Exhibit A

KC HARVEY, LLC
SOIL AND WATER RESOURCE CONSULTANTS

May 4, 2006

Mr. Bill DiRienzo
Wyoming Department of Environmental Quality
Water Quality Division
Herschler Building, 4th Floor West
122 West 25th Street
Cheyenne, Wyoming 82002

Subject: Comments pertaining to the proposed default SAR effluent limit cap of 10 in the Draft Section 20 Agricultural Use Protection Policy.

Dear Mr. DiRienzo:

I respectfully submit for your consideration the following comments regarding the fourth draft of the Section 20 Agricultural Use Protection Policy as it pertains to the derivation of effluent limits for SAR, particularly the proposed SAR cap of 10. These comments are being submitted on behalf of Yates Petroleum Company, Williams Production RMT Company, Petro-Canada Resources (USA) Inc., Marathon Oil Company, Lance Oil & Gas Company, Inc., Fidelity Exploration & Production Company, Devon Energy Production Company L.P., Bill Barrett Corporation, and Anadarko Petroleum Corporation. I have submitted additional comments regarding the derivation of EC limits in a separate letter.

By way of introduction, I am a board-certified professional soil scientist having practiced as an environmental consultant in Montana and Wyoming, and throughout the world, for nearly 25 years. For the past seven years, my practice has focused on water management and soil and water salinity/sodicity issues associated with oil and gas development. I am credited as the first to research, develop, and apply managed irrigation techniques for the beneficial use of coalbed natural gas produced water. I have directed or participated in over 75 separate projects related to produced water management, WPDES permitting, soil and water chemistry investigations, and reclamation for coalbed and conventional natural gas projects in Wyoming, Colorado, and Montana. I have a M.S. degree in land rehabilitation (soil science emphasis) from Montana State University and a B.S. in Resource Conservation (soil science emphasis) from the University of Montana.

I would like to comment on the proposed changes made to the Agricultural Use Protection Policy by the WDEQ subsequent to the January 26, 2006 meeting of the Water and Waste Advisory Board. My comments will focus on the comments provided by Dr. Larry Munn in his letter to the DEQ dated December 5, 2005. It is my understanding that Dr. Munn's comments resulted in the changes made to the proposed Policy. Specifically, I comment on Dr. Munn's proposal that all WPDES default effluent limits for SAR be capped at 10 under the Tier 1 process.

Summary of Findings

The fourth draft of the Agricultural Use Protection Policy describes a 3-tiered decision making process for deriving appropriate effluent limits for EC and SAR whenever a proposed discharge may reach irrigated lands. The Tier 1 process would be followed for deriving "default" limits, and as such, this procedure would require a minimum of background information from the applicant. The default SAR limits would be extrapolated from the Hanson et al. (1999) chart relating the established EC effluent limit to SAR, up to a maximum default value of 10. The effluent limit for SAR will be determined in conjunction with EC so that the relationship of SAR to EC remains within the "no reduction in rate of infiltration" zone of the Hanson et al. (1999) diagram.

Two key concerns arise from Dr. Munn's letter regarding sodicity and the discharge of CBNG produced water in the Powder River Basin: (1) the potential impacts on the hydraulic function of irrigated soils during produced water discharge; and (2) the potential impacts of residual adsorbed sodium on the hydraulic function of irrigated fields after produced water discharge has ceased and rainfall/snowmelt leaches salts from the upper root zone. It is assumed that these concerns led Dr. Munn and the WDEQ to propose the SAR effluent limit cap of 10 under the Tier 1 process.

In addressing these concerns, I performed a considerable amount of research, including three months searching and reviewing the relevant scientific literature, and compiling and analyzing available and relevant soil, plant, and water data. The key conclusions of the literature review and data analysis are presented below and will be substantiated by the discussion that follows.

Review of Soil Sodicity

- Plant growth problems associated with excess sodium adsorption are in response to negative changes in soil structure resulting in reduced air exchange, water infiltration and hydraulic conductivity.

- The universally applied sodic soil threshold is an exchangeable sodium percentage (ESP) greater than 15.

- SAR is a measure of the sodicity risk in irrigation water. The higher the salinity of irrigation water, the higher the SAR can be without impacting soil structure and impairing soil infiltration and permeability.

The ESP-SAR Relationship for Soils in Northeastern Wyoming

- Using regression analysis, the relationship between ESP and soil SAR was determined for the Powder River Basin ($n=382$, $R^2=.74$).

- A 1:1 relationship of soil SAR to water SAR exists for soils in equilibrium with irrigation water. This relationship is widely accepted and confirmed by recent research led by Dr.

James Bauder at Montana State University. The relationship of ESP to soil SAR is therefore equivalent to the relationship of ESP to water SAR.

- Based on the regional specific relationship of ESP and SAR, an effluent limit of SAR = 16 corresponds to an ESP of 10, and provides a 33% margin of safety against the formation of sodic conditions (i.e., exceeding an ESP of 15). The proposed default SAR cap of 10 is, therefore, unnecessarily conservative.

The Effect of Rainwater Leaching on Soils Irrigated with Produced Water

- Concern has been raised that subsequent rainfall/snowmelt leaching of residual soil salinity may lower the electrolyte concentration and naturally raise the ESP past the dispersive sodic soil threshold.

- Research demonstrates that arid land soils can release 0.3 to 0.5 dS/m of Ca and Mg to solution as a result of the dissolution of primary minerals and the inherent calcium carbonate content of surface soils. Shainberg et al. (1981) indicates that these concentrations are sufficient to counter the deleterious effects of exchangeable sodium, even when the soil is leached with rainwater.

