Attachment 6

A Review of the Report:

EVALUATION OF WATER QUALITY CRITERIA FOR RAIN-IRRIGATION CROPPING SYSTEMS

Final Report to EPA, June 30, 2006 by,

Donald L. Suarez, James D. Wood and Scott M. Lesch,
USDA-ARS U.S. Salinity Laboratory, Riverside, California

Prepared for:

Patton Boggs, LLP
2550 M Street, NW
Washington, DC 20037

Prepared by:

Kevin Harvey
Consulting Soil Scientist
KC Harvey, Inc.
376 Gallatin Park Drive
Bozeman, Montana, 59715

April 15, 2009

TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 OVERVIEW OF SOIL SALINITY AND SODICITY 1

Soil Salinity 2

Soil Sodicity 2

3.0 SUMMARY OF THE CALIFORNIA STUDY 4

4.0 REVIEW FINDINGS 4

General Findings 4

Specific Issues Related to the Methods Used 5

Specific Issues Related to the Results of the Study 12

5.0 SUMMARY OF THE REVIEW 13

6.0 REFERENCES CITED 15

7.0 QUALIFICATIONS OF THE REVIEWER 18

1.0 INTRODUCTION

The following summarizes Mr. Kevin Harvey's review of a research report entitled "Evaluation of Water Quality Criteria for Rain-Irrigation Cropping Systems" by Donald L. Suarez, James D. Wood and Scott M. Lesch of the USDA-ARS U.S. Salinity Laboratory in Riverside, California (Suarez et al., 2006a). This report was submitted to the U.S. EPA on June 30, 2006. A journal article summarizing the first year of the evaluation was also included in the review (Suarez et al., 2006b). Hereafter, these two documents will be collectively referred to as the "California study."

Mr. Kevin Harvey of KC Harvey, Inc. was retained by Patton Boggs, LLP of Washington, DC to provide a critical review of these reports and provide an opinion as to the suitability of the results for setting water quality criteria for the protection of irrigation uses in the Tongue River and Powder River watersheds of Montana. The scope of this review involved a comprehensive assessment of the methods, results and conclusions of the California study, including a review of the relevant scientific literature.

Kevin Harvey and KC Harvey, Inc. reserve the right to modify and/or change the conclusions presented in this report, based on, and not limited to, the continuing evaluation of data, reports, rebuttal reports, publications, correspondence, oral and written testimony in this matter, and personal observations. Additionally, Mr. Harvey reserves the right to obtain and review additional information and to incorporate this information into additional analyses and reports.

Seven sections comprise this report including this introduction (Section 1.0). Section 2.0 presents an overview of soil salinity and sodicity science. Section 3.0 briefly summarizes the objectives, methods and findings of the California study. Section 4.0 describes the general and specific findings of the review. Section 5.0 provides a summary of the review and Section 6.0 includes the references cited throughout this report. Mr. Harvey's relevant qualifications are summarized at the end in Section 7.0. Figure 1 showing the locations of bulk soil sample locations in relation to the Tongue River and Powder River watersheds in Montana is attached at the back of this report.

2.0 OVERVIEW OF SOIL SALINITY AND SODICITY

The following overview of soil and water salinity/sodicity is provided in order for the reader to better understand the ramifications of the California study and this review.

Soil chemical properties can affect the infiltration of water into soil and the permeability of water through the soil, as well as plant growth potential. Soil electrical conductivity (EC), the sodium adsorption ratio (SAR), and pH are the three primary soil parameters that are used to determine if soil conditions are saline or sodic. Measurements of the EC and SAR in irrigation water are also made to predict whether a particular source of water will cause a soil to become saline and/or sodic over time.

Soil Salinity

Soil salinity is simply the amount of soluble salts in a soil, and is measured by the electrical conductivity (EC) of the saturated paste extract. The salinity of a soil is important because high salt levels make it difficult for plants to extract water (Bohn, et al., 1985), i.e., salts make a soil more droughty. Saline soils are conventionally defined as having EC values of greater than 4000 uS/cm, however sensitive plants can be affected at 2000 uS/cm and more tolerant plants (e.g., many of the native species of the Powder River Basin) are productive at EC levels greater than 8000 uS/cm. In the arid western United States, naturally occurring saline soils are more typical because arid regions are subject to high evaporation rates, thus allowing salt concentration to occur (Soil Improvement Committee, California Plant Health Association, 2002). The primary source of soil salinity includes the weathering of soil minerals within the soil itself. Secondary sources include saline groundwater, irrigation water, fertilizers and soil amendments.

Soil Sodicity

The physical and chemical phenomena associated with soil sodicity are complex. A large body of research concerning natural and unnatural 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. 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,

$$ESP = \left(\frac{exchangeable\ sodium}{cation\ exchange\ capacity} \right) \times 100$$

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. 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. The type of clay mineral species making up the clay content is also important with the swelling type smectite clays being the most problematic.

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 irrigation 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:

$$SAR = \frac{[sodium]}{\sqrt{\frac{[calcium]+[magnesium]}{2}}}$$

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. (2006) are used to assess the potential sodicity risk of irrigation water.

3.0 SUMMARY OF THE CALIFORNIA STUDY

The primary objective of the California study was to establish irrigation water quality criteria for EC and SAR under conditions of combined rain and irrigation, and on cropped and non-cropped soils from southeastern Montana. This study focuses on the effects of sodium (and interactive effects with salinity) on soil infiltration. To this end, the California researchers irrigated disturbed soils with variable EC-SAR water qualities, in addition to the application of synthetic rainfall. Water applications alternated between simulated rainfall and flood irrigation. Infiltration rate and hydraulic conductivity measurements determined the effect of various water qualities on the soil. The California study used two Montana soils, a Kobase Silty Clay from the Miles City, Montana area and a Glendive Sandy Loam from the Powder River area. Following excavation, the bulk soil material was transported to Riverside, California where it was dried, crushed, sieved and placed into small containers approximately ten inches wide by eleven and a half inches tall.

Simulated rainfall and flood irrigation began in August 2003 to the bare (uncropped) soils and ended in January 2004. Infiltration rates were measured throughout the study period and the hydraulic conductivity of undisturbed core samples taken from the containers was measured at the conclusion of the water applications. After the completion of the 2003 study, the soil materials were recycled for the 2004 study. For the 2004 study, alfalfa was completely established in the containers before irrigation and rainfall applications began. Irrigation and simulated rainfall application for the 2004 study began in April 2004 and continued through March 2005 using the same methods as the 2003 study.

