for analysis of sulfate levels, as sulfates were typically higher in Dry Creek than for other water bodies. The results showed that the sulfate levels in Dry Creek did not cause the death of the cow. Lab results indicated, "the amount of sulfur in the tissue sample was not sufficient to cause polio."

Mr. Schlaf also related that, in the past when Dry Creek was an intermittent stream, incidences of polio and blindness occurred in his cattle as a result of drinking evapoconcentrated pools of water.

Telephone interview with Mr. Frank Shepperson, 11/1/06

Mr. Frank Shepperson owns ~1,500 head of cattle on 80,000 acres in the Salt Creek valley of the Powder River basin in Wyoming (Commerce, Natrona and Johnson counties). The ranch includes the bulk of the Salt Creek oil field. It has 25.8 miles of frontage on Salt Creek, including the sections immediately adjacent to the discharge points. It also has access to several tributaries (such as Coal Draw and Castle Creek).

Salt Creek is the main water source on his lands. Other creeks in the area (above Salt Creek) include Teapot and Castle creeks, both of which have natural water sources. The natural water sources contain an average of 2,000 mg/L TDS and 1,200 mg/L sulfates in 2003 and 2004, but concentrations are at times as high as 4,000 mg/L sulfate and 7,000 mg/L TDS. Downstream of produced water inputs, concentrations average 1,100 mg/L sulfate and 4,300 mg/L TDS.

Mr. Shepperson's cattle use both the natural and produced water sources, and he notes that produced water sources are the preferred water to use for his cattle. The use of natural waters in the area have, at times, caused breeding rates and number of head to decline relative to other areas in Wyoming receiving natural water sources. Other effects of the natural water sources included dehydration, blindness, disorientation and death typically due to consumption of evapoconcentrated puddles of water left in the dry creek beds. Wildlife densities also appeared to decline when only natural water sources were available. According to Mr. Shepperson, weight data collected by the University of Wyoming indicated that cattle weights were significantly affected in areas where access was limited to only natural water sources. Conversely, the weight data did not indicate that produced water sources adversely affected cattle weights.

Another positive effect of produced water sources is that the creeks now run year-round, instead of being intermittent. The intermittent nature of the creeks before the event of produced water resulted in isolated, concentrated water puddles surrounded by thick mud. The cattle would not only drink the concentrated water, but would also get stuck in the mud, causing physical injury.

Mr. Shepperson also noted that wildlife appeared to be using the water downstream of the outfalls, and densities appear greater than populations present upstream of the outfalls. Mr. Shepperson speculates that this phenomenon is a result both of changing water quantity as well as quality.

Table A-1. Weaning rates of calves on the Flitners' ranches between 1999 and 2005. The Dry Creek pasture is associated with produced water sources, whereas the remaining pastures have access to only natural water sources.

Year	Dry Creek	Potato Ridge	Home Place	Whistle Creek
1999	473	451	469	483
2000	501	492	476	500
2001	462	454	473	465
2002	487	509	512	525
2003	522	503	497	503
2004	515	498	526	486
2005	526	482	501	492
Average:	**498**	**484**	**493**	**493**