A Review of Soil Sodicity

The physical and chemical phenomena associated with soil sodicity are complex. Therefore, a brief summary is provided regarding the soil and water chemistry associated with the physical affects of soil sodicity.

A large body of research concerning sodic, or "black alkali" soils has been generated in response to the negative effects of high sodium concentrations on soils. Toxicity effects of sodium are rarely expressed in forage and grass crops, but do cause injury to selected woody plants (Lilleand et al., 1945; Ayers et al., 1951; Brown et al., 1953). Plant growth problems associated with high concentrations of sodium are generally a response to negative changes in soil structure. Sodic soils are "nonsaline soils containing sufficient exchangeable sodium to adversely affect crop production and soil structure (Soil Science Society of America, 2001)." High levels of adsorbed sodium tend to disperse soil particles thereby sealing the soil. The result can produce clogged soil pores, hard surface crusts, reduced infiltration, reduced permeability, and reduced oxygen diffusion rates, all of which interfere with or prevent plant growth. By definition, sodic soils are those that have an exchangeable sodium percentage (ESP) greater than 15. The universally applied ESP threshold of 15 percent is acknowledged in numerous publications, including Levy et al. (1998), Abrol et al., (1988), Evangelou (1998), McNeal and Coleman (1966), Sparks (1995), Sumner et al. (1998), Shainberg et al. (1971), the Soil Improvement Committee (2002), university extension publications, etc.

Clay minerals are the most physically and chemically reactive components of the sand, silt, and clay matrix in soil. The structural arrangement of clay minerals in soil is akin to a deck of cards; the clay mineral itself can be thought of as the deck, and the cards as individual layers. The properties of the deck depend upon the arrangement of the cards and the electrochemical interlayer forces holding the cards together.

Clay minerals in soils are negatively charged and consequently attract ions with a positive charge such as calcium, magnesium, potassium, and sodium. Positively charged ions are called cations. Each cation competes with others in the soil solution for access to the bonding sites based on its valence and hydrated size. Every soil has a definite capacity to adsorb the positively charged cations. This is termed the cation exchange capacity (CEC). The various adsorbed cations (such as calcium and sodium) can be exchanged one for another and the extent of exchange depends upon their relative concentrations in the soil solution (dissolved), the ionic charge (valence), the nature and amount of other cations, etc. ESP is, accordingly, the amount of adsorbed sodium on the soil exchange complex expressed in percent of the cation exchange capacity in milliequivalents per 100 grams of soil (meq/100 g). Thus,

$$\text{ESP} = (\text{exchangeable sodium} / \text{cation exchange capacity}) \times 100.$$

Sodic soil conditions arise when greater than 15 percent of the ions bonded to the deck are sodium, which has a +1 valence and a large hydrated radius. When the ESP exceeds 15, the large hydrated sodium ions can wedge in-between the individual cards and cause "swelling" of the deck (Levy et al., 1998). This causes negative effects on the physical structure of the soil. Upon re-wetting, the individual decks may disperse and settle into soil pores, effectively clogging them and reducing the efficiency of air exchange, water infiltration, and permeability (i.e., hydraulic conductivity). In general, soils with moderately high, to high, clay contents are at higher risk.

Excessive adsorbed or exchangeable sodium can result from sustained use of irrigation water that is high in sodium and low in calcium and magnesium. Consequently, the ratio of sodium to calcium and magnesium ions in water is an important property affecting the infiltration and permeability hazard. The water quality index used to measure the hazard related to sodium abundance or sodicity in irrigation water is the sodium adsorption ratio or SAR.

The SAR is the ratio of the dissolved sodium concentration in water divided by the square root of the average calcium plus magnesium concentration. The SAR can be calculated from the sodium, calcium and magnesium concentrations via the formula:

$$\text{SAR} = [\text{sodium}] / (([\text{calcium}] + [\text{magnesium}])/2)^{1/2}$$

where the concentrations are in milliequivalents per liter (meq/L).

What is not apparent from the SAR formula is the fact that the higher the salinity of the water, the higher the SAR can be without impacting soil structure and impairing soil infiltration and permeability. Put another way, for a given SAR, infiltration rates generally increase as salinity (measured by the EC) increases. The changes in soil infiltration and permeability occur at varying SAR levels, higher if the salinity is high, and lower if the salinity is low. Therefore, in order to evaluate the sodicity risk of irrigation water, the EC must be considered. To this end, the SAR-EC guidelines presented in Ayers and Westcot (1985) and Hanson et al. (1999) are used to assess the potential sodicity risk of irrigation water.

The ESP-SAR Relationship for Soils in Northeastern Wyoming

In addition to measuring the SAR of irrigation water, one can also measure the SAR of the soil solution via a saturated paste extract (i.e., the dissolved concentrations of sodium, calcium, and magnesium are measured in a saturated paste extract and applied via the SAR formula presented above). The soil SAR was developed to serve as a rapid and relatively inexpensive index of ESP. It is widely accepted that the SAR of the soil in equilibrium with the SAR of the irrigation water is equal to the long-term average SAR of the irrigation water.