Based on this study the researchers claim that the infiltration rate of water into the soil decreased as SAR increased for both the uncropped and cropped soils. In the disturbed bare clay soil an SAR increase from 2 to 4 resulted in a decreased infiltration rate. Infiltration rates determined that for the loam soil an SAR of 6 caused a decrease. Hydraulic conductivity (the rate of water movement through the soil) decreased as SAR increased in the loam soil for both the uncropped and cropped treatments. No hydraulic conductivity differences were observed with respect to SAR for the uncropped and cropped clay soil. There were no measureable differences in alfalfa yield between the variable EC-SAR irrigation water treatments.

4.0 REVIEW FINDINGS

General Findings

The California study summarized above in Section 3 is an important attempt at understanding the regional-specific behavior of irrigation, climate, EC, and SAR, on soil infiltration. Dr. Suarez and his team at the USDA ARS U.S. Salinity Laboratory are considered to be among the world's leading experts on irrigation water and soil salinity and sodicity. They, like all researchers, must conform to fundamental scientific standards, including the need to properly document all research methods to the extent that the reader of a report can reproduce the study, and that the methods used in simulating field conditions in the laboratory are as representative of the field as possible. Unfortunately, these two standards were not achieved for the California study. In

addition to these fundamental issues, the "master" EPA report that supposedly presents all of the available data, analyses and results is difficult to read, poorly organized, and is missing several critical pieces of information related to sampling procedures, baseline soil data, experimental design, laboratory methodology, and actual measured response data.

The following summarizes some of the reasons why the California study falls short of its worthy objectives.

Specific Issues Related to the Methods Used

1) **The methods in the California study are poorly documented, difficult to understand, and do not provide enough information to repeat the study. Without proper explanation of sampling methods, the study is not repeatable and the results are therefore questionable.**

   According to the Agronomy Society of America, the purpose of the methods section of a report or refereed journal article is to provide enough detail for a competent scientist to be able to repeat the experiment (ASA et al., 1988). The materials and methods sections of the one report and two journal articles that constitute the California study are not clearly organized and do not include details that are necessary to repeat the experiment. Some of the methodology documentation problems are as follows:

   - The soil sample methods do not contain a description of the soil collection sites or an explanation of site selection. The reports states that "surface" samples were collected, but it is unknown the depth of sample collection and if the samples were collected by horizon or an arbitrary depth measurement. No clarification is given to explain how the soil samples were excavated and if the samples were composite or discrete samples. All sampling information is necessary to reproduce the study and to determine whether or not the lab experiment is representative of actual field conditions.

   - The soils in the study were "crushed," but an explanation of how the samples were crushed is not provided.

   - The methods state that the crushed, sieved, and air dried soils were analyzed for chemical characteristics. No chemical analysis results are provided. In fact no soil chemistry results are ever provided in the study. This seems insufficient for a study that is about the changes to soil hydraulic properties from the effects of irrigation water chemistry on soil chemistry.

   - Vacuum extractors were applied to the bottom of each soil container without a clear explanation of why they were used. The vacuum was used before, during, and after the study. The actual quantity of time the vacuum was on before and after the irrigation event is not reported. Without this information the experiment cannot be repeated.

   - Soil samples from the 2003 study were reutilized for the 2004 study. Reusing soil that has had excessive leaching and elevated sodium applied from the irrigation water treatments will cause residual effects in the 2004 study. The excessive leaching will

remove salts from the soil-water solution while the sodium ions remain on the soil clay particles. Effects from the 2004 study alone will not be able to be determined because of the unknown antecedent condition of the soil. Regardless of the residual effects from the 2003 study, the California study does not clearly explain how the soils were reused. The methods state that the soils were removed from containers, remixed, leached, and added to new containers. The methodology explaining the mixing process of the reutilized soils is not specified. If the soil was mixed within irrigation treatments then the observed differences between treatments in the 2004 study may be amplified because of the residual effects from 2003 irrigation. If all of the soil was mixed regardless of irrigation treatment then an overall decrease in the infiltration rate may be observed because all of the soils are initially affected by sodium. The reutilizing of the soil will cause residual effects. How the reutilized soils are affecting the results is unknown since the methods for mixing are not clearly stated and no soil chemical analysis was performed.

- Rainfall simulation cannot be repeated due to a vague description of the simulation apparatus. The simulator was located 140 cm above the soil surface but the diameter of the spray at the surface is unknown. The time to complete a rainfall cycle is also not stated.

- Hydraulic measurements (infiltration and hydraulic conductivity) are the primary measurements of the California study yet an explanation of how the measurements were made is not provided. Conclusions about the treatment effects are drawn from these unrepeatable measurements. This is a fundamental flaw of the California study. It is inconceivable that this oversight passed the peer review process.

  Within the experimental design section of the materials and methods, it was stated that infiltration was measured from temporary ponding conditions within the containers after simulated rain events. In the results section it describes during which pass of the rainfall simulator that infiltration was actually measured. There is no explanation as to how ponding depth was measured or how the infiltration time was determined for each of the 66 containers.

  Hydraulic conductivity measurements were made in the laboratory on soil cores from the 66 containers. The core sampling method is well documented, but it is unclear how the saturated hydraulic conductivity was measured; the composition of the test water was specified as of the “same composition as used in the container experiment.” It is unclear if the irrigation water chemistry was used or the simulated rainfall water chemistry was used for the test fluid when conducting the hydraulic conductivity measurements. Because the chemistry of the water greatly influences the hydraulic conductivity measurements, the water chemistry of the test fluid is a very important detail that should be explained (Klute and Dirksen, 1986).

  The materials and methods reference an additional laboratory infiltration rate method, but no measurement results are ever reported. The infiltration was measured on a 31

mm diameter soil column of an unknown length. The number of times infiltration rate measurements occurred is not stated and no measurement method is reported.

Since the results and conclusions of the California study are based on hydraulic measurements it is critical that they are fully described. The three hydraulic measurements performed in the California study would not be repeatable because of incomplete methods descriptions.

- A complete description of the statistics performed is not written within the methods section. Statistical methods are found throughout the results section of the paper and vary for each measurement. All methods should be found within the methods section.
- It is important the methods are complete, clear, and concise. The methods of the California study are scattered throughout the reports and difficult to understand.