The fourth draft of the Agricultural Use Protection Policy includes a proposed SAR cap of 10 for Tier 1 default effluent limits. To evaluate the appropriateness of the proposed cap, an analysis was performed using 382 ESP-SAR data pairs generated from ongoing soils assessment work in the Powder River Basin of Wyoming (KC Harvey LLC, 2006). This database represents flood plain soils associated with tributaries to the Powder River and the Tongue River, including spreader dike irrigated fields. This database represents baseline soil chemical conditions. In no case were any of these soils irrigated with or influenced by coalbed natural gas produced water. The soil samples from which the analyses were made were collected during soil profile descriptions to five feet, and with a Giddings hydraulic probe up to eight feet in depth. The numerous soil investigations involved were required for various coalbed natural gas water management planning, permitting, and design purposes.

The ESP-SAR data pairs were graphed in Microsoft Excel using simple scatter-plot and trend line analysis. The best fit line resulted in a linear regression which yielded the equation:

$$ESP = 0.5(SAR) + 1.96, \text{ with an } R^2 \text{ value of } 0.74.$$

The regional-specific "Powder River Basin" relationship, based on 382 soil samples, is shown on Figure 1. According to the Powder River Basin equation, a soil SAR of 26 corresponds to the critical ESP threshold of 15 percent.

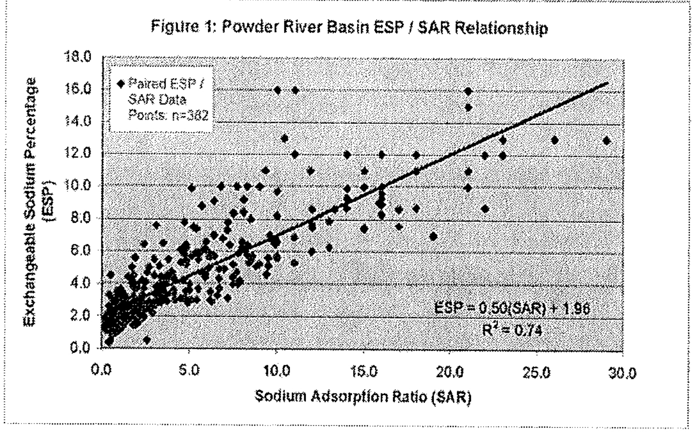

Figure 1: Powder River Basin ESP / SAR Relationship

It is widely accepted that the SAR of soil in equilibrium with irrigation water equals the long-term average SAR of irrigation water. Recent Department of Energy funded research directed by Dr. James Bauder at Montana State University (Robinson and Bauder, 2003) confirms this relationship. Their research, which is related to the potential effects of coalbed natural gas produced water on soils, reports that in general, soil solution SAR represents the SAR of the applied water. The 1:1 soil SAR to water SAR relationship allows one to relate the SAR of discharge water to the SAR of the soil in the Powder River Basin ESP-SAR graph and equation described above. For example, after long-term irrigation with water exhibiting an SAR of 15, the equilibrated ESP of the irrigated soil would be approximately 9.5 percent. The proposed SAR cap of 10 would equate to a corresponding ESP of 7. An ESP cap of 7 appears to be unnecessarily conservative given the regional specific relationship of ESP and SAR. While an ESP threshold of 15 is widely accepted to be the point at which clay swelling and dispersion occurs, we respectfully suggest that the WDEQ consider establishing a Tier 1 default SAR effluent limit cap of 16, which corresponds to an ESP of 10. An ESP value of 10 provides a 33 percent margin of safety.

The Effect of Rainwater Leaching on Soils Irrigated with Produced Water

In his December 5, 2005 letter, Dr. Munn indicates his concern about the potential effects of rainwater leaching of fields that had received produced water due to upstream permitted discharges. In particular, what is the effect of leaching on the sodicity status and hydraulic function of soils after discharge and irrigation with produced water ceases? Fortunately, the considerable research on this subject has been well documented in the scientific literature.

Discontinuation of produced water discharge in the Powder River Basin will effectively reduce the EC and SAR of irrigation waters from tributaries and mainstems so long as the surface water is of higher quality than the produced water. In the case of fields that are irrigated opportunistically (e.g., in response to runoff events that are captured behind spreader dike systems), there can be three sources of water supplying soil moisture: (1) meteoric water (rain and snowmelt); (2) natural runoff water; and (3) subirrigation from a shallow aquifer. In the case of rainfall and snowmelt, the EC of these waters will be similar to that of distilled water, i.e., they will exhibit very low dissolved solids. Owing to the dissolution of soluble constituents within the watershed, natural runoff EC values can range up to 5 dS/m or higher. Regarding subirrigation, shallow aquifers can be relatively saline due to the entrainment of dissolved minerals along the groundwater flowpath.

The concern arises from leaching of residual surface soil salinity with rainfall and snowmelt. Intermittent rainfall and snowmelt may lower the electrolyte concentration (i.e., EC) sufficiently to promote clay dispersion, depending on soil properties (Levy et al., 1998). Conversely, when the electrolyte concentration in the soil solution reaches a moderate level (1-2 dS/m), high sodicity levels (ESP between 10 and 30) cause only small to moderate changes in the physical and hydraulic properties of the soils, which are mostly reversible (Levy et al., 1998). Shainberg et al. (1981) showed that a major factor causing differences among various sodic soils in their susceptibility to hydraulic failure when leached with low electrolyte concentrations (i.e., a low EC) was their rate of salt release from mineral dissolution.

Arid land soils can release 0.3 to 0.5 dS/m of calcium and magnesium to solution as a result of the dissolution of plagioclase, feldspars, hornblends and other sparingly soluble minerals within the soil matrix (Rhoades et al. 1968). The solution composition of a calcareous soil at a given ESP in contact with distilled water (i.e., rainwater or snowmelt) can be calculated (Shainberg et al., 1981). As calcium carbonate ($CaCO_3$) dissolves, the EC of the soil solution increases and calcium replaces sodium on exchange sites until the solution is in equilibrium with the cation exchange system and the $CaCO_3$ solid phase. Shainberg et al. (1981) calculated that the EC values of solutions in equilibrium with soils having ESP values of 5, 10, and 20 are 0.4, 0.6, and 1.2 dS/m, respectively. Shainberg et al. (1981) indicates that these concentrations are sufficient to counter the deleterious effects of exchangeable sodium, even when the soil is leached with rainwater.

It is evident that water equilibrated with a calcareous soil can never be a very low salinity (Shainberg et al., 1981). Using the same database discussed above for evaluation of the ESP-SAR relationship in 382 soil samples from the Powder River Basin, we can compute an average percent lime ($CaCO_3$) content in surface soil samples (n=81), which is 5.1 percent. This represents a considerable reserve of calcium. Other sources of calcium include residual gypsum ($CaSO_4$) which we know to be prevalent in Wyoming soils.

Various soil SAR-EC relationships (not to be confused with irrigation water SAR-EC relationships) have been reported in the literature by introducing low electrolyte concentration waters to sodic soils. Felhendler et al. (1974) measured the hydraulic conductivity of two montmorillonitic soils as a function of the SAR and found that both were only slightly affected by the SAR of the percolating solution up to a SAR of 20 as long as the concentration of the percolating solution exceeded 1 dS/m. Shainberg et al. (1981) studied the effects of leaching a 1:1 sand-soil column with distilled water and increasing concentrations of a weak electrolyte solution. His findings concluded that an electrolyte concentration of 0.3 dS/m in the percolating solution was adequate to prevent the adverse effects of a SAR of 15 on the hydraulic conductivity of the soil-sand mixture. These findings are very similar to the conclusions of the U.S. Salinity Laboratory Staff (1954) who used electrolyte concentrations equal to or greater than 0.3 dS/m in their regression analysis to determine the sodic soils threshold of ESP = 15.

As a review, an electrolyte concentration of 0.3 dS/m is the minimum value of calcium and magnesium contributions to soil solution associated solely to arid soil weathering. This suggests that an arid Powder River Basin soil with a SAR of 16 (ESP = 10), will have no sodicity related impacts to the hydraulic conductivity, even when the salt concentration of the irrigation or rainwater is equal to that of distilled water.

Of course, irrigation water in the Powder River Basin has an intrinsic electrical conductivity greater than that of distilled water. Use of surface water for irrigation will actually supplement the inputs of calcium and magnesium from weathering and carbonate dissolution alone.

Using the aforementioned Powder River Basin soils assessment database (KC Harvey LLC, 2006), an average surface soil ECe of 1.64 dS/m was calculated from 81 individual surface soil samples. This value suggests that electrolyte concentrations in surface soils of the Powder River Basin, in equilibrium with mineral dissolution, the salinity of runoff irrigation water, and rainwater/snowmelt, is about 1.6 dS/m, or five times (1.6 dS/m divided by 0.3 dS/m) the concentration required to maintain the hydraulic conductivity of a soil at an ESP of 16.

Closing Statement

Results of the Powder River Basin regression analysis indicates that a relationship between ESP and soil/water SAR exists, which allows the calculation of one parameter from the other. Using the proposed, default ESP cap of 10 percent, the scientific literature indicates that water with a SAR of 16 can be effectively used for irrigation without adverse effects on the physical structure or hydraulic conductivity of Powder River Basin soils during irrigation. Furthermore, it has been shown that inputs of Ca and Mg from the natural dissolution of plagioclase, feldspars, hornblends and other sparingly soluble minerals, especially calcium carbonate and gypsum, will provide an effective buffer to residual soil sodicity after the discontinuation of produced water discharge and the transition back to native irrigation, precipitation, and runoff regimes.

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Thank you very much for your time and consideration of this review and the recommendations stemming from it. If you, your WDEQ colleagues, or the members of the Water and Waste Advisory Board have any questions or comments regarding our findings, please contact me.

Sincerely,

Kevin C. Harvey, M.Sc., CPSSc.
Principal Soil Scientist

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May 4, 2006

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I would like to comment on the proposed changes made to the Agricultural Use Protection Policy by the WDEQ subsequent to the January 26, 2006 meeting of the Water and Waste Advisory Board. My comments will focus on the comments provided by Dr. Larry Munn in his letter to the DEQ dated December 5, 2005. It is my understanding that Dr. Munn's comments resulted in the changes made to the proposed Policy. Specifically, I comment on Dr. Munn's request that the California-based soil salinity tolerance thresholds be used to establish default effluent limits for electrical conductivity (EC) under the Tier 1 process.

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Summary of Findings

The fourth draft of the Agricultural Use Protection Policy describes a 3-tiered decision making process for deriving appropriate effluent limits for EC and SAR whenever a proposed discharge may reach irrigated lands. The Tier 1 process would be followed for deriving "default" limits, and as such, this procedure would require a minimum of background information from the applicant. Specifically, the default EC limits would be based on the species-specific 100 percent yield potential values for soil EC reported by the USDA Agricultural Research Service (ARS) Salt Tolerance Database (USDA ARS, 2006).

Alfalfa is considered to be the most salt sensitive plant irrigated in northeastern Wyoming. Given this, my comments focus on the relevant information regarding alfalfa salinity tolerance. The ramifications of the concepts and data discussed herein for alfalfa can be applied to the more tolerant irrigated forage species commonly found in northeastern Wyoming, for example, western wheatgrass and smooth brome.