A fundamental rule of the scientific method is repeatability. For an experiment's results to be considered valid the experiment must be able to be repeated to obtain the same results. The California study could not be repeated because the methods are not only difficult to understand, but lack important details that are necessary to duplicate the experiment.

2) **The bulk soil material collected from Montana and transported to California was excavated, dried, crushed, sieved, and repacked into soil containers destroying all natural soil structure, pore space, root channels, and aggregates. The primary objective of the California study was to measure changes in infiltration due to sodium adsorption and the resulting damage to soil structure. Soil structure is a key factor controlling soil infiltration and permeability. Destroying the natural soil structure at the beginning of the study will certainly lead to reduced infiltration rates. Using soil in this way is not representative of field conditions and represents a fundamental flaw in the California study that significantly reduces our confidence in the results**.

The term soil "structure" refers to the aggregation of soil particles bound together by organic matter and clay minerals. In Montana, the natural structure of the soil may have taken up to 10,000 years to develop. The movement of water into (infiltration) and through (permeability) a soil is largely controlled by soil structure and the pore spaces that it creates. Small pores are present within the individual aggregates and larger pores are present between the aggregates. Water will move into and through a developed soil with strong soil structure much more effectively than the same soil that has been crushed and reduced to dust.

The California study measured infiltration rates on soil that was excavated in Montana, transported to Riverside, California, dried, crushed, sieved to less than 5 mm, and packed into small containers. This process completely destroyed the natural structure of the soil, which is the very thing that this study was trying to measure as a result of excess sodium adsorption. Put another way, the soil structure was already destroyed before the study began. It is the soil structure that is impacted from excess sodium adsorption and the resulting decrease in infiltration that this study attempted to measure.

It is the impact to soil structure that we are concerned about when we discuss excess sodium adsorption caused by irrigation with water that exhibits a high SAR. Over time, the positively charged sodium ions delivered by the high SAR irrigation water replace calcium, magnesium and other ions on the negative exchange sites of the clay minerals. If conditions are right, the excess sodium adsorption on the soil clays can lead to the swelling and dispersion of certain clay mineral types (smectite clays). This in turn, can lead to the destruction of the natural soil structure and a reduction in infiltration and permeability.

It stands to reason then, that a study on the effects of irrigation water SAR on soil infiltration would utilize an undisturbed soil with intact soil structure. This is one way to ensure that the conditions of the laboratory study are representative of actual field conditions. The difference in soil infiltration and permeability between undisturbed and disturbed soils is mostly governed by soil structure and the porosity it provides. In a study by Hopmans et al. (2005), it was found that air and water permeability was significantly greater in undisturbed samples (with intact soil structure) than in disturbed soil samples (with destroyed soil structure). This is due to the major influence of soil structure and porosity on permeability. The California study was fundamentally flawed from the beginning because it did not involve the use of undisturbed soil with intact soil structure, and, therefore, is not representative of actual field conditions in Montana.

3) **One-half of the soil used in the California study that was intended to represent irrigated soils along the Tongue River contains 54% clay. An ongoing study funded by the State of Montana indicates that the average clay content in irrigated surface soils along the Tongue River is 30%. The "clay" soil used in the California study did not come from the Tongue River watershed and is not representative of these soils**.

In the California study, it was reported that the Kobase soil sample was taken near the Tongue River. The sample was actually taken within the Yellowstone River drainage (see Figure 1 attached to the back of this report). Soils formed within the Yellowstone River drainage will have different parent materials and thus have different chemical and physical properties than soils formed within the Tongue River drainage. Specifically, clay content and clay mineralogy differences will greatly influence the susceptibility of a soil to sodic soil formation from irrigation with sodic water. It is inappropriate to use the California study to make inferences to soils of the Tongue River drainage. The soil samples collected from northeast of Miles City and used in the California study were formed in Yellowstone River sediments; they are technically Yellowstone River soils.

A State of Montana funded study of irrigated agricultural soil conditions was undertaken in the Tongue River drainage in 2003 (Schafer, et al, 2007). Since then, data are collected annually in this study to try to determine changes in soil chemistry with time. As part of the Schafer study, soil samples were also collected from fields within other river drainages for comparison purposes. Two fields were sampled within the Yellowstone River drainage, one field that is irrigated with Tongue River water (from the T&Y Canal) and another field that is irrigated with Yellowstone River water.

Data collected from 12 Tongue River fields in 2003 indicate that soil surface sample clay content ranges from 10 to 48 percent, with an average clay content of 30 percent (Schafer, et al, 2007). The surface soil samples were collected from the top three to eight inches of the soil profile depending on the depth of the surface horizon. Yet the Kobase soil used in the California study had a clay content of 54 percent. Soils with high clay contents are more adversely impacted than soils with low clay content (Carlstrom, et. al, 1987) due to the greater surface area and thus reactivity of clays and to the sodium induced swelling of expanding type clay minerals. To conduct a study such as the California study, the soil used should have had a clay content of approximately 30 percent to be representative of Tongue River soils.

In addition, while the California study describes the importance of clay mineralogy (clay type) in the literature review, the authors did not complete a clay mineralogy analysis. The clay mineralogy of a soil is a controlling physical property for sodic soil formation (Frenkel et al., 1978; McNeal and Coleman, 1966). Clay mineralogy analysis results from the 12 Tongue River fields indicate that the soils sampled were dominated by kaolinite and illite clay minerals, which are non-swelling clays that are not easily affected by excess sodium (Schafer, et al, 2007). In the two Yellowstone River fields sampled by Schafer, et al, (2007), clay mineralogy was dominated by smectite, a swelling clay that is easily affected by excess sodium. For the CALIFORNIA study to be representative of Tongue River soils, the clay mineralogy of the test soil should have had a clay mineralogy dominated by kaolinite and illite clay minerals.

While the Schafer study did not sample all fields within the Tongue River drainage, it is the most complete data set available and fields sampled are distributed throughout the drainage (Figure 1). As stated above, soils with higher clay contents and smectite dominated clay mineralogy are more susceptible to sodic soil formation from irrigation with sodic water. Therefore, by choosing a soil formed within the Yellowstone River drainage that is more susceptible to sodic soil formation the study results can only be extended to fields located within this area of the Yellowstone River drainage.