A considerable amount of research went into preparing these comments, including three months searching and reviewing the relevant scientific literature, and compiling and analyzing available and relevant soil, plant, and water data. The key conclusions of the literature review and data analysis are presented below and will be substantiated by the discussion that follows.

California Based Salinity Thresholds

- The ARS Salt tolerance database relies on California based salinity thresholds developed to approximate the specific plant, soil and environmental variables associated with that region.

- Regional differences in soil chemistry, climate and agricultural practices are likely to have a profound effect on the applicability of California based salinity threshold data to alfalfa growing in Wyoming.

Chloridic Versus Sulfatic Soils

- The natural soil salinity in the Powder River Basin is dominated by the sulfate ion; California soils are dominated by chloride. This conclusion is supported herein by the literature and by an evaluation of actual soil chemistry data provided by the USDA National Soil Survey Center.

- The term "gypsiferous" refers to sulfatic soils and is applicable to the Powder River Basin of Wyoming. Numerous documents, including the ARS Salt Tolerance Database, indicate that in sulfatic (or "gypsiferous") soils, plants will tolerate about 2 dS/m higher salinity than indicated.

<u>The Influence of Soil Salinity on Alfalfa Yield</u>

- Alfalfa is considered the most salt sensitive plant irrigated in northeastern Wyoming. Conditions required for the growth of alfalfa at 100 percent of its physiological yield potential probably do not exist anywhere in northeastern Wyoming and place doubt on the application of this benchmark value there.

- Sources of research and field guidance outside of California suggest alfalfa has a higher relative 100 percent yield soil EC tolerance than 2 dS/m, perhaps as high as 4 to 8 dS/m.

- Alfalfa yield comparisons between California and Wyoming show actual harvest values independent of soil salinity. Identical yields were reported in Wyoming for soil EC values ranging from 1.8 dS/m to 6.5 dS/m.

Based on the review summarized herein, we respectfully suggest that the WDEQ consider adopting an acceptable average root zone EC threshold of 4 dS/m for protection of alfalfa. This would equate to a default (Tier 1) effluent limit of 2.7 dS/m based on the 1.5 concentration factor cited by the draft Agricultural Use Protection Policy. The EC limits for protecting other species of concern in the Powder River Basin, e.g., western wheatgrass, should also be adjusted accordingly, based on the inherent differences in soil chemistry and climate between the northern Great Plains and the California agricultural areas. These conclusions and recommendations are substantiated by the discussion below.

California-based Salinity Thresholds

The majority of salinity tolerance data generated in the United States have been a product of field and laboratory trials conducted by the U.S. Salinity Laboratory (USSL) in Riverside, California. The salinity tolerance data generated by the USSL were prompted in response to agricultural production in the areas of the San Joaquin and Imperial Valleys of California. In 1977, Maas and Hoffman compiled the California research in a seminal article titled "Crop Salt Tolerance -- Current Assessment," listing salt tolerance levels for various crops. The subsequent year, Francois and Maas (1978) published an indexed bibliography of plant responses to salinity from 1900 to 1977 with 2,357 references to about 1,400 species. These articles serve as the primary references regarding crop tolerance and yield potential of selected crops as influenced by irrigation water (EC_w) or the average root zone soil salinity level (EC_e). This information was updated by Mass (1990). The ARS Salt Tolerance Database relies entirely on the Mass (1990) summary as the primary source of relative salt tolerance levels among crops. With respect to alfalfa, the original salt tolerance listings remain unchanged from the original Mass and Hoffman (1977) article.

The Mass and Hoffman (1977) and Mass (1990) listings of salt tolerance levels include the establishment of the 100 percent yield threshold for soil salinity. This value refers to the maximum allowable average root zone salinity level (EC_e) that results in no yield reduction for crops grown in chloritic soils. The term chloritic soil refers to the dominant salt type found in California soils (see below). For alfalfa, Mass and Hoffman (1977) and Mass (1990) list the 100 percent yield potential for alfalfa grown in chloritic soils as 2.0 dS/m (EC_e). The Mass and

Hoffman (1977) and Mass (1990) assessments also contain a disclaimer that the yield potentials listed should only serve as a guide to relative tolerances among crops, and that the absolute salt tolerance of crops is not simply a function of soil EC but is dependent on "many plant, soil, water, and environmental variables."

Six studies conducted at the US Salinity Laboratory in Riverside, California, served as the foundation for the determination of Maas and Hoffman's 2.0 dS/m threshold value (Gauch and Magistad, 1943; Brown and Hayward, 1956; Bernstein and Ogata, 1966; Bower et al., 1969; Bernstein and Francois, 1973; Hoffman et al., 1975). These studies vary in their methodology, including greenhouse and field experiments, different growth mediums (sand, gravel and soil), various watering regimes (automatic watering, tension-based watering), and multiple sources of chloritic salinity (NaCl, $CaCl_2$, and $MgCl_2$). These studies were designed to assess relative yield values, irrigation leaching fractions, root zone salt profiles, or salinity-ozone interactions. They were not specifically designed to determine a threshold salinity value for alfalfa. Usually, only four salinity levels were tested, with data used to produce a crop yield reduction line.

Furthermore, the source of salinity in the six studies was consistently chloride dominated, with either NaCl or a blend of NaCl, $CaCl_2$, and $MgCl_2$ added to the irrigation water. In Southern California, where these studies occurred, salts found in the soils are largely chloride-dominated. None of these studies were conducted using sulfate-dominated salts, such as are found in Wyoming soils (see below). Such regional differences in soil salinity are likely to have a profound effect on the application of existing salinity threshold data to alfalfa growing in the Northern Great Plains. Recognizing this, Mass (1990), Ayers and Westcot (1985), Hanson et al. (1999), as well as the ARS Salt Tolerance Database, all indicate that plants grown in sulfatic soils will tolerate average root zone EC_e values about 2 dS/m higher than indicated by each of these references. For alfalfa, this would equate to a 100 percent yield threshold of approximately 4 dS/m. This fact is discussed in detail below.

Chloridic Versus Sulfatic Soils

Research efforts of the USSL in California identified adjustments in effective plant salinity tolerance expressed or repressed in the field by physiological responses to climate, cultural practices, soil fertility, irrigation methods, physical condition of the soils and the distribution and speciation of salts within soil profiles. A critical difference between the environmental conditions in California and the northern Great Plains (including northeastern Wyoming) is soil chemistry and the primary salt constituents found in these soils. It is widely accepted that the soils of the agricultural areas of California are dominated by salts where chloride is the dominant anion, and that the soils of the northern Great Plains are dominated by salts where sulfate is the dominant anion. In earlier publications, sulfatic soils are sometimes termed "gypsiferous," referring to the most common sulfate salt found in semi-arid soils -- gypsum (calcium sulfate dehydrate). The correct term used today is sulfatic soils.

To incorporate the variation of salinity tolerance exhibited by plant response to different salt distributions and dominant salt species, the authors of salt tolerance research included a provision for sulfatic soils. Soils may contain amounts of sparingly soluble salts, such as gypsum and other sulfate salts, many times greater than can be held in solution in the field water-content range. Sulfatic soils may appear to be saline when exhaustively extracted in the lab (i.e., saturated paste extract), but the in-situ soil solution may be nonsaline because of the limited solubility of gypsum and other sulfate salts (Bernstein, 1975). Thus, the EC measured in a saturated paste extract is higher than the actual concentration of salts seen by plants in sulfatic soils. It was suggested originally by Bernstein (1962) that plants will tolerate about 2 dS/m higher soil salinity (EC_e) than indicated in sulfatic soils due to this solubility effect. Since calcium sulfate is disproportionately dissolved in preparing saturated-soil extracts, the EC_e of sulfatic soils will range an average of 2 dS/m higher than that of chloritic soils with the same water conductivity at field capacity (Bernstein 1962). Therefore, plants grown in sulfatic soils will tolerate an EC_e of approximately 2 dS/m higher than those grown where chloride is the predominant ion (Maas, 1990). This narrative provision for sulfatic soils is included in the ARS Salt Tolerance Database, and the classic irrigation guidelines presented in Ayers and Wescot (1985).

Sulfatic soils are the rule not the exception in Wyoming and the northern Great Plains. Sulfatic soils identified by salinity tolerance references are characterized by the presence and influence of gypsum, or calcium sulfate dihydrate ($CaSO_4 \cdot 2H_20$), within the soil profile, as well as the geological and climactic prerequisites for sulfatic soil conditions. Soil gypsum may stem from one of several sources. Soils formed from geologic material containing anhydrite or gypsum often contains gypsum. The amount of rainfall and the topographic setting will strongly influence the amount and location of gypsum in the soil (Dixon and Weed, 1989). Accumulations of soluble salts, including sulfates in the surface layers, are characteristic of saline soils of arid and semiarid regions (Brady, 1974), including Wyoming. Research conducted by the U.S. Geological Survey confirms the presence of gypsiferous parent materials in the Powder River Basin (Johnson, 1993). At this point, it is important to differentiate between the soil taxonomic terms "gypsic" or "petrogypsic," which are used to describe significant gypsum accumulation within soil horizons, from the terms "gypsiferous" or "sulfatic" soils which refer to the dominate salt type in soils of Wyoming and the northern Great Plains.

Published research has addressed the issue of prevailing salt distribution and climate influenced salt dominance. In Springer et al. (1999), Curtin et al. (1993) and Trooien (2001), northern Great Plains prairie soil chemistry is comparatively summarized and/or contrasted to soils of California. Research suggests that recommendations developed for the western United States, where chloride is the major anion in soil and water chemistry, may not be appropriate for sulfatic soils (Springer et al., 1999). Trooien (2001) notes that most plant salinity tolerance information is developed in California and that the chemistry of salinity is different in the northern Great Plains (i.e., sulfate dominated salinity). Therefore, Trooien (2001) indicates that salinity thresholds are greater and yield losses are somewhat smaller in the Northern Great Plains compared to those of California (i.e., chloride dominated salinity). Research in Canadian prairie soils by Curtin et al. (1993) and Wentz (2001) suggest that salt tolerance testing at the Swift Current, Saskatchewan, salinity laboratory (and also at the US Salinity Laboratory) has mostly involved the determination of crop responses to chloride salinity. However, there is reason to suspect that responses to sulfate salinity, which is the predominant form of salinity in prairie soils, may differ from those observed in chloride salt systems. Wentz (2001) summarizes that crop tolerances developed for chloride dominated soils, such as those in California, may not be applicable to crops grown on the sulfate dominated soils typically found in western Canada.