4) The California study states that a baseline chemical analysis of the soil was performed. The soils data are not included in any of the reports. If the soils were sodic before the various EC/SAR water applications were made, reduced infiltration rates in the study could be a result of the original soil chemical condition, not the various EC/SAR irrigation treatments. The absence of soil chemical data is troubling given that this is a soil infiltration study directly related to the effects of irrigation water on soil chemistry.

It is entirely unknown what the baseline chemical condition of the soils used in the California study was. In a statement made to a Hearing on Land-Use Issues Associated with Onshore Oil and Gas Leasing and Development, House Subcommittee on Energy and Mineral Resources, House Subcommittee on National Parks, Forests and Public Lands, on April 26, 2007, the landowner of the sampling site near Miles City, Montana on the Yellowstone River drainage, Mr. Roger Muggli, claimed that his family has struggled with salty soils on their

farm for many decades (Muggli, 2007). He stated, “Many discussions I listened to as a kid between my father and grandfather centered around water quality and the effects of salts on crops and soil. They worried me so much that I wondered if the farm could survive until I was old enough to have a shot at managing it and the Irrigation District.” While this is anecdotal information, the statement creates doubt as to the suitability and representativeness of the soils for use in the study.

Saline-sodic soil conditions exist within irrigated fields of eastern Montana. Data collected from 12 Tongue River fields in 2003 indicate that soil surface sample pH ranged from 7.3 to 8.0; EC ranged from 620 to 2800 uS/cm with an average EC of 1030 uS/cm; and, soil sample SAR ranged from 0.5 to 11, with an average SAR of 2.08 (Schafer, et al, 2007). Surface samples were collected from the top three to eight inches of the soil profile depending on the depth of the surface horizon. Clearly there is a wide variation in the soil chemistry in these 12 Tongue River fields. While not representative of a typical Tongue River soil, one of the 12 fields from the Tongue River study would be considered saline-sodic, with soil sample pH ranging from 7.8 to 9.2; EC ranging from 2800 to 18900 uS/cm; and, SAR ranging from 11 to 66 in the samples collected from 0 to 60 inches. It is likely that past irrigation management practices conducted over decades have created the high levels of salinity and sodicity in this field. If the soils from the saline-sodic field were used in the California study, while not representative of Tongue River soils, they would be more easily impacted by manipulation and testing in the laboratory. Without baseline soil chemical data, it cannot be fully concluded that the infiltration limitations observed in the California study are from alternating rain and irrigation events and not residual effects from the soil.

5) **The intensity of the simulated rainfall used in the California study was 0.21 centimeters per second, which is over 3000 times more intense than the estimated average rainfall intensity for the Miles City, Montana area. This extreme high intensity rainfall is not representative of field conditions and can limit infiltration by physically impacting the surface of the soil.**

Soil samples used in the California study were collected near Miles City, Montana. During this review, actual rainfall intensity data were not identified for the Miles City, Montana area. Therefore, for the purposes of this review, the CLIGEN weather generator model, created by the United States Department of Agriculture- Agricultural Research Service (USDA-ARS), was used to simulate a 100-year climate for Miles City, Montana. The CLIGEN model predicts the climate using various equations and algorithms from average monthly input values (minimum temperature, maximum temperature, solar radiation, and precipitation) using data from the Miles City weather station (Nicks et al., 1995). The average rainfall intensity used in the California study was 7560 millimeters per hour which is equivalent to 0.21 centimeters per second. The CLIGEN model predicted the normalized peak intensities for each storm within the simulation period. The normalized peak intensity is calculated by dividing the peak intensity by the average intensity. The maximum normalized peak intensity predicted by the CLIGEN model for a 100-year simulation at Miles City, Montana is 103 millimeters per hour (0.0029 centimeters per second). The average normalized peak intensity for all the storms in the 100-year simulation of the Miles City weather was 2.23

millimeters per hour or 6.2 $\times$ 10^{-5} centimeters per second. Therefore, the maximum normalized peak intensity and the average normalized peak intensity for rainfall in the Miles City, Montana area are estimated to be 73 and 3400 times less, respectively, than the rainfall intensity used in the California study. The rainfall intensity used in the California study is not representative of the field conditions near Miles City, Montana.

High intensity rainfall often decreases infiltration and increases erosion risks due to raindrop impact and surface crusting. Raindrop impact, especially from an intense precipitation event, breaks apart soil aggregates and detaches soil particles, which can result in formation of surface crusts upon drying (Brady, 1990). As indicated above, bulk soil samples from Montana were excavated, dried, crushed, sieved, and repacked into containers, which destroyed the natural structure of the soil. The soil erodibility (vulnerability to the erosivity of rain or running water) depends on many factors (Meyer and Harmon, 1984). Examples of these factors are texture (Stern et al., 1991) and soil structure (Moore and Singer, 1990). Since there was no soil structure in the disturbed samples in the California study, soil crusts were likely formed during this study. Detached soil particles were confined within the sample container, and were settled on the surface forming a surface crust. Surface crusts tend to inhibit infiltration of water into the soil, gas exchange between atmosphere and the soil, and seedling emergence (Hillel, 1998). The decreased infiltration rate throughout time could be attributed to the high intensity rainfall application and surface crust formation during the study. Therefore, it can be concluded that synthetic rainfall at the intensity of 0.21 centimeters per second will certainly lead to severe raindrop impact and soil sealing, especially a soil that has been pulverized and exhibits no structure.

6) **The quantity of simulated rain applied to the soil containers during the California study is not representative of the natural precipitation for Miles City, Montana. The result of the over application of rain is lower infiltration rates, because additional salts were leached from the soil profile (the lower the salt content, the lower the infiltration for any given SAR).**

The average annual precipitation for Miles City, Montana is 29.0 cm or about 11.4 inches (US Department of the Interior and Bureau of Land Reclamation Great Plains Region, 2009). The simulated rainwater applied to the disturbed Montana soil in the California study was 34.1 cm in 2003 and 91.8 cm in 2004. In both study years, the applied rainfall was greater than the average precipitation for Miles City, Montana. The simulated rain applied in the 2003 study was slightly greater than the quantity of rainfall for one year in Miles City, Montana, but was applied over a five and half month period. The 2004 study applied 3.2 times more rainwater than Miles City, Montana soils receive in the average year. The evapotranspiration rate in Riverside, California is greater than the rate in Miles City, Montana (California Irrigation Management Information Systems, 2009), but the difference between the two locations was not enough to prevent excess rain leaching through the soil containers. The additional application of the low EC rainwater would leach more salts from the soil than would naturally occur in Miles City, Montana. This additional leaching would result in a lower soil EC. As discussed above, the relative rate of water infiltration is affected by a relationship between salinity (as measured by the EC) and SAR (Ayers and Wescot,

1985). This well understood relationship indicates that for any given SAR, there will be greater impact to soil structure and infiltration as the EC decreases.