Comparison of actual soil analytical data from the NSSC Soil Survey Laboratory, Lincoln, Nebraska, supports the chloride and sulfate salt dominance designations suggested by Springer et al. (1999), Curtin et al. (1993), Trooien (2001), and Wentz (2001). Analyses from the U.S. Soil Survey Laboratory are available online at http://ssldata.nrcs.usda.gov/ and organized by soil pedon. Data from selected counties in Wyoming and California were obtained from the NSSC Soil Survey Laboratory Research Database in order to determine the dominance of chloride or sulfate soil chemistry in the respective regions. Soil chemistry data were downloaded for use in this study for counties of the Powder River Basin in Wyoming (Sheridan, Campbell and Johnson Counties). Soil chemistry data were also downloaded for counties in California where intensive agricultural production takes place (Imperial, Fresno, Kern, Kings and Tulare).

Data pertaining to soil chloride and sulfate in the saturated paste extract are arranged and averaged by county and state in Table 1 below. These values are based on all of the available data provided by the U.S. Soil Survey Laboratory.

Table 1
A Comparison of Average Soil Saturated Paste Extract Sulfate and Chloride Levels from Counties in Wyoming and California.

County	Average Soil Sulfate Level (meq/L)	Average Soil Chloride Level (meq/L)
Sheridan, WY	14.9	4.1
Campbell, WY	130.4	3.0
Johnson, WY	30.9	1.8
Wyoming Average	**58.7**	**2.9**
Imperial, CA	48.4	295.7
Fresno, CA	98.6	26.3
Kern, CA	44.3	73.0
Kings, CA	110.7	23.9
Tulare, CA	9.3	21.6
California Average	**62.3**	**88.1**

The summary data suggest that the relative proportion of chloride salts in the selected California counties outweigh the proportion of sulfate salts and verify the chloride dominance suggested by the literature summarized above. In northeastern Wyoming, the relative proportion of sulfate salts in selected counties outweigh the proportion of chloride by an order of magnitude and verify the sulfate dominance and sulfatic conditions implied by the literature. Therefore, the recommendation by the ARS Salt Tolerance Database signifying that plants grown in sulfatic soils will tolerate average root zone EC_e values about 2 dS/m higher than indicated, is valid for the Powder River Basin, and probably all of Wyoming. For alfalfa, this would equate to a 100 percent yield threshold of 4 dS/m.

The Influence of Soil Salinity on Alfalfa Yield

As indicated above, the *relative* 100 percent yield potential reported for alfalfa in the ARS Salt Tolerance Database is 2 dS/m (EC_e). As such, alfalfa is regarded in the California-based literature as "moderately sensitive" to salinity. An *absolute* salinity tolerance would reflect predictable inherent physiological responses by plants, but cannot be determined because interactions among plant, salt, water and environmental factors influence the plant's ability to tolerate salt. *Relative* salt tolerance is a value based on the climatic and cultural conditions under which a crop is grown (Maas and Hoffman, 1977). Research generated outside the U.S. Salinity Laboratory in the U.S. and Canada has introduced alternative salinity tolerance values for alfalfa influenced by these climatic and cultural conditions.

In a study based on field trials in western Canada, McKenzie (1988) reported the "relative maximum salinity crops will tolerate when combined with intermittent moisture stress throughout the growing season." McKenzie (1988) places alfalfa within a moderate tolerance category, as opposed to moderate sensitivity, and extends alfalfa's 100 percent yield tolerance to an EC range of 4-8 dS/m, as opposed to 2 dS/m. Similar tolerance descriptors and EC values for alfalfa can be found associated with Britton et al. (1977), who supports moderate salt tolerance and an EC range of 5-10 dS/m for alfalfa. Likewise, Milne and Rapp (1968) present alfalfa with a moderate tolerance and an EC range of 4-8 dS/m. Cavers (2002); Wentz (2001); Schafer (1983); Holzworth and Wiesner (1990) and Dodds and Vasey (1985) also contribute to a departure from the established Maas classification of alfalfa salinity tolerance and threshold values. Bower et al., suggests an alfalfa tolerance somewhat between the previous authors and Maas (1990), suggesting maximum alfalfa yield is obtained when the average EC_e value for the root zone is 3 dS/m. Using salinized field plots in southern Saskatchewan, Holm (1983) reported a small, 0.037 ton/acre, reduction in alfalfa yields resulting from an increase in the surface EC_e (0 to 15 cm sample) from a 0 to 4 dS/m range to a 4 to 8 dS/m range. Holm presented these scales as representative of low and medium EC levels.

Relative salinity tolerances reported outside of peer reviewed literature stem from professional observations and judgments, roundtable discussions, experience in the field, and experience with the region, culture and climate; not from experimental data. Incorporation of field experience, observation, and limited data into supporting documents of the Salt Tolerance Database is acknowledged in Ayers and Wescot (1985). Alternative sources listed herein do not always report EC values in terms of 100 percent yield thresholds for alfalfa, but should not be discounted, as they pertain to what is realistic in the field. As an example, the Montana Salinity Control Association reports forage salt tolerances in terms of marginal establishment levels, not 100 percent yield potentials. Conditions allowing alfalfa to produce at 100 percent of its physiochemical yield potential probably do not exist anywhere within the northern Great Plains.

A suggested field-yield value corresponding to the 100 percent yield of alfalfa has never been reported by authors of salinity literature. Specifically, what yield of alfalfa, in tons per acre, could one expect if it was grown under conditions supporting 100 percent yield? Conditions supporting 100 percent alfalfa yields recommended by the ARS Salt Tolerance Database and its supporting documents would be: a soil EC_e of 2 dS/m or less, an irrigation water EC_w less than or equal to 1.3 dS/m, water contents maintained at field capacity, available N, P and K nutrient levels maximized for alfalfa growth, a sufficiently long growing season, no associated phytotoxicity or pest issues, etc. This data limitation precludes the direct comparison of alfalfa yields generated in an agricultural area to the potential yields theoretically available under optimized conditions. The only available analysis is to compare an alfalfa yield to the average yield generated in its area, or generated between areas.