Excess and rapid leaching of salts from any soil can certainly lead to decreases in infiltration and permeability due to the relationship between EC and SAR. The lowered EC in the soil containers of the California study would not have been able to offset the infiltration problems that occurred with the application of variable SAR irrigation waters. Therefore, we hypothesize that the application of additional simulated rainfall in the California study resulted in lower infiltration rates than would have occurred if the application of rainwater and rate of application was similar to the actual rainfall in Miles City, Montana. In addition, it is likely that the combination of total quantity of rainfall applied to the soil containers and the intensity of 0.21 centimeters per second affected soil infiltration by physically impacting and sealing the soil surface.

Specific Issues Related to the Results of the Study

7) The statistical analysis of the measured infiltration data did not include a comparison to the experimental controls (the containers that did not receive the varying EC/SAR irrigation treatments). Without comparison to a control, it is unknown if measured effects are caused by experimental factors (for example, the effects of crushing the soil and rainfall impact cannot be isolated from the effects of the irrigation water).

The primary objective of the California study was to apply varying EC/SAR irrigation waters to soil and measure the affect on soil infiltration rates. The experimental treatment was the multiple EC and SAR irrigation water combinations, and infiltration rate was the measured variable. In order to determine if the treatment was solely responsible for changes in infiltration, the data must be compared to a control treatment. The control treatment was no different from other treatments in the California study except that the irrigation water applied to the control was not affected by EC and SAR. Since the control treatment has the same experimental factors as the other treatments, it can be used for comparison to the other treatments. This comparison is used to determine if the experimental factors influenced infiltration. If infiltration of the control sample decreased throughout the experiment, the change would be attributed to another experimental factor and not the application of EC and SAR irrigation water.

For example, it is discussed above that the natural soil structure of the bulk soil samples was destroyed during sampling and laboratory preparation procedures; the effect of the applying large quantities of water (irrigation and synthetic rainfall) on the disturbed soil cannot be isolated without comparison to the controls. The same is true for the effect of the varying EC/SAR combinations, i.e., without comparisons to the controls, it is unknown if the decreases in infiltration rates observed during the study are caused by the SAR in the irrigation waters. While the California study indicates that controls were used, data regarding infiltration for the control containers are not reported. This issue means that the first sentence of the Conclusions on page 51 of the California study report (Suarez et al., 2006a) could be re-written as follows: ""The increase in SAR of the applied irrigation water, *or the effect of the destroyed soil structure, or the physical impact associated with the extreme*

intensity and quantity of the simulated rainfall, or the combined effect of all three factors, had an adverse impact on water infiltration for both the cropped and bare (uncropped) soils." [added language in italics]

8) **Hydraulic conductivity was not significantly (statistically) different for variable EC/SAR irrigation and rain applications for clay soil samples. This is not what would be hypothesized because the permeability of soils higher in clay content should be impacted greater than loam soils. This may indicate a problem with the experimental procedures.**

   The California researchers determined that the hydraulic conductivity was not significantly different across the various EC/SAR treatments on the clay soil. Clays are the most reactive portion of the soil due to the small mass relative to the surface area, because they have a negative charge and their ability to swell and disperse (Brady, 1990). Due to this high reactivity, it is expected that the hydraulic conductivity would decrease in the clay soils. No explanation was given in the reports as to the importance of this finding and why this was not observed.

9) **The alfalfa yield was not significantly (statistically) different between any of the treatments. Therefore, no effects to plant growth were observed as a result of the EC/SAR irrigation water and alternating rainwater applications. The relevance of this key result was not discussed fully in the conclusion sections of the California study reports.**

   Water quality standards in the U.S. are designed to protect the various designated and beneficial uses of water bodies of the U.S., including irrigation and agricultural uses. For example, in Wyoming, the state water quality standards indicate that there will be "no measurable decrease" in agricultural production due to the discharge of wastewaters to streams and rivers. This means, for example, that if coalbed natural gas produced water is discharged to a stream, then that cannot result in a water quality change to that stream that in turn causes a measurable decrease in crop production due to its use as an irrigation source.

   In the California study, there was no statistically significant difference in alfalfa production for any of the EC-SAR irrigation treatments in both soil types. Given that crop production is the ultimate activity that is to be protected from an irrigation water quality standard, it is curious as to why this key finding was omitted from the conclusion sections of the California study reports.

5.0 SUMMARY OF THE REVIEW

Robust scientific research that is intended to measure natural phenomena associated with soil, water and plants must meet minimum standards associated with the methods and reporting of that research. These standards include, but are not limited to: (1) complete documentation of experimental methods to the extent that the reader of the research report can reproduce the

study; and (2) ensuring that the methods used to simulate field conditions in the laboratory are as representative of the field as possible. The California study was an important attempt at quantifying the regional-specific and cumulative effect of irrigation, rainfall, EC and SAR on the infiltration of water in local Montana soils. Unfortunately, this study did not achieve the two standards listed above. In addition, there are numerous other shortcomings apparent from the review of these reports, including that it is difficult to read and comprehend, and critical information regarding sampling procedures, baseline soil data, experimental design, laboratory methods, and actual measured response data is frequently vague or omitted. It appears that these reports were written by a statistician and not a soil/water quality specialist.

The primary issues identified during this review are as follows:

1. The methods in the California study are poorly documented, difficult to understand, and do not provide enough information to repeat the study. Without proper explanation of sampling methods, the study is not repeatable and the results are therefore questionable.

2. The bulk soil material collected from Montana and transported to California was excavated, dried, crushed, sieved, and repacked into soil containers destroying all natural soil structure, pore space, root channels, and aggregates. The primary objective of the California study was to measure changes in infiltration due to sodium adsorption and the resulting damage to soil structure. Soil structure is a key factor controlling soil infiltration and permeability. Destroying the natural soil structure at the beginning of the study will certainly lead to reduced infiltration rates. Using soil in this way is not representative of field conditions and represents a fundamental flaw in the California study that significantly reduces our confidence in the results.

3. One-half of the soil used in the California study that was intended to represent irrigated soils along the Tongue River contains 54% clay. An ongoing study funded by the State of Montana indicates that the average clay content in irrigated surface soils along the Tongue River is 30%. The “clay” soil used in the California study did not come from the Tongue River watershed and is not representative of these soils.

4. The California study states that a baseline chemical analysis of the soil was performed. The soils data are not included in any of the reports. If the soils were sodic before the various EC/SAR water applications were made, reduced infiltration rates in the study could be a result of the original soil chemical condition, not the various EC/SAR irrigation treatments. The absence of soil chemical data is troubling given that this is a soil infiltration study directly related to the affects of irrigation water chemistry on soil chemistry.

5. The intensity of the simulated rainfall used in the California study was 0.21 centimeters per second, which is over 3000 times more intense than the estimated average rainfall intensity for the Miles City, Montana area. This extreme high intensity rainfall is not representative of field conditions and can limit infiltration by physically impacting the surface of the soil.

6. The quantity of simulated rain applied to the soil containers during the California study is not representative of the natural precipitation for Miles City, Montana. The result of the over

application of rain is lower infiltration rates, because additional salts were leached from the soil profile (the lower the salt content, the lower the infiltration for any given SAR).

7. The statistical analysis of the measured infiltration data did not include a comparison to the experimental controls (the containers that did not receive the varying EC/SAR irrigation treatments). Without comparison to a control, it is unknown if measured effects are caused by experimental factors.

8. Hydraulic conductivity was not significantly (statistically) different for variable EC/SAR irrigation and rain applications for clay soil samples. This is not what would be hypothesized because the permeability of soils higher in clay content should be impacted greater than loam soils. This may indicate a problem with the experimental procedures.

9. The alfalfa yield was not significantly (statistically) different between any of the treatments. Therefore, no effects to plant growth were observed as a result of the EC/SAR irrigation water and alternating rainwater applications. The primary purpose of irrigation water quality standards is to protect crop production. The relevance of this key result was not discussed fully in the conclusions section of the California study reports.

The first sentence of the Conclusions section on page 51 of the Suarez et al. (2006a) report is an attempt to summarize the entire California study by stating that “The increase in SAR had an adverse impact on water infiltration for both the cropped and bare (uncropped) soils.” Unfortunately, given that there were several other uncontrolled influences on the infiltration performance of these soil samples in the lab, the first sentence would be scientifically correct if it were re-written as follows: “The increase in SAR of the applied irrigation water, *or the effect of the destroyed soil structure, or the physical impact associated with the extremely high intensity and quantity of the simulated rainfall, or the combined effect of all three factors*, had an adverse impact on water infiltration for both the cropped and bare (uncropped) soils.” Given the methods used and the results reported, no conclusions can be made from this study regarding the effect of increasing SAR of applied irrigation water on soil samples collected in Montana. In conclusion, based on the review of the two documents comprising the California study, it is the opinion of this author that the California study cannot be relied upon as a basis for setting or validating surface water quality criteria for EC and SAR in Montana or anywhere.

6.0 REFERENCES CITED

Abrol, I.P., Yadav, J.S.P. and Massoud, F.I. 1988. Salt-affected soils and their management. FAO Land and Water Management Division, Soils Bulletin 39.

American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. 1988. Publication Handbook and Style Manual. Madison, WI.

Ayers, A.D., Aldrich, D.G. and Coony, J.J. 1951. Sodium chloride and injury of Fuerte avocado leafs. California Avocado Soc. Yearbook: 1951 174-178 illus.

Ayers, R.S. and D.W. Westcot. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 (Rev. 1). Food and Agriculture Organization of the United Nations, Rome.

Bohn, H.L., B.L. McNeal, and G.A. O'Connor. 1985. Soil Chemistry. John Wiley and Sons, New York, NY.

Brady, N.C. 1990. The Nature and Properties of Soils. 10th ed. Macmillan Publishing Company., New York.

Brown, J.W., Wadleigh, C.H. and Hayward, H.E. 1953. Foliar analysis of stone fruit and almond trees on saline substrates. Amer. Soc. Hort. Proc. 61: 49-55.

California Irrigation Management Information Systems (CIMIS). 2009. Los Angeles Basin- UC Riverside #44, Riverside, CA. http://www.cimis.water.ca.gov/cimis/frontMonthlyReport.do

Carlstrom, M.G., F.A. Amendola, D.A. Shay, and D.J. Dollhopf. 1987. Sodium. p. 75-108. *In* R.D. Williams and G.E. Schuman (ed.) Reclaiming Mine Soils and Overburden in the Western United States Analytic Parameters and Procedures. Soil and Water Conservation Society of America, Ankeny, IA.

Evangelou, V.P. 1998. Environmental soil and water chemistry principles and applications. John Wiley and Sons (Pub), New York, NY.

Frenkel, H., J.D. Goertzen, and J.D. Rhodes. 1978 Effects of clay type and content, exchangeable sodium percentage and electrolyte concentration on clay dispersion and soil hydraulic conductivity. Soil Sci. Soc. Am. J. 42:32-39.

Hanson, B., Grattan, S.R. and Fulton, A.F. 1999. Agricultural salinity and drainage. Division of Agriculture and Natural Resources Publication 3375. University of California Irrigation Program. University of California, Davis, California.

Hillel, D. 1998. Environmental Soil Physics. Academic Press. London.

Hopmans, J.W., A. Tuli, D.E. Rolston, and P. Moldrup. 2005. Comparison of Air and Water Permeability between Disturbed and Undisturbed Soils. Soil Sci. Soc. Am. J. 69:1361-1371.

Klute, A. and C. Dirksen. 1986. Hydraulic conductivity and diffusivity: laboratory methods. p 687-734. In A. Klute (ed.) Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods. 2nd ed. Agronomy Monograph No. 9. ASA and SSSA , Madison, WI.

Levy, G.J., Shainberg, I. and Miller, W.P. 1998. Physical Properties of Sodic Soils. In: Sumner, M.E. and Naidu, R. 1998. Sodic soils: Distribution, properties, management and environmental consequences. Oxford University Press, Inc. New York, NY.