Using data available from the National Agricultural Statistics Service, selected county agricultural commissioner's data, and the U.S. Census of Agriculture (2002, 1997), irrigated alfalfa yield data were obtained for periods of interest. Alfalfa yield data for Wyoming counties are available from 1959 through 2005, but were averaged from 1970-2005 to reflect the integration of new irrigation technologies. Alfalfa yield data were summarized for the area encompassing the Powder River Basin: Sheridan, Johnson and Campbell counties. Alfalfa yield data for California counties are available from 1980-2004 so the entire dataset was averaged. Alfalfa data were summarized for counties in California related to intensive agriculture: Imperial, Fresno, Kern, Kings and Tulare counties.

Soil salinity data (as measured by EC) collected by the USDA National Soil Survey and analyzed by the National Soil Survey Center (NSSC) Soil Survey Laboratory were also obtained and summarized for the aforementioned counties. Average root zone EC values were calculated to a maximum depth of five feet. The county alfalfa yield and average root zone EC summaries are presented in Table 2 below.

Table 2
Comparison of Average Root Zone Soil Salinity (EC) Values with Historical Alfalfa Yields for Selected Counties in Wyoming and California.

County	**Average Root Zone Soil Salinity (EC as dS/m)**	**Historical Average Alfalfa Yield (tons/acre)**
Sheridan, WY	1.5	2.7
Johnson, WY	1.9	2.4
Campbell, WY	2.0	2.4
Wyoming Average	**1.8**	**2.5**
Tulare, CA	2.8	8.4
Kings, CA	6.9	6.9
Kern, CA	4.6	8.0
Fresno, CA	6.7	7.9
Imperial, CA	6.7	7.8
California Average	**5.5**	**8.0**

Values expressed in Table 2 show substantially higher average root zone salinities in California than in Wyoming. Alfalfa yields reported in California are three times greater than those in Wyoming, even though, on average, the soil salinity values are nearly three times higher than those reported for the Wyoming counties. The values generated in this exercise suggest that environmental factors other than salinity, e.g., climate, may be dictating the obtainable degree of alfalfa yield produced. However, the data also suggest that the California-based 100 percent yield threshold of 2 dS/m may not be appropriate for even the chloritic soils of California. For example, the historical average yield of alfalfa in Tulare County is 8.4 tons per acre with a corresponding average root zone EC of 2.8 dS/m. The yield from Tulare County is actually slightly greater than the yields from Fresno and Imperial Counties where the corresponding average root zone EC values are substantially higher at 6.7 and 6.7 dS/m, respectively. Regardless, there does not appear to be a substantial difference in yields reported by the California counties with soil EC values ranging from 2.8 to 6.7 dS/m.

Other field data from Wyoming have been reviewed that also suggest an alternative to the California-based salinity tolerance values. The Use Attainability Analysis (UAA) report for Cottonwood Creek (SWWRC et al., 2002) was downloaded from the Wyoming Department of Quality, Water Quality Division webpage. Cottonwood Creek is located in Hot Springs County within the Bighorn Basin of Wyoming. This is an area of extensive conventional oil and gas production. According to the UAA report, discharge of produced water from the Hamilton Dome oil field to Cottonwood Creek constitutes the majority of flow to the ephemeral stream and constitutes the only irrigation water source for approximately 35 ranching operations. The waters of Cottonwood Creek exhibit an EC_w between 4.1 and 4.5 dS/m. At an average EC_w of 4.3 dS/m, an average root zone soil EC_e value can be calculated using the widely accepted relationship: $EC_e = 1.5\ EC_w$ (Ayers and Wescot, 1985). This relationship is expressed in the draft Section 20 Agricultural Use Protection Policy. From this relationship, an average root zone soil EC value of 6.5 is estimated for the fields irrigated long-term with water from Cottonwood Creek. Average alfalfa hay yields reported in the UAA amount to 2.5 tons per acre. This yield is identical to the average of the three Wyoming counties reported in Table 2 above. This is compelling given that the average soil EC value for the three other Wyoming counties is 1.8 dS/m, while the estimated soil EC for the fields irrigated with water from Cottonwood Creek is 6.5.

Closing Statement

Based on the review summarized herein, we respectfully suggest that the WDEQ consider adopting an acceptable average root zone EC threshold of 4 dS/m for protection of alfalfa. This would equate to a default (Tier 1) effluent limit of 2.7 dS/m based on the 1.5 concentration factor cited by the draft Agricultural Use Protection Policy. Other species of concern, including western wheatgrass, should be given equal consideration due to the inherent differences in soil chemistry between the northern Great Plains and the California agricultural areas for which the ARS Salt Tolerance Database is based. Factors such as extreme climate, periodic drought, soil moisture regime, duration of growing season, soil depth, and fertility limitations can collectively exert an overriding regional influence on the yield potential of forage crops. Based on this, we ask that the WDEQ exercise caution interpreting the applicability of specific salinity tolerances outlined by the ARS Salt Tolerance Database and thoughtfully consider the difficulty in detecting a "measurable" change in plant production due to soil salinity alone.

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Thank you very much for your time and consideration of this review and the recommendations stemming from it. If you, your WDEQ colleagues, or the members of the Water and Waste Advisory Board have any questions or comments regarding our findings, please contact me.

Sincerely,

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