Lilleand, O., Brown, J.G. and Swanson, C. 1945. Research shows sodium may cause leaf tip burn. Almond Facts 9 (2) : 1, 5, illus.

McNeal, B.L and Coleman, N.T. 1966. Effect of solution composition on hydraulic conductivity. Soil Sci. Soc. Am. Proc., 30, 308-312.

Meyer, L.D. and W.C. Harmon. 1984. Susceptibility of agricultural soils to inter-rill erosion. Soil Sci. Soc. Am. J. 48: 1152-1157.

Moore, D.C. and M.J. Singer. 1990. Crust formation effect on soil erosion processes. Soil Sci. Soc. Am. J. 54: 1117-1123.

Muggli, Roger (Manager, Tongue and Yellowstone River Irrigation District, Miles City, Montana). 2007. "Statement before the House Subcommittee on Energy and Mineral Resources, House Subcommittee on National Parks, Forests and Public Lands, Hearing on Land-Use Issues Associated with Onshore Oil and Gas Leasing and Development (Date: 4/26/2007)." Text from: http://worc.org/oil-gas-coalbed-methane/; accessed 4/9/2009.

Nicks, A.D., L.J. Lane, and G.A. Gander. 1995. Weather Generator. p. 2.1-2.2. *In* D.C. Flanagan and M. A. Nearing (ed.) USDA-Water Erosion Prediction Project Hillslope Profile and Watershed Model Documentation.

Schafer, W., N. Fehringer, K. Harvey, and HydroSolutions Inc. 2007. Tongue river agronomic monitoring & protection program: Tongue river information program – 2007 progress report. *Prepared for:* Montana Board of Oil & Gas Conservation, Montana Department of Natural Resources and Conservation.

Shainberg, I., Bresler, E., and Klausner, Y. 1971. Studies on Na/Ca montmorillonite systems, I: The swelling pressure. Soil Sci. 111:214-219.

Soil Improvement Committee, California Plant Health Association. 2002. Western Fertilizer Handbook, ninth edition. Interstate Publishers, Inc. Danville, Illinois.

Soil Science Society of America. 2001. Glossary of Soil Science Terms. SSSA, Madison, WI.

Sparks, D.L. 1995. Environmental Soil Chemistry. Academic Press, San Diego, Ca.

Stern, R., M. Ben-Hur, and I. Shainberg. 1991. Clay mineralogy effect on rain infiltration, seal formation, and soil losses. Soil Sci. 152: 455-461.

Suarez. D.L., J.D. Wood, S.M. Lesch. 2006a. Evaluation of water quality criteria for rain-irrigation cropping systems. Final report to EPA. Interagency agreement DW-12-95386801. Salinity Laboratory USDA-ARS.

Suarez, D.L., J.D. Wood and S.M. Lesch. 2006b. Effect on SAR on water infiltration under a sequential rain-irrigation management system. Ag Water Management. 86:150-164.

Sumner, M.E., Rengasamy, P. and Naiud, R. 1998. Sodic soils: A reappraisal. In: Sumner, M.E and Naidu, R. 1998. Sodic soils: Distribution, properties, management and environmental consequences. Oxford University Press, Inc. New York, NY.

U.S. Department of the Interior and Bureau of Land Reclamation Great Plains Region. 2009. Buffalo Rapids Terry, MT (BRTM) Weather Station. http://www.usbr.gov/gp/agrimet/agrimet _station_list.cfm

7.0 QUALIFICATIONS OF THE REVIEWER

Patton Boggs, LLP retained Kevin Harvey of KC Harvey, Inc. to review the California study. Mr. Harvey is a consulting soil scientist with 27 years experience in the field of environmental management consulting. Mr. Harvey's education includes a B.S. in Resource Conservation with an emphasis in soil science from the School of Forestry, University of Montana, Missoula, and a M.S. in Land Rehabilitation with an emphasis in soil science from the Reclamation Research Unit, Montana State University, Bozeman. In addition, he has completed the coursework requirements towards a Ph.D. in soil science at Montana State University, Bozeman. During his academic work, he accumulated 52 semester credits in soil science including four courses in environmental soil and water chemistry. In addition, he has accumulated 20 semester credits in surface water hydrology, and 18 credits in range management/range ecology. Mr. Harvey is a member of the Soil Science Society of America and the Soil and Water Conservation Society. He is board-certified as a soil scientist (Certified Professional Soil Scientist No. 11076) by a recognized federation of certifying boards in association with the Soil Science Society of America and the American Society of Agronomy.

Mr. Harvey is currently the Executive Vice President and Chief Scientist of EnerCrest, Inc. and the President of KC Harvey, Inc., the science and engineering consulting subsidiary of EnerCrest, Inc. Mr. Harvey's practice focuses on the management and rehabilitation of soil, water, and vegetation resources associated with natural resource extraction. Mr. Harvey's technical strengths are in soil science, soil and water chemistry, land reclamation, surface water management, and general environmental problem solving. He has particular expertise in the management of soil and surface water resources associated with the oil and gas, and mining industries, including the chemistry of soil and water salinity/sodicity.

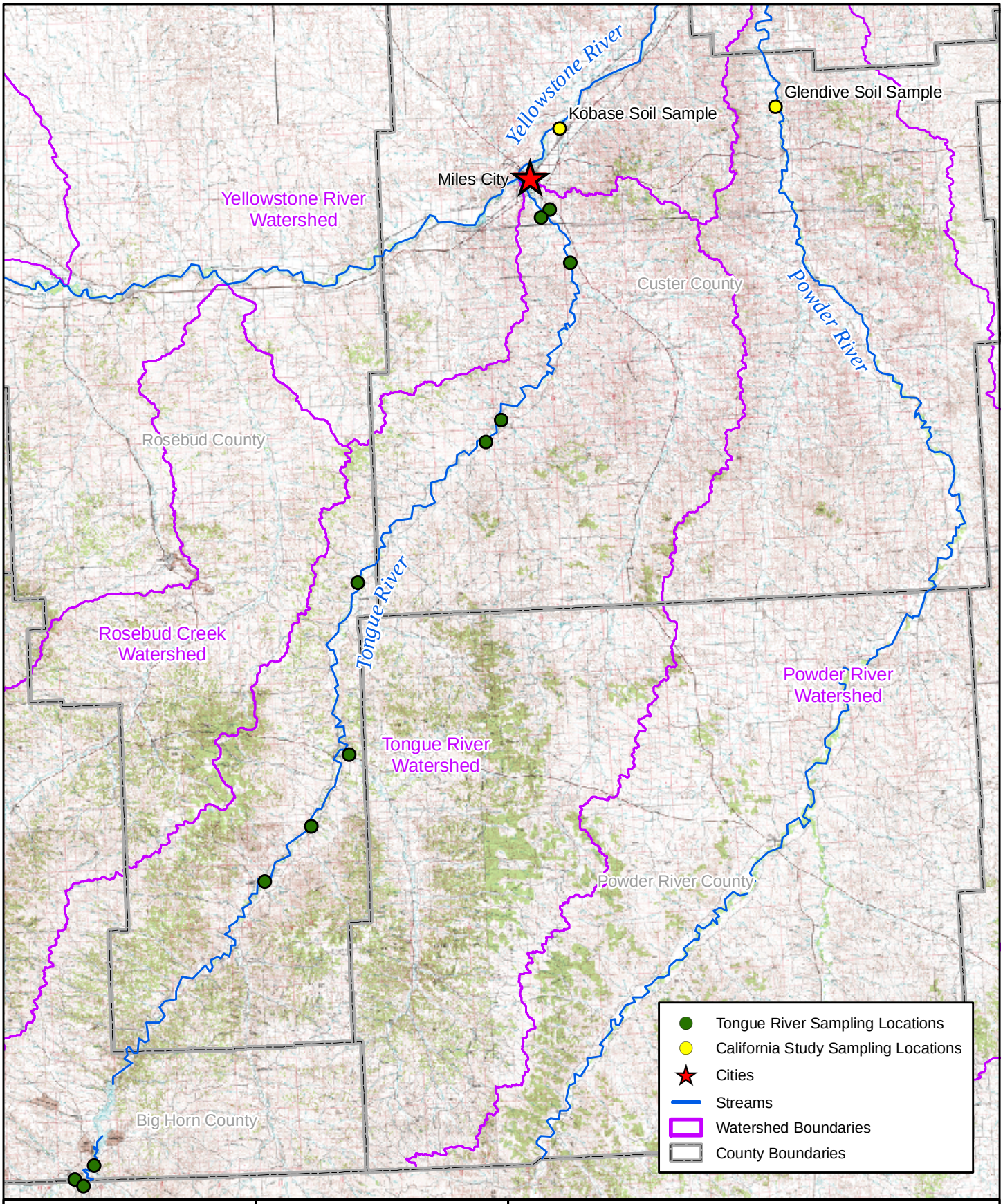
Mr. Harvey has provided environmental consulting services to the private and public sector throughout the U.S., Canada, Mexico, Europe, and Australasia. He has held senior level management positions in the consulting industry and has directed and managed professional staff and contractors on multi-million dollar environmental management, permitting and remediation projects. Mr. Harvey's work experience includes baseline soil, water and environmental studies, soil contamination studies, soil mapping, facility reclamation and closure plans, CERCLA investigations and remediation (PA/SI, EE/CA, RI/FS, RD/RA), development of soil remediation technologies, NPDES permitting, surface water mixing zone analyses, watershed assessment, wetland delineation and mitigation, water balance modeling, geochemical modeling, wastewater land application, storm water management plans, NEPA EIS and EA, ecological risk assessment, technical litigation support, pre-acquisition environmental due diligence, compliance audits, and hazardous waste management.

As a technical writer and editor, Mr. Harvey has been involved in the preparation of several technical articles, EIS sections, permitting documents, book chapters, technical reports for the U.S. EPA, documents in support of litigation, and numerous technical project reports for public review. Mr. Harvey has testified before administrative agencies including the Montana Board of Environmental Review, the Wyoming Environmental Quality Council, various state and federal regulatory agencies, and U.S. Congressional field hearings. He has consulted for the U.S. EPA, U.S. BLM, U.S. Forest Service, U.S. Department of Energy, U.S. Department of Defense, and various state regulatory agencies. In 1990, Mr. Harvey was recruited to plan, establish and manage the European operations for a major international environmental engineering and consulting firm. While in Europe, he provided senior environmental management services to multi-national industries and served as a special advisor to the government of Ireland on matters relating to environmental remediation.

Mr. Harvey has participated in over 35 Clean Water Act NPDES (wastewater discharge) permit-related investigations, applications, effluent limit derivations, mixing zone analyses, compliance schedules, water management plans, water balance analyses, sampling and analysis plans, negotiations, and public hearings for the oil and gas, and mining industries. In 1999, he was invited to speak at the 45th Institute of the Rocky Mountain Mineral Law Foundation in regards to the application of new NPDES permitting requirements for resource extraction projects.

For the last nine years, Mr. Harvey's practice has focused on the management of produced water from coal bed natural gas production in the Powder River Basin of Wyoming and Montana. In this time, he has participated in over 75 separate projects related to produced water management, including project water management planning, NPDES permitting, soil and water chemistry investigations, laboratory and field research related to the behavior of produced water on soils and vegetation, "Section 20 compliance assessments" for Wyoming, environmental forensic investigations, design and operation of full-scale managed irrigation systems, water balance modeling, watershed assessments, water treatment testing, geochemical mixing analyses, and technical litigation support.

Mr. Harvey is credited with researching and developing, designing, and deploying the first full-scale managed irrigation systems in the Powder River Basin to produce forage and to provide a beneficial means for managing CBM water. In 2005, Mr. Harvey was invited by the Wyoming Department of Environmental Quality to serve on a committee charged with developing a policy for the protection of agricultural resources associated with the discharge of coal bed natural gas produced water. Mr. Harvey also participated in the Montana rulemaking process for the development of EC and SAR water quality standards for the Tongue River and Powder River. In 2007, the Soil Science Society of America presented Mr. Harvey with a Professional Certification Service Award for his work associated with the management and beneficial use of sodic coalbed natural gas produced water.



KC HARVEY
Soil & Water Resource Consulting
376 Gallatin Park Drive
Bozeman, MT 59715
406-585-7402
www.kcharvey.com

N W E S

0 5 10 20
Miles

Figure 1

Soil sample locations for the California study and for the State of Montana Tongue River study. (Schafer et al., 2007)

Project No: 11-389-09	Date: April 8, 2009	Version: